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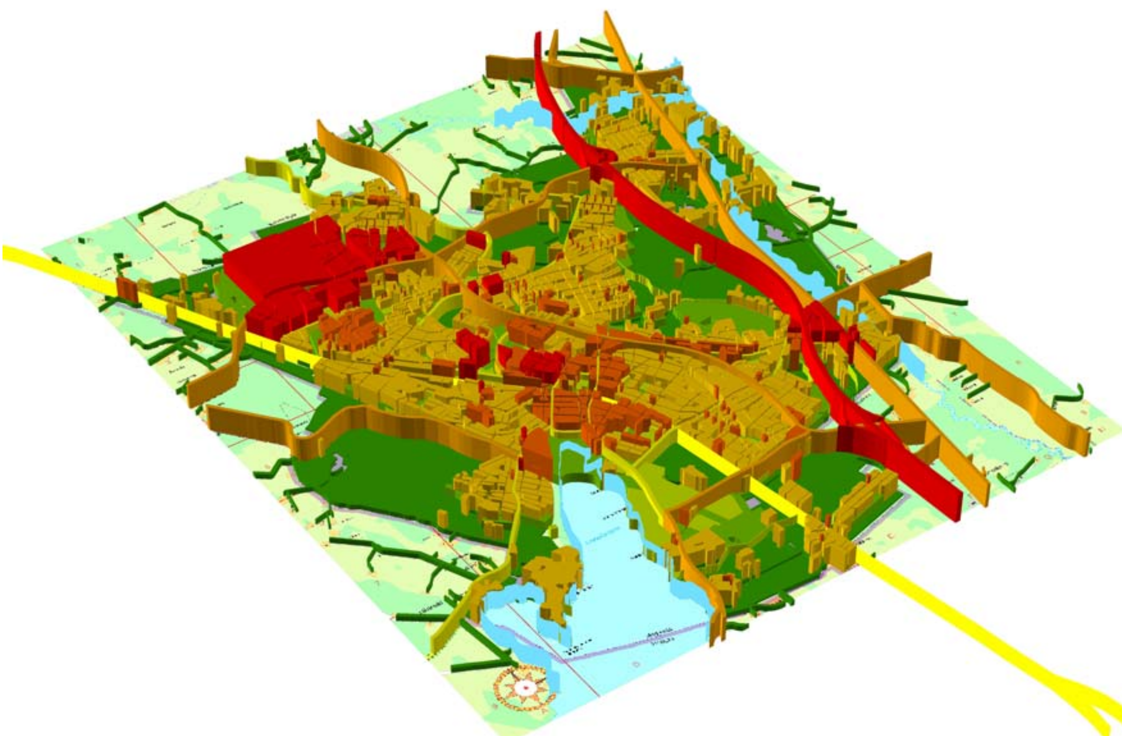
Jukka Matthias Krisp



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Jukka Matthias Krisp

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Abstract

Within the theoretical framework of this research it is recognized that a very large amount of real-world facts and (geospatial) data are collected and stored. Decision makers cannot consider all the available raw facts and data. Problem-specific variables have to be selected from this data and they need to be validated in their value for the specific model. A modeling process joins and aggregates the selected meaningful variables. This process may include extensive consultation between GIS-experts (or Geoscientists) with domain experts, and might result in several alternative problem-specific models. Geovisualization provides theory, methods and tools for the visual exploration, analysis, synthesis and presentation of data that contains geographic information. The focus of this research is on geovisualization and its crucial role to derive problem-specific models and design task-specific maps to discover and incorporate knowledge into planning and decision making. This research applies geovisualization in the knowledge discovery process for problem-specific spatial models and integrates geovisualization concepts and processes to provide task-specific maps to improve planning & decision making. The aim of this work is to apply selected geovisualization functionalities to support the creation of task-specific maps in selected case studies that relate to ecological network planning. The concept of ecological networks emphasizes that nature reserves should contain sufficient, high quality areas of habitat that are connected by corridors. The case studies investigate changing moose habitats (case I), wildlife warning sign locations (case II), and ecological barriers (case III). Case I describes an investigation of moose population density changes in southern Finland. Concepts of geovisualization used include interaction, animation, and three-dimensional density estimations. The results are displayed as density maps in a four-dimensional explorative visualization to present and highlight changes in moose habitats. Case II investigates the current placement of wildlife warning signs. In this context density estimations are incorporated, which are based on existing accident records are used to optimize warning sign locations. Applying a well-documented computational method, based on these moose and white-tailed deer accident locations, assists the Finnish road administration in its task to place or replace wildlife-warning signs along specific road sections. Case study III describes a process of modeling "ecological barriers" by a list of landuse and landcover elements and their impact on animal movement. These can split natural ecosystems into smaller and more isolated patches. This case study defines the ecological barriers, using experts' knowledge to classify spatial objects with an abstract ecological barrier value. Eleven experts from the field of landuse planning have commented on the maps obtained in case III and are generally in agreement that these kinds of maps are useful for planning. One of this dissertation's basic findings is that geovisualization can assist the formulation of first ideas and hypothesis from the GIScientist, when interacting with the data. Furthermore may aid the modeling process and the interaction process between the GIS-expert (or Geoscientist) with domain experts. A GIS expert has the knowledge of a set of tools and processes-related to geo-referenced data. Domain experts from an organization have their knowledge regarding the processes and experience dealt with in the specific field. Within the spatial modeling process, the actors have to find ways to integrate the knowledge from the experts into a spatial model. This requires interaction and an understanding between actors. Geovisualization can have a crucial role in creating this understanding. Domain experts are the most important information source in the problem-specific spatial modeling process. One of the findings in this research is that bringing in expert knowledge is one of the crucial points in developing the problem-specific spatial models and finally the problem-specific maps that assist the decision making. The use of exploratory geovisualization tools help to study the ecological landscape and alternative approaches for landuse. Perhaps decision makers in landscape planning and ecological network planning underestimate the importance of geovisualization that provides a wide set of tools and processes to interact and work with spatial data. This research indicates that making use of these tools with help of a GIScientist, assist the interaction between the decision-maker and domain experts.

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I want to thank Prof. Kirsi Virrantaus for devoting her time to supervise this thesis and for her valuable comments. Furthermore I am grateful to have Prof Menno-Jan Kraak (International Institute for Geo-Information Science and Earth Observation - ITC) and Prof. Liqiu Meng, (Technical University of Munich) as evaluators for this thesis – many thanks to accept this duty. Furthermore I would like to thank the following persons (mainly people I published with related to this research, listed in no particular order): Paula Ahonen-Rainio, Sara Durot, Arzu Cöltekin, Juliane Dame, Vanessa Heinzel, Seija Väre, Urska Demsar, Wolfgang Ludwig, Risto Kalliola, Olga Spatenkova, Vera Karasova, Ari Jolma, Stefan Fronzek, Pekka Horttanainen, Rangsima Sunila, Riikka Henriksson, Anke Hilbig; furthermore other changing people in the lab, my Finnish and German parts of family and I apologize for the ones I might have missed in this list. Finally very special thanks to Piret, Linda & Andres.

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1 Chapter 1 – Introduction

1.1 Theoretical Framework Of The Focal Study

A large amount of real-world data has been collected and stored. The scope, coverage and volume of digital geographic data sets have grown rapidly in recent years, due to the progress in data collection and data processing technologies. These data sets include the following: (1) digital data of all sorts, regarding land and socioeconomic infrastructure, including those created, processed, and disseminated by both government and private-sector agencies; (2) vast amounts of geo-referenced digital imagery and video data, acquired through high-resolution remote sensing systems and other monitoring devices; (3) geographic and spatiotemporal data collected by global positioning systems, as well as other position-aware devices, including cellular phones, in-vehicle navigation systems; and (4) wireless internet clients, and digital geographic data repositories on the web (Han, Altman et al., 2002). Because of large data volumes, no visualization is simultaneously capable of providing an overall view (Andrienko and Andrienko, 2006). Cartographers (Bertin, 1967; Dent, 1996; Imhof, 1972; Slocum, 1999; Slocum, 2005) have developed sophisticated methods of graphically encoding spatial data and making use of the human visual systems ability for pattern detection, recognition and interpretation. More recently research in cartography as been extended and the historically more or less defined research field of cartography has enlarged to be more uncertain (McMaster and McMaster, 2002). This more uncertain research area includes the field of geovisualization (Dykes, MacEachren et al., 2005a; Guo, Gahegan et al., 2005; Kraak, 2003a; Slocum, 2005). The focus of this research is on geovisualization and its crucial role in deriving problem-specific models and designing task-specific maps to discover and incorporate knowledge into planning and decision making. Generally most maps are created for a specific task after data processing. Task specific maps in this case intend to present only the meaningful variables to a decision maker. Interaction and expertise are key issues for the planners. An interpretation of abstract phenomena may require expertise that cannot be expected from decision makers. Decision makers are typically not motivated to explore the situation, rather are more interested in hearing reasoning for proposed actions. Geoscientists, in close cooperation with domain experts, produce task specific-maps for them in order to convince them on the proper actions. These maps can be based on problem-specific models. The decision maker cannot consider all the available data and all possible variables that might influence the decision. Figure 1 illustrates this idea. Because of the large amount of geospatial data for a decision-maker, considering all facts and data for making a decision becomes increasingly difficult or in some cases nearly impossible. The decision distinctiveness is higher with a reduced and generalized amount of input data.

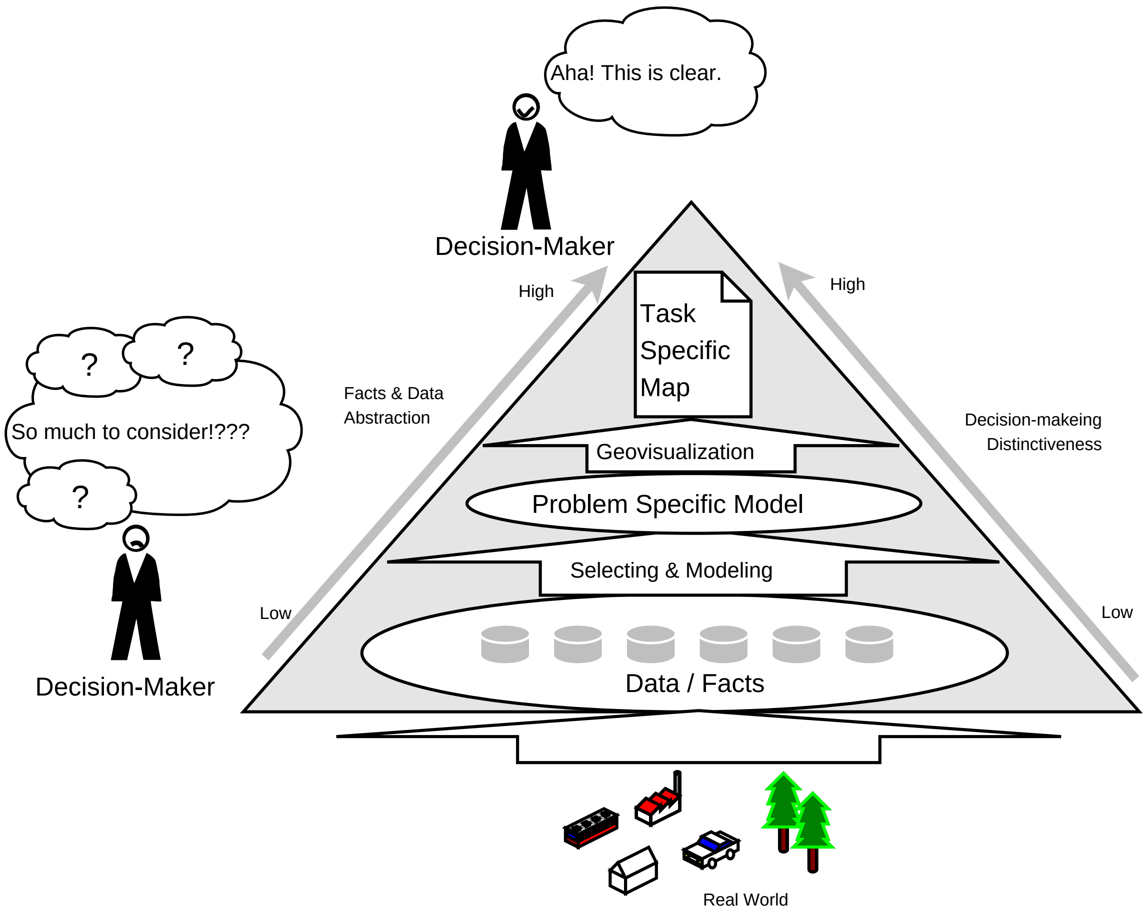


Figure 1. Theoretical framework - from data and facts to task specific maps

The triangle represents the amount of data used for the decision making. Problem-specific variables are selected from existing data and they need to be validated, with regard to their value for the specific decision. The modeling process joins and aggregates the selected significant variables. This process includes extensive consultation with domain experts and might come to several alternative, problem-specific models. These alternatives can be visualized in a task-specific map and can be used as the basis for a decision. The raw data quality might lose its primary accuracy during this process, but its relevance for a particular decision remains high. It is important that the essence of the data remains intact. Geovisualization can be used in (1) the data selection and modeling process and (2) in the task-specific map production and communication process. This involves the use of geovisualization as a tool for knowledge discovery. As Gahegan (2001) has pointed out, only few practical examples are documented (Gahegan, Harrower et al., 2001). By applying geovisualization to the selected case studies, this research intends to support the ecological network planning processes, and additionally serve as a practical example concerning visual support in knowledge construction for decision-making. Peuquet and Kraak (2002) suggest, that maps need to change, as mapping has already changed, and that we need research into how maps can be best used as visualization tools for exploring digital geographic databases, and as interactive aids in experiencing the world, deriving decisions, and solving spatial problems. Therefore instruments for geovisualization can be regarded as (among other things) being cognitive decision support tools. People (in this research context domain-experts, planners & decision-makers) can cognitively operate much more effectively with an external artifact, such as a map, than with a purely mental image (Fuhrmann, Ahonen-Rainio et al., 2005).

1.2 Wider Research Context

The paper *Research Challenges in Geovisualization*, (MacEachren and Kraak, 2001) delineates five challenge categories, with four to eight specific challenges detailed in each. One, in particular, states the need: “To develop extensible methods and tools that enable understanding of, and insight to be derived from, the increasingly large and complex geospatial datasets available.” (p.8) This list has been extended by Dykes et al (2005a) and further suggests the “Developing and extending geovisualization methods and tools to support knowledge construction.” (p.694) The initial promise of visualization methods was to harness the power of human vision to extract meaning from complex sets of information. This will require both advances in geovisualization methods and in the integration of these methods with geocomputational ones. The challenge is to find patterns in spatial datasets and take advantage of human vision and domain knowledge to determine whether the patterns uncovered are meaningful. A fundamental issue addressed by MacEachren and Kraak (2001) is that current methods and tools may not always support effective representation or encoding of geographic knowledge and meaning. It is an extraordinary challenge to transform data and facts into information, and subsequently into knowledge, to develop insight into a problem.

Several other attempts to manage the selection of meaningful variables from this data, and to model and visualize it to assist planning and decision making, are researched in the present study. In a wide context these include methods of knowledge discovery from databases (KDD) and data mining, which is often set in the broader context of KDD. (Fayyad, Grinstein et al., 2002; Han, Altman et al., 2002; Koperski and Han, 1999; Koperski, Han et al., 1998). Additionally the context may include spatial data mining (Ester, Kriegel et al., 1997; Miller and Han, 2001), visual data-mining (Demšar, 2006; Demšar, Krisp et al., 2006; Fayyad, Grinstein et al., 2002; Keim, Panse et al., 2004), exploratory analysis of spatial data (Andrienko and Andrienko, 2006) and (geo-)visual analytics (Schmidt, Chen et al., 2004; Thomas and Cook, 2005). Lavers and Haines-Young (1994) suggest that through the wider use of spatial information systems, we may gain deeper insight into the spatial structure and dynamics of systems. In wider scope planning and, in the case of this research, spatial planning (in particular ecological network planning), one can perceive several concepts that can be described as a human interpretation of relationships that have occurred in nature. The importance of the concept is not that it exists; it is that humans are using nature as a modeling instrument in spatial or physical planning in a meaningful way. Physical planning concepts based on this idea will always have human interpretation and, as such, can never really be natural (Cook and van Lier, 1994b). With a view of spatial planning from a geo-informational perspective, Meng (2003) states that spatial planning as a decision making process is typically based on teamwork that takes place in a collaborative communication system. In such a system, human-computer interaction, human-human interaction, geo-database information, networks, domain knowledge, and the experience of the planners should work together harmoniously with maps as working language, thinking instruments, and presentation media. The smooth and constructive exchange between the map and various planners at the same or different places requires a common visual literacy, a consistent interface, a typology of collaborative actions, communication rules, and a generative team memory. Typically these requirements are not fulfilled, and information and knowledge exchange between planner, decision-makers, domain experts, the general public and others is difficult. The communication of the problem and of the tasks has to be clear, and decisions have to be based on data and facts. For a decision maker, it seems to be increasingly difficult to consider and interpret all the facts and data at hand, when trying to decide about areas for a national ecological network. Therefore, ecological network planning represented in this research is only one example of a planning approach. It is possible that these ideas can also be applied in other fields, as has been already attempted in military applications (Janlöv, Salonen et al., 2005) and fire & rescue service planning (Krisp, Henriksson et al., 2005; Krisp, Jolma et al., 2005).

Planning ecological networks is clearly not the responsibility of anyone's discipline. The best approaches generally involve an interdisciplinary team, which may include ecologists, geographers, wildlife biologists, foresters, hydrologists, geologists, landscape architects, planners, agricultural scientists and a range of social scientists (Cook and van Lier, 1994a). Additionally it may involve disciplines like GIScience, Geomatics and Geoinformatics. Each of these disciplines influences that approach and the outcome. As a result of different disciplinary traditions and perhaps sponsoring agencies' perspectives, a range of approaches is represented in the literature regarding ecological network planning. In 1992, the EU established a European Ecological Network, called Natura 2000, as part of the EU Habitats Directive. Natura 2000 is a European network of protected sites, which represent areas of the highest value for natural habitats and species of plants and animals. These are rare, endangered or vulnerable in the European Community. The term Natura 2000 originates from the 1992 EC Habitats Directive and represents the conservation of precious natural resources for the 21st century (EU-Council, 1992). In 1995, 53 European countries established the Pan-European Ecological

Network as part of the Pan-European Biological and Landscape Diversity Strategy (Drucker, 1998; Ostermann, 1998). The European Center for Nature Conservation (ECNC), together with the Council of Europe, coordinates a program for the development of a pan-European ecological network.

1.3 Motivation

The environmental issues differ from country to country, with regard to environmental settings, characteristics of development, and national preferences and priorities. There is a tremendous need for careful and skilled management of all systems that affect the quality of life, in order to provide opportunities for environmentally sound development. The Finnish Ministry of the Environment asked for research on the ecological networks in Finnish urban areas. This request resulted in a report (Väre and Krisp, 2005) and raised methodological questions about how to model and visualize variables that might be important for ecological network planning. This, in turn, triggered a number of thoughts, among them the idea that the use of geovisualization methods might significantly assist in the identification of meaningful variables in the planning process of ecological networks. In Finland, ecological network planning has been thought of as a "bottom up" process. Many studies deal with detailed research on metapopulation of specific species. Hanski (2005) has carried out extensive research in Finland among others (Laine and Hanski, 2006; Luoto, 2002). In many cases this detailed research, from the perspective of biological accuracy, results in very specific maps for the distribution and migration patterns for a particular species. The result is an extensive amount of very detailed information, which is difficult to integrate into a wider planning approach. In the European perspective the ecological network planning is organized by a "top-down" approach and follows a more comprehensive landscape planning perspective. The ecological network cannot be based on very detailed studies of individual species (even though they are also considered); the method should follow a more broad approach. The problem is how to select meaningful variables from the existing geospatial information that needs to be considered by the decision maker in the case of ecological network planning.

1.4 Hypothesis

The hypothesis of this research is that tools and processes using geovisualization can enhance knowledge extraction in the cooperation with domain experts and need to be integrated to derive better problem-specific spatial models that provide better task-specific maps for decision-making.

1.5 Objectives And Aim Of This Research

General objectives of this research are:

- To apply geovisualization in the knowledge discovery process for problem-specific spatial models.
- The advancement of geospatial model development for planning by using geovisualization and the support of "spatial thinking" in landuse planning, specifically ecological network planning.
- To integrate geovisualization concepts and processes to provide task specific maps to improve planning & decision-making based on spatial data.

The aim of this work is to apply selected geovisualization functionalities to support the creation of task-specific maps in selected case studies. These case studies visualize spatial data to discover knowledge about changing moose habitats (case I), wildlife warning sign locations (case II) and ecological barriers (case III). The case studies related to the framework are represented in figure 2.

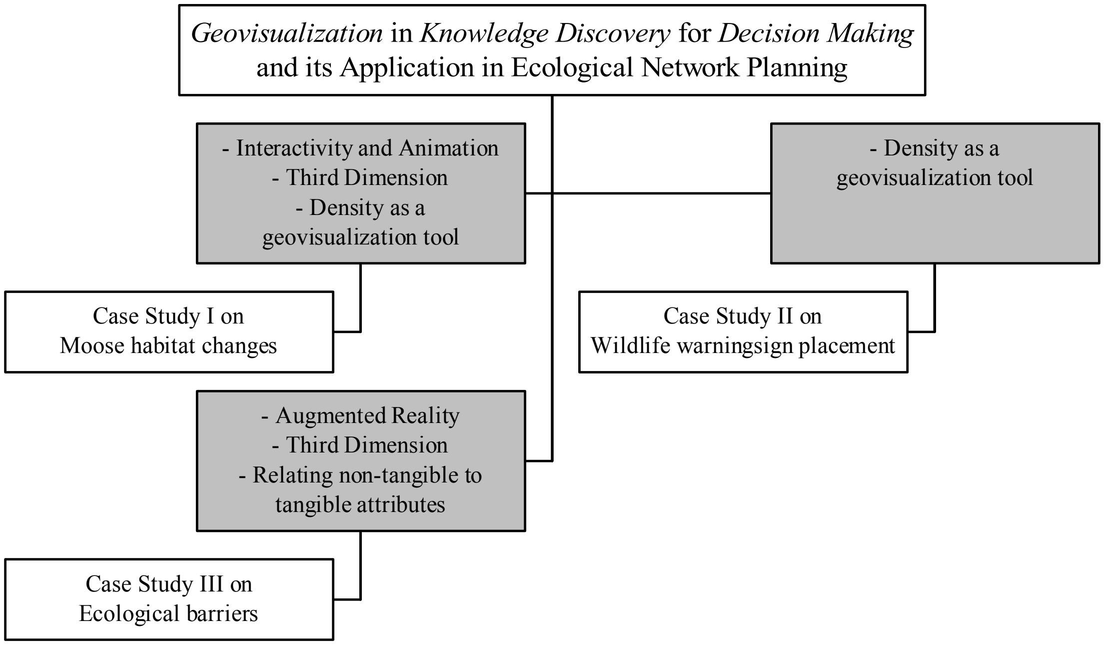


Figure 2. Geovisualization methods and their application in the case studies

The information, knowledge and insight gained from these maps contribute to the planning of ecological networks. Each case study used in this research provides an individual perspective that contributes to the base of knowledge about planning for ecological networks. An emphasis in this research is on geovisualization and how it contributes to planning and decision making in the three case studies.

1.6 Research Questions

In general, what questions do we have to answer to achieve our goals? The core questions here are:

- Can geovisualization methods enhance the selection of meaningful variables from spatial data that is used in planning and decision-making?
- Do geovisualization methods and their application in task specific maps assist decision-making and decision distinctiveness?
- Do the applied geovisualization methods bring advantages in the field of the case studies?

Considering selected geovisualization concepts, this research specifically considers questions like:

- Can we integrate animation into maps as a meaningful feature?
- Can we incorporate augmented reality into maps as a meaningful feature?
- Can we integrate density information into maps as a meaningful feature?
- Do we gain further information from a map, when visualizing data in a three-dimensional environment?

1.7 Relevance Of This Research

From a theoretical point of view, the results of this research are novel and are applicable to knowledge discovery in geographical databases for spatial models and for computing methods for examining complex spatial phenomena. This is a pre-work for building models and provides a relevant contribution to the development of advanced spatial analysis applications. This research advances the technological solutions to the problem of spatial modeling and provides sample cases, which document knowledge discovery from spatial databases using geovisualization methods in this context. By applying geovisualization methods to selected cases studies, this research supports the process of ecological network planning and advances this method as a tool for landscape planning. Additionally, the application of geovisualization methods provides applied cases to advance geovisualization as a research field. The evaluation of user opinions helps to identify gaps and rules for using geovisualization methods in ecological network planning.

1.8 Thesis Structure

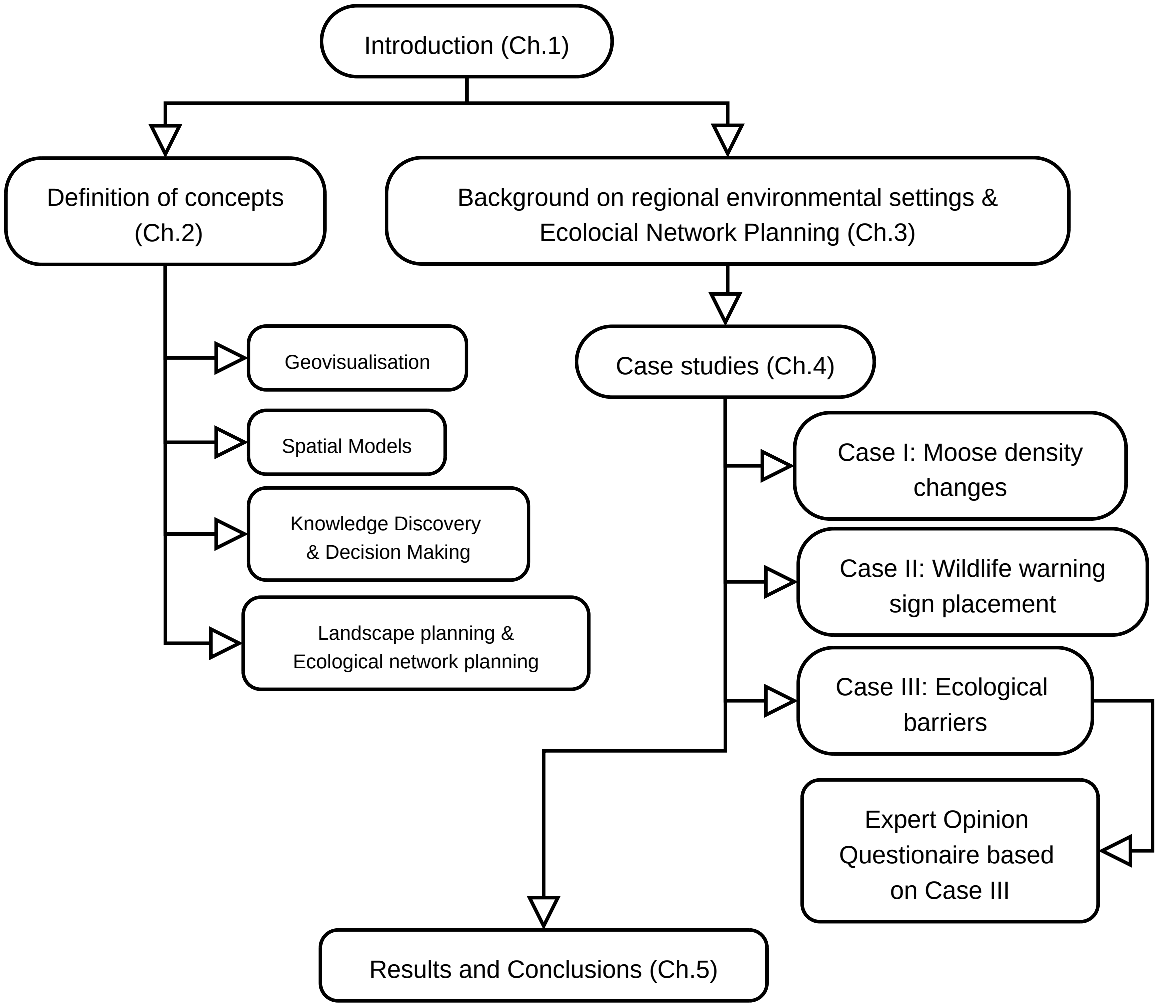


Figure 3. Overview of the dissertation structure

The structure of this dissertation is shown in figure 3. Chapter 2 frames this research within the larger context of *geovisualization*, *spatial models*, *knowledge discovery & decision-making*, and provides selected concepts in landscape planning, particularly *ecological network planning*. Chapter 3 reviews relevant previous research on the case study problem (ecological network planning) and provides the background information for the regional setting in Finland. In Chapter 4, three case studies are documented, each with its own results, in which selected geovisualization methods are applied to provide task-specific maps for planning and decision making. It includes an expert opinion feedback on the results for case study III (Ecological Barriers). A questionnaire is used to determine potential users and applications for these types of maps. Chapter 5 concludes the results and relates them to the theoretical framework. Additionally, this chapter provides propositions based on the case analysis, with some suggestions for further research.

2 Chapter 2 - Definition Of Concepts

This research has a very wide approach and includes concepts from various fields, which are organized and introduced. Therefore it does not allow for a very deep and comprehensive review of every specific theory. This chapter provides, rather, an overview of the different concepts, specifically cartography and geovisualization, and provides the theoretical background for geovisualization as a method that is used in the case studies. It presents an introductory overview on knowledge discovery & decision-making without too much detail. Many books provide details on various aspects of the methodology (Clemen and Reilly, 2001; Keeney, 1992; Lindley, 1985; Simon, 1960). The purpose here is to give an overview of the general concepts. The case studies deal with concepts of ecological networks in landscape ecology, habitat fragmentation, metapopulation theory and ecological barriers, which are introduced in this chapter.

2.1 Overview of Associated Concepts

The wider scope of this research includes several concepts. Figure 4 suggests an organization of these concepts around the proposed research fields. It indicates the scope of this research in a light gray circle and the core scope with a gray circle. Core concepts and fields are proposed and involve GIScience, Geomatics and Landuse Planning. Individual concepts are arranged somewhat around these core fields. The boundary between these fields is very fuzzy and indicated by a dashed line.

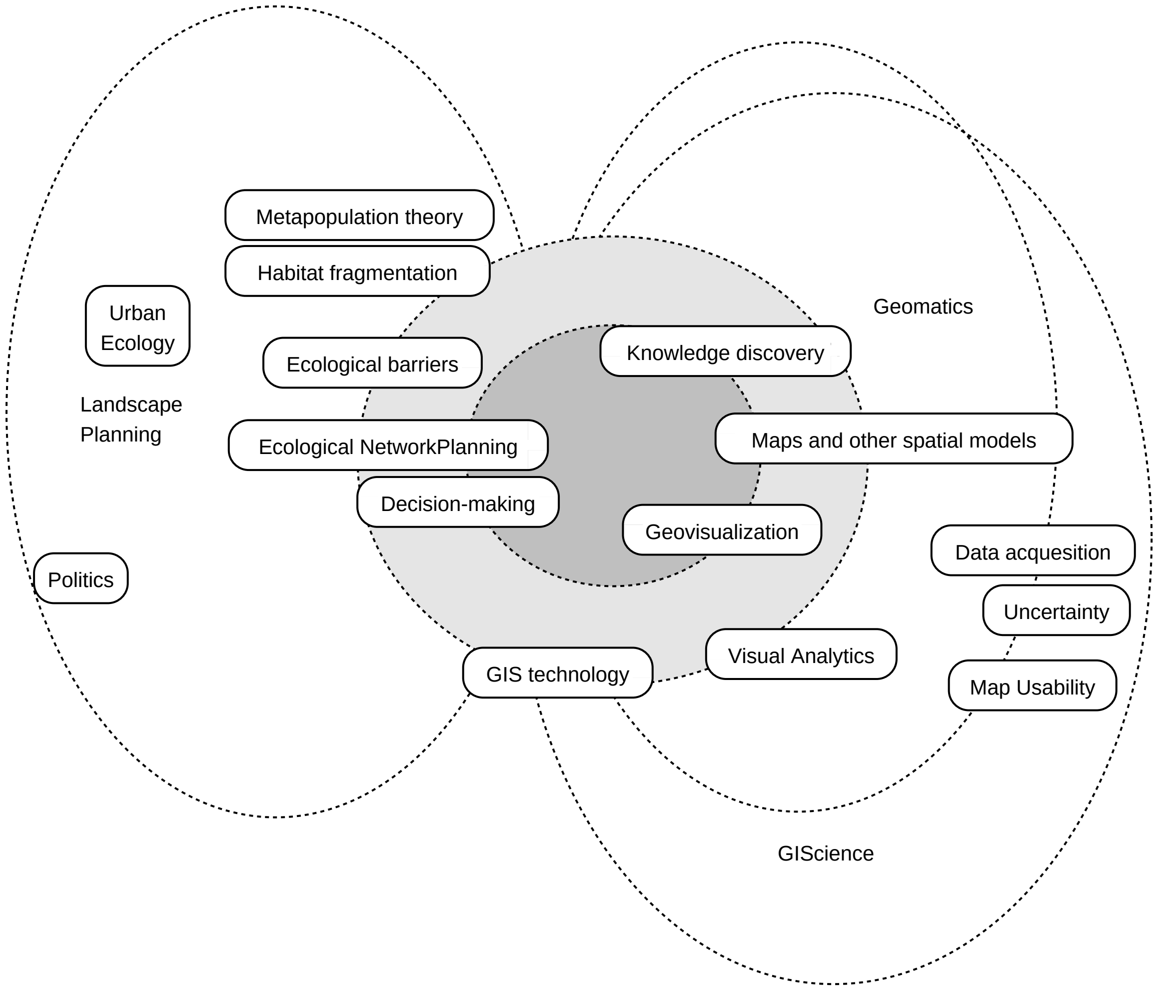


Figure 4. Wider scope of concepts and research fields related to this study

Within this general overview, specific concepts are identified and examined. These include the concepts of spatial models, in particular maps (see chapter 2.3), geovisualization (see chapter 2.2), and landscape planning, particularly ecological network planning (see chapter 2.5). The wide fields of knowledge discovery and decision making (see chapter 2.4) are not included as separate fields but are integrated as important supporting concepts.

Geomatics is the field that integrates the acquisition, processing, analysis, display and management of spatial information. It includes the new and traditional disciplines of photogrammetry and remote sensing, land and engineering surveying, geodesy, land information management, and other fields (Artimo, 1993; Artimo, 1994). Geoinformatics is a subfield of Geomatics, which emphasizes information systems and data processing. Geomatics also covers data collection and various application areas in which geographical data is used (Artimo, 1998). Geographic information science (or GIScience) is the science behind the GIS technology. A general early definition by Goodchild describes GIScience as a "science which deals with generic issues that surround the use of GIS technology, hamper its successful implementation, or contribute to the understanding of its capabilities" (Goodchild, 1992). Furthermore, it considers fundamental questions raised by the use of systems and technologies and is the science needed to keep technology at the cutting edge[1]. A full definition of GIScience was provided in a report on a workshop held in January 1999 at the National Science Foundation on Geographic Information Science: "Geographic Information Science (GIScience) is the basic research field that seeks to redefine geographic concepts and their use in the context of geographic information systems. GIScience also examines the impacts of GIS on individuals and society, and the influences of society on GIS. GIScience re-examines some of the most fundamental themes in traditional spatially oriented fields such as geography, cartography, and geodesy, while incorporating more recent developments in cognitive and information science. It also overlaps with and draws from more specialized research fields such as computer science, statistics, mathematics, and psychology, and contributes to progress in those fields. It supports research in political science and anthropology and draws on those fields in studies of geographic information and society" (Mark, 2000; Mark, 2003). Based on this definition it is a multidisciplinary field, which includes many disciplines that have traditionally researched geographic information technologies (like cartography, remote sensing, geodesy, surveying, photogrammetry, and image processing) and disciplines that have traditionally researched digital technology and information, in general (e.g., computer science, particularly: databases, computational geometry, image processing, pattern recognition, information science). Furthermore GIScience takes account of disciplines

[1] as outlined in Goodchild, M.F., 1997. What is Geographic Information Science? NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u002/u002.html, posted October 7, 1997

that have traditionally studied the Earth, particularly its surface, with regard to the earth itself or with regard to humans (e.g., biology, particularly ecology, biogeography, environmental science, geography etc.). These are all sciences that are potential users of GIS. All these disciplines have traditionally studied the nature of human understanding and its interactions with machines. Further these disciplines may involve fields like psychology, particularly cognitive psychology, environmental psychology, cognitive science and artificial intelligence. Concerning the difference between the terms *spatial* and *geographic*, it might be suggested that *geographic* has to do with the earth, including its two-dimensional surface and its three-dimensional atmosphere, oceans, sub-surface. *Spatial* has to do with any multi-dimensional frame (e.g., engineering drawings are referenced to a mechanical object or architectural drawings are referenced to a building). Within this framework, *geographic* is a subset of *spatial*, the terms are often used interchangeably. In the literature *geographic* is called also *geospatial*.

2.2 Mapping, Cartography and Geovisualization

Cartography continuously evolves with numerous technical (r)evolutions and has been redefined again and again. There are about 42 definitions on the word "Cartography" compiled by D'Ignazio[2] and about 320 definitions for the word "map", collected by Andrews (Andrews, 1998)[3]. The Commission on Cartographic Education of the International Cartographic Association (ICA) defined Cartography as the totality of investigation and operations - scientific, artistic and technical - which have as their aim the making of maps and as well as the use of maps[4]. The ICA strategic plan for 2003-2011 offers two definitions, (1) Short definition: "The art, science and technology of making and using maps." (2) Long definition: "A unique facility for the creation and

[2] Report compiled by D'Ignazio, C., 2004. The Limits of Cartography, The Institute for Infinitely Small Things.

[3] A full list of the definitions mentioned in the reference is available in the Editor's notes http://www.usm.maine.edu/~maps/essays/andrews.htm

[4] International Cartographic Association (ICA), 1999. Definition of Cartography, *ICA Commission meeting on Cartographic Education*.

manipulation of visual or virtual representations of geospace – maps – to permit the exploration, analysis, understanding and communication of information about that space”.[5] For general understanding and the creation of cartographic representations, we can utilize knowledge from the fields of geography, art, science and technology of map making, the use of maps as research tools and as sources of information, as well as the study of maps as historical documents and works of art. Traditional cartographic research focused on the role of maps as information storage and communication devices. In a narrow sense, this discipline of cartography, also referred to as mapping, is disappearing. Denis Wood points this out strongly in his polemic “Cartography is Dead (Thank God!)” (Wood, 2003). Meng suggests that in the long run the lack of theories and methods that should guide cartographic processes may cause the degradation of the scientific value of cartography. She argues that the current cartographic practice is still strongly purpose-driven and offers the division of a digital map can be designed as a “Map as view-only graphic”, a “Map as a window of analytical GIS” or a “Map as thinking instrument of explorative GIS ”, depending on its intended purpose (Meng, 2003).

In a broader view, it seems the academic discipline grew from a certain to a less certain discipline of cartography. Graduate programs adjust the balances among the many components of mapping science, including cartography, geovisualization, GIscience, GIS systems, spatial analysis & statistics and remote sensing (McMaster and McMaster, 2002). Within this less certain discipline, geovisualization (sometimes referred to as geographic visualization) is defined as a loosely bound domain that addresses the visual exploration, analysis, synthesis and presentation of data that contains geographic information, by integrating approaches from disciplines within GIScience, including cartography, with those from scientific visualization, image analysis, information

[5] International Cartographic Association (ICA), 1999. Definition of Cartography, A Strategic Plan for the International Cartographic Association 2003-2011,As adopted by the ICA General Assembly 2003-08-16,
http://www.icaci.org/en/ICA_Strategic_Plan_2003-08-16.pdf

visualization and exploratory data analysis (Dykes, MacEachren et al., 2005a). The concept of geovisualization built upon work by Tuckey (1977) on exploratory data analysis. Exploratory data analysis aims to identify data properties for purposes of pattern detection and hypothesis formulation, and, in some cases, to evaluate the aspects of model assessment (e.g., goodness of fit, identifying data effects on model fit). Exploratory data analysis is based on the use of graphical and visual methods and the use of numerical techniques that are statistically robust (i.e., not significantly impacted by extreme or atypical data values). This method is also used as exploratory *spatial* data analysis, as an extension of exploratory data analysis, to detect spatial properties of data[6]. This includes detecting spatial patterns in data and formulating hypotheses based on the geography of the data. It is important to be able to link numerical and graphical procedures with the map and to be able to identify where specific cases are located on the map. Bertin (1967) structured this based on ideas about the representation and analysis of geographic information. During the eighties, MacEachren and others began to focus on the concept of geovisualization as a method that goes beyond information communication. It evolves geovisualization as a tool for knowledge construction (MacEachren, 1994; MacEachren, 1995; MacEachren, 2001b; MacEachren and Kraak, 1997). Geovisualization, from that perspective, is about the use of visual geospatial displays to explore data and, through that exploration, to generate hypotheses, develop problem solutions and construct knowledge (MacEachren, 1994; MacEachren and Ganter, 1990; MacEachren, Wachowicz et al., 1999). As Dykes states, whomever it involves and however it is used, geovisualization is about people, maps, process and the acquisition of information and knowledge. It can lead to enlightenment, thought, decision-making and information satisfaction, but can also result in frustration. (Dykes, MacEachren et al., 2005b). The emphasis is on information insight for the further use in spatial models upon which decisions can be based; the general idea is to use

[6] an overview can be found by Haining, R. and Wise, S., 1997. Exploratory Spatial Data Analysis. NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u128/u128.html, posted December 05, 1997

geovisualization to aid knowledge discovery in large spatial databases and to aid interactive analysis and complex problem solving.

An often-referenced concept is the map cube by MacEarchren (1994) shown in Figure 5, which he later modified with Kraak (1997). It proposes the major dimensions of map use as target audience presentation intension, and the degree of human-map interaction. A similar distinction has been proposed by DiBiase (1990). In his schema, the presentation of geographic information in the public realm is called visual communication instead of visual thinking.

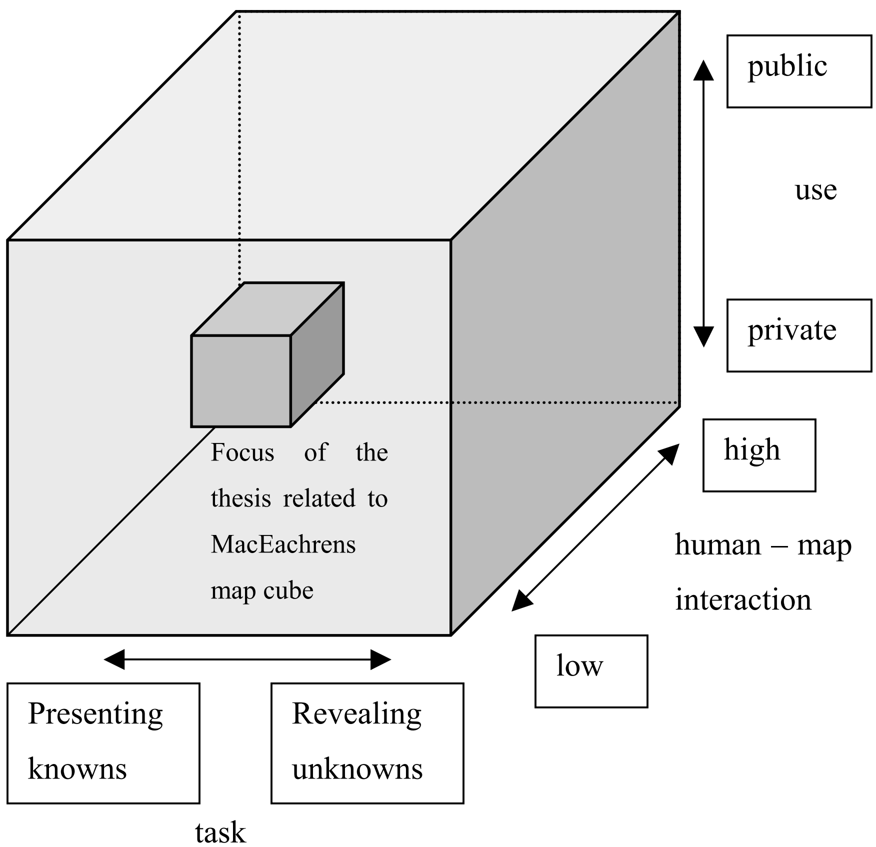


Figure 5. Focus of this research related to MacEachrens map cube

Concerning the maps as outcomes, the present work investigates the use of geovisualization in the development for problem-specific models and task-specific maps. It is rather difficult to place the scope of this research into the framework of the map-cube; still we might make an attempt. Within this research, perhaps the human-map interaction is rather low, as task-specific maps intend to deliver a clear message, even though they might include interactivity and explorative concepts. The task-specific maps try to present “knowns”, as the knowledge discovery process (resulting in the selection of meaningful variables) has been done within the problem-specific modeling process. In a way, we may present “knowns” to reveal “unknowns”, which might cause a dilemma in this arrangement of the map cube. The target audience for the maps is private and, to a certain degree, public, as the task-specific maps might be used to reason proposed actions in planning and decision-making. This places the focus of the research slightly away from the center of the cube towards the areas of “presenting knowns” and “low interactivity”.

The use of geovisualization heavily depends on the user and the purpose of the visualization (Nielsen, 1993; Slocum, Blok et al., 2001). There have been some efforts to design systems that address the explicit needs of specific user types; researchers have conducted a number of studies regarding the usability of geovisualization (Fuhrmann, Ahonen-Rainio et al., 2005). Monmonier (1993) explored the quality of enumeration-area data with graphic scripts. Howard (1996) has explored interface design for geographic visualization and tools for representing spatial data reliability. Andrienko, et al. (2006; 2002) investigated the usability of interactive tools for exploratory analysis of geospatial data. Tools for the exploratory analysis of spatial data have been applied on various cases. Griffin (2004) used data-display devices for interactive visual computing with geographical models on medical data and investigated how experts use maps in conjunction with other statistical graphics to think about the problem of hantavirus pulmonary syndrome risk. Koua (2005) investigated the computational and visual support for exploratory geovisualization and knowledge construction using self-organizing maps developed by Kohonen (2001). It is very often not clear who are the actual users of a system and what their specific tasks are. Slocum, et al., (2001) note, “a clear specification of tasks (and sometimes of users) is often not possible due to the exploratory and interactive nature of geovisualization.” Additionally, visual displays of geospatial information have long served as enabling devices for group work. Urban and regional planners, for example, often gather around large paper maps (or digital maps projected) to discuss master plans or specific development choices. These same large format maps are used as the object of discussion at subsequent public meetings. In these cases, multiple users with perhaps different backgrounds use the same maps. MacEachren, among others, investigated to support this group work and defines the concept as geocollaboration (MacEachren, Brewer et al., 2003; MacEachren, 2005).

From a broader perspective, geovisualization provides theory, methods and tools for the visual exploration, analysis, synthesis and presentation of data that contain geographic information (MacEachren and Kraak, 2001). There are different types of users who use geovisualization systems differently and bring different knowledge to the decision-making process. Within the framework of this research we suggest distinguishing between the processes of classic mapping and cartography and the process of geovisualization. This distinction considers mapping as the process of creating maps that are a two-dimensional representation of a three-dimensional world, while geovisualization, in this approach, is a process of producing maps that can include elements of interactivity and animation, augmented reality or even virtual reality, the third-dimension (in a wider sense than for "classic" cartographic maps), and the representation of an intangible environment—a process that may lead to the representation of more abstract concepts.

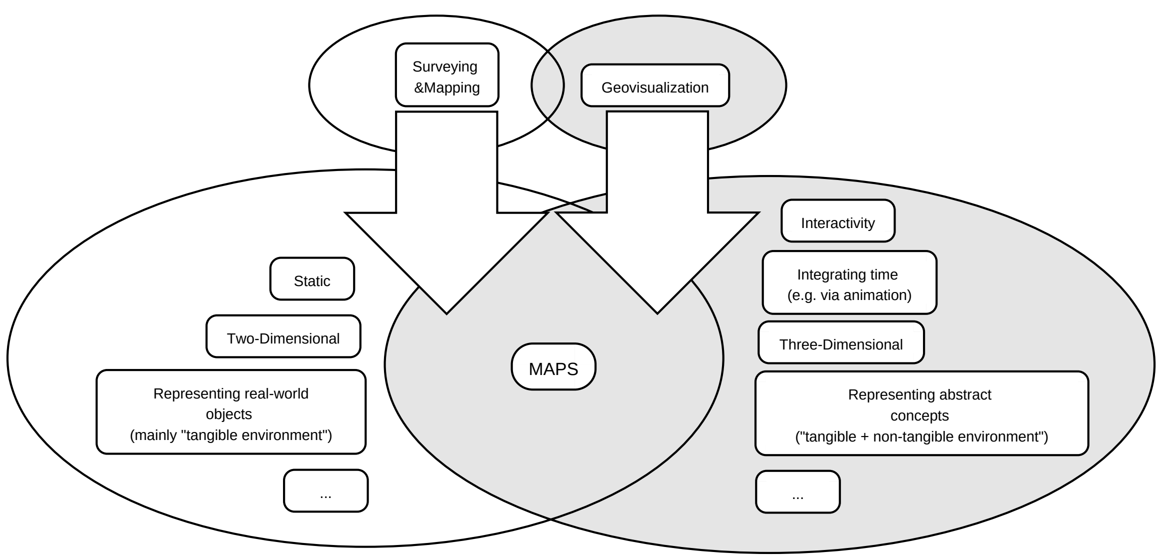


Figure 6. Mapping and Geovisualization as processes to create maps

Figure 6 illustrates surveying and mapping and geovisualization as processes to create maps as well as some, though not all, concepts that might be incorporated into this process. It should be noted that the process of creating maps using mapping and that of geovisualization overlap somewhat; no firm boundary can be drawn between these maps. A distinction is suggested between the processes of classic mapping and cartography that produce static 2D maps and the process of geovisualization that includes interactive and multi-dimensional maps (Figure 6). Perhaps from another point of view, it would be possible to regard geovisualization as the state-of-the-art mapmaking techniques, being a part of the modern cartography and producing all kinds of maps as well as map-like presentations. Within this framework aspects such as dimensionality, VR / AR and interactivity are considered. Additionally we may suggest methods like the density-based highlight method along with the third dimension as display metaphor.

2.2.1 Interactivity and Animation

One of the key factors distinguishing geovisualization from traditional cartography is an emphasis on interactive maps. Interactivity has been there before geovisualization, as not every clickable map on the web is a product of geovisualization, but interactivity also has been adapted as an important research area in geovisualization (Kraak, 1998; Kraak and MacEachren, 1999). Therefore geovisualization, as such, is not merely a passive process of seeing or reading maps. It is an active process in which an individual engages in sorting, highlighting, filtering and otherwise transforming data in a search for patterns and relationships (MacEachren, 2001b). Computers allow the use of interactivity to a certain degree; one typically interacts by clicking buttons, panning, zooming, turning, etc. The possibilities have been investigated by several authors from different fields, for example Cartwright (1999) on multimedia cartography and Buziek (2000) on dynamic cartography, which includes also examples dealing with animation in cartography. Animations can use temporal or non-temporal attributes. Most research in cartographic animation focuses on the two-dimensional visualization of spatial-temporal themes. Concerning three-dimensional animations, early research on this subject is from Tobler (1970), who investigated the general possibilities of animating three-dimensional thematic maps. Moellering (1980a; 1980b; 1984) examined the use of interactive visualization to support expert exploration of spatio-temporal phenomena and processes, which attributed substantially to the theory of cartographic computer animation. Several authors discuss the communicative aspects of spatio-temporal maps (Buziek, 1999; Dransch, 1997; Koussoulakou and Kraak, 1992; Kraak, 1999). It is important to determine the nature of animation as a tool for exploratory analysis, beyond its straightforward display function (Fairbairn, Andrienko et al., 2001). Shepherd (1995)suggests that whenever dynamic features are added to maps it should be asked "why" and also "how" and "when" animation can be used appropriately and successfully for visualization. Blok (2005) considered the use of dynamic visualization variables in animation to support monitoring of spatial phenomena and to discover spatio-temporal patterns, relationships and trends.

2.2.2 Virtual Reality And Augmented Reality

Virtual Reality addresses the construction of artificial worlds with clear spatial dimensions (Unwin and Fisher, 2001). The databases for virtual reality can structure and store data using methods trying to minimize spatial abstractions. The computer systems are able to combine a mixture of real world experiences and computer-generated material to allow a simulated real world representation. Virtual reality is one way for integrating, storing, accessing and viewing a multitude of spatial data using a variety of tools. It can be considered under the general heading of visualization. From a technical point of view the virtual reality markup language (VRML) might enable us to incorporate virtual reality with geographic datasets. Cartographers have used VRML to add interactivity to their maps and to explore the potential for realistic representations with some success (Dykes, Moore et al., 1999). The methods vary depending on whether usage is for private investigation or for public demonstration of spatial phenomena. Geographical data can be implemented in virtual reality systems, but there might be complications for geographical data. Such complications may arise, for example, in data structuring, as it might be difficult to alter or enhance data and may reduce the importance of a reference system for the data.

Augmented reality (and *mixed reality*) are interdisciplinary fields involving signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, computer networks, distributed computing, information access, information visualization, and hardware design for new displays and sensors. Mixed reality and augmented reality concepts are applicable to a wide range of applications. Milgram, Takamura et. al (1994a) describe a taxonomy that identifies how augmented reality and virtual reality work are related. They define the Reality-Virtuality (RV) continuum shown in Figure 7.

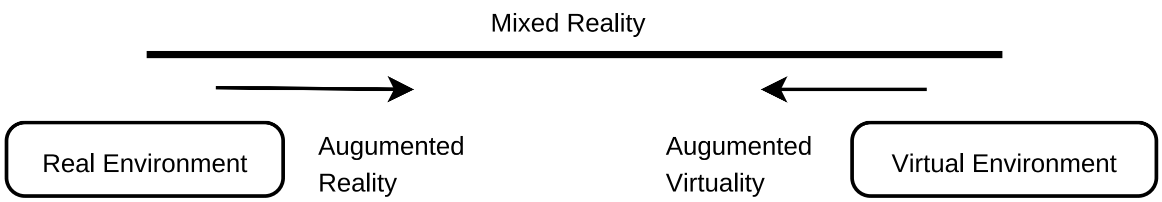


Figure 7. An organization of displays on the Reality - Virtuality continuum adapted from Milgram (1994a)

The *real world* and a *virtual environment* are at the two ends of this continuum while the middle region is called mixed reality (MR). Augmented reality lies near the real world end of the line with predominate perception being the real world augmented by computer-generated data. *Augmented virtuality* is a term created by Milgram and Kishino (1994b) to identify systems that are mostly synthetic with some real world imagery added. Pioneering work in this domain has been performed by Fournier (1993). Hedley (2002) applied explorations in the use of hybrid user interfaces for collaborative geographic data visualization. Vallino (1998) suggests that the distinction between real and virtual elements will fade as the technology improves and the virtual elements in the scene become less distinguishable from the real ones. From a cartographic point of view, the combination of modern computing technology and the exhaustive digital coverage of the earth at multiple scales is a particular form of cyberspace, blurring the distinction between reality and a representation of it (Peuquet, 2002; Peuquet and Kraak, 2002). The boundary between direct and indirect experience of the environment is becoming so fuzzy that it turns out to be difficult in a cyber-world to distinguish between the real and the created. Is that ever going to replace textual and graphic representations of geographic space? According to Peuquet and Kraak (2002), the answer is clearly no, because maps by definition are symbolized abstractions of reality. Maps abstract reality and provide selections from reality that facilitate an understanding of the selected features. The motivation of the development of virtual reality relating to geography has been in providing as realistic a view as possible (Unwin and Fisher, 2001). On the other hand, the combination of realistic and virtual components might have advantages in the understanding of the phenomenon.

2.2.3 Density visualizations to explore geographic point data

Density as a geovisualization tool is not strictly formulated; perhaps it is seen more as a "thematic mapping method". In a wider sense it might be regarded as a geovisualization tool as the calculation of density maps with varying parameters and changeable visual outputs can aid the visual exploration of geographic data. This might additionally very well help the communication process between domain experts and GIScientist (see also chapter 5.1). Density itself is just a mathematic measure. Density surface is an analytical function applicable to a map or modeling method for the creation of a thematic density map. Additionally it has to be kept in mind that density calculation for visualization is only one of many available methods. Density calculations are methods used for visualizing the distribution of point data. In some cases they are used to find hot spots. They are commonly used in the analysis of point patterns and have been investigated by several authors (Bailey and Gatrell, 1995; O'Sullivan and Unwin, 2003). Points can be aggregated within a specified search radius and create a smooth, continuous surface that represents the density (or volume) in the study area. Density maps are commonly used in many applications, for instance, to show surfaces representing temperature, rainfall, digital elevation models and in crime- or population-hotspot detection. They are calculated to visualize a concentration, population, or a height value taken from sample locations to estimate values for all locations between sample sites in the study area. Common density interpolation techniques are, for example, inverse distance weighting and kriging.

Kernel density estimation

The kernel density method (applied in case study I and II) is used (we might say as a geovisualization tool) to acquire information about the spatial distribution of a phenomenon, for example, for population density from different perspectives. The kernel density estimate replaces each point with a kernel, giving the surface a "spatial meaning". Applying a kernel to statistical estimations can be useful, as the method allows adjustment in cases of high variance from a "normal" distribution. This is made possible by an adjustable width of the kernel--with a wide kernel allowing for higher smoothing--and an adjustable bandwidth, influencing the amount of detail in the resulting plot. The determining factors are the search radius (also referred to as bandwidth) and the grid size. If the search radius is too large, the estimated densities will be similar everywhere and close to the average density of the entire study area. Experimentation or expert knowledge is required to achieve the optimal search radius. An adjustable kernel width--with a wide kernel allowing for higher smoothing--influences the amount of detail in the resulting plot (Silverman, 1986).

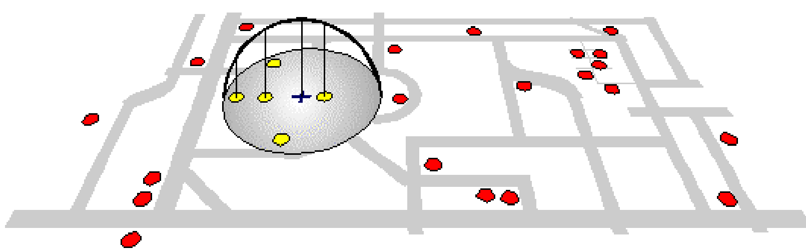


Figure 8. Weight calculation for each point within the kernel radius (Ratcliffe, 1999)

A moving three-dimensional function of a specified search radius visits each individual point and calculates weights for each point within the kernel radius, as illustrated in Figure 8. Points closer to the center receive a higher weight and, therefore, contribute more to the total density value of the cells. The final grid values are calculated by summing the values of all circle surfaces for each location. The selection of an appropriate bandwidth is a critical step in kernel estimation and requires testing. A core problem is to have enough expert knowledge to be able to determine the correct search radius and visualize the correct information; expertise on the calculation of kernel density estimations and expertise on the application field are required. Generally this is done with GIS-experts (or other Geoscientists), who communicate with the domain experts from the application field. In general, a large search radius will result in a large amount of smoothing and a large number of low-density values, producing a map that is generalized in appearance. In contrast, a small search radius will result in less smoothing, producing a map that shows local variations in point densities (Bailey and Gatrell, 1995).

Kernel density estimates have been used for hotspot detection in various fields, such as crime analysis (Ratcliffe and McCullagh, 1999). Kwan (2000; 2003) uses geovisualization of activity density patterns in space-time and displays the results as a continuous density surface. She applies the density estimation as a method of geovisualization to find patterns in human activities related to other social attributes. Continuous surface representations of population density have been shown to have advantages in the visualization and analysis of population distributions (Langford and Unwin 1994; Martin and Bracken 1991). In this research the method is applied to investigate wildlife density changes (see chapter 4.2) and wildlife-traffic-vehicle accident concentrations (see chapter 4.3). In the applied cases I and II the bandwidth and the grid sizes are set to specific values, which have proven to be appropriate settings for the scale of the study area in the particular case.

2.2.4 The Third Dimension In Geovisualization

Classic cartography provides a rich history of both practice and science relevant to current geospatial visualization challenges. Using three-dimensional visualization in the cartographic process of creating a map is used mainly to explain measurements that have a third dimension in "real-appearance". One example of this is a digital elevation model (DEM) in which the heights of buildings are visualized three-dimensionally. The fundamentals for designing three-dimensional visualizations--grayscale DEMs, vertical exaggeration, and illumination--are explained, for example, by Raper (1989) and Patterson (1999). Much of cartography's familiarity with three-dimensional landscapes originates from the research and artistic achievements of Harrison (1944) and Imhof (1982). Their traditional works (panoramas, sculpted physical models and orthographic globes) are highly aesthetic, compelling readers to pause and explore spatial relationships within a landscape (Patterson, 1999). In these cases of a three-dimensional representation, geo-objects are visualized in a natural way that is rather close to what we experience in our daily life. The essential depth cues embedded in this sort of representation make it easy for readers to interpret the presented geo-objects and their spatial relationships without having to consult a legend (Meng, 2002). Many examples can be found in which an overlay image (e.g., a satellite image, a photograph or an aerial photograph) is draped over a digital elevation model or a city model (Cartwright, Peterson et al., 1999; Rakkolainen, Timmerheid et al., 2000).

Numerous papers describe several GIS-based three-dimensional geovisualization methods for dealing with the spatial (and sometimes temporal) dimensions of human activity patterns. These can result in a space-time path in a space-time cube (Gatalsky, Andrienko et al., 2004; Kraak, 2003b) or they can be visualized in activity density patterns with a continuous surface (Kwan, 2000). The theoretical approach on the advantages and disadvantages regarding two- and three-dimensional visualizations are taken into account by several authors who have explored the general factors and use of three-dimensional maps (Kraak, 1988; Kraak, 1994; MacEachren and Fraser Taylor, 1994). Slocum (1999) has investigated the use of the third dimension in thematic maps. To use geovisualization and create interactive three-dimensional thematic maps is not new, but, up to now, only some examples can be found (Krisp, 2004; Krisp and Fronzek, 2003; Swanson, 1999). An overriding opinion amongst general users of modern visualization techniques is that much can be gained from interacting with innovative and dynamic graphical representations such as animation, three-dimensional maps or virtual worlds (Ogao, 2002).

Three-dimensional density maps

Three-dimensional visualization methods have been applied to represent space-related distributions where the third dimension usually serves as a metaphor of a geo-referenced theme. Wood (1999) explores both the visualization potential of such three-dimensional surfaces and the use of a landscape "metaphor" as a way of understanding the data. He argues that a relief metaphor, together with concepts and techniques developed for the analysis of real terrain surfaces, provides interesting analytical and visual insights into population distributions in the greater London area. A similar attempt has been carried out by Krisp, et al.(2005) within developing a planning application for the fire and rescue services for the Helsinki city center area. Applying slopes to these continuous surface densities somewhat demonstrates the effect of physical features on the distribution of residential areas and may indicate some "channels" between the steep changes in the density of residents. These channels will possibly, in some cases, assist the planning of emergency routes for fire and rescue services. In both of these cases, the population density presented in the third dimension is based on density estimations.

2.2.5 Relating Non-tangible Attributes To Tangible Objects

Maps may represent non-tangible (non-visible) aspects of the world. Kraak, MacEachren et.al, suggest this distinction into tangible and non-tangible attributes in relation to GeoVirtual environments. (Kraak, 1999; MacEachren, Kraak et al., 1999). Virtual environment can be used to simulate the tangible world (e.g., to allow users to experience places distant in space and/or time). Generally maps are thought to represent spatial objects that have a real appearance. This might be called tangible environment. On the other hand, virtual environment and maps can be used to represent non-tangible (non-visible) aspects of the world. It is a form of cartographic abstraction to explore complex multivariate relationships in geospatial information (e.g., integrated regional assessment in which economic, social, and environmental factors). These are thematic concepts and they can be referred to as non-tangible environment. The approach presented in this research includes thematic variables to visualize variables that are not represented and measured in reality. Research in this field of thematic maps has been done on various topics. In the case studies (see chapter 4), the subject of research is related to the non-tangible environment. The resulting maps do not represent the real world, but are used as a tool to advance our understanding of processes and states. In the case studies presented, the subject of research is the use of geovisualization to communicate a non-tangible attribute. These cannot be observed directly in nature and are abstract concepts of changing moose habitat locations, ecological barriers, and specific road sections endangered by wildlife crossing.

2.3 Categorization Of Models

Dictionaries offer a variety of definitions for a "model". The Oxford New English dictionary offers as one of many definitions for a model "A three-dimensional representation, esp. on a small scale, of a person or thing or of a projected or existing structure; esp. one showing the component parts in accurate proportion and relative disposition." (New-English-Dictionary, 2006). A definition by Hestens (1996), originating from the field of physics, identifies a model as "a representation of structure in a physical system and/or its properties". Within the context of this research we may add to the conceptual definition "a model is a representation to help visualize something that cannot be directly observed". Due to the complexity of the world and the interactions in it, models are created as a simplified, manageable view of reality. Giordano and others state that models help to understand, describe, or predict how things work in the real world. A model should represent only those factors that are important to a specific case and create a simplified, manageable view of the real world (Giordano, Weir et al., 1997). But how do we know what is important? This is a severe problem, in general. In some cases it is known, but how can we extract, measure, weigh and integrate knowledge into a model or, in the context of this research, into a spatial model? The real world is infinitely complex, and it follows that it is impossible to create a perfect representation of it. Zhang and Goodchild (2002) review research into the measurement, characterization, modeling and propagation of uncertainty. Hestens (1996) identifies a model as a representation of structure in a physical system and/or its properties. He specifies four types of structure, each with internal and external components:

- Systemic structure specifies
    a. Composition (internal parts of the system)
    b. Environment (external agents linked to the system)
    c. Connections (external and internal causal links)
- Geometric structure specifies

a. Position with respect to a reference frame (external geometry)
b. Configuration (geometric relations among the parts)

- Temporal structure specifies change in state variables (system properties)
  a. Descriptive models represent change by explicit functions of time
  b. Causal models specify change by differential equations with interaction laws
- Interaction structure specifies interaction laws expressing interactions among causal links, usually as function of state variables.

Ford (1999) provides an outline of generic model structure that is useful for geosciences instruction and gives a philosophical discussion of what models are and why they are useful. According to Ford, the key features in common with the development of any model are that:

- Simplifying assumptions must be made.
- Boundary conditions (spatial and temporal) or initial conditions must be identified.
- The range of applicability of the model should be understood.

Generally a model cuts us off from our reality, thus making the human-reality interaction indirect. When using a model, we have to first understand the contents of the model and then associate them with their counterparts in the reality. Selected points summarized from Meng (2001) on the characteristics of human-model interaction point out that, despite its incompleteness, a digital model holds much more information than what we can acquire through direct perception. Unnecessary details have been filtered away in a model. Additionally a model represents a scaled down reality and a digital model is based on a consistent system, which allows different users to share the information. Within this research the concept of spatial models is organized as shown in Figure 9, with spatial models classified into maps, mathematical models, representation or cartographic models and process models.

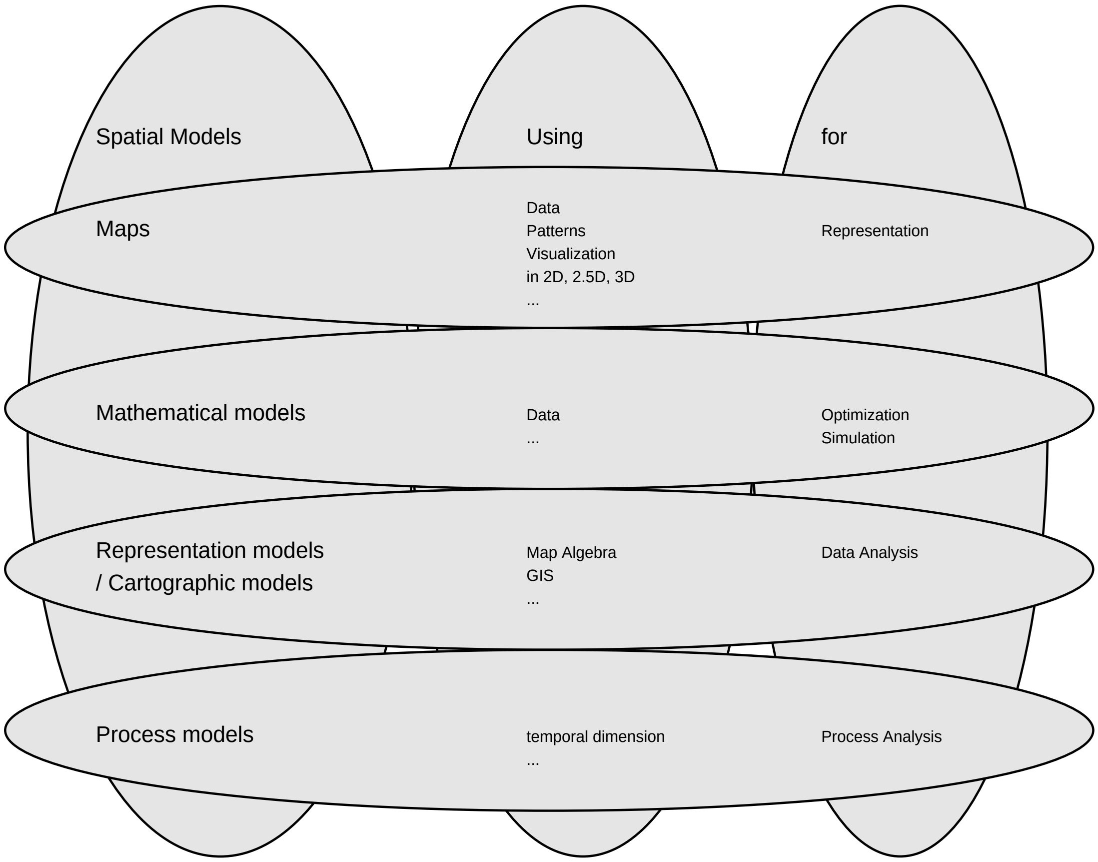


Figure 9. Suggested categorization of spatial models

2.3.1 Maps

In the literature describing the history of maps and mapping technologies there is a classic distinction between "military" and "scientific/civilian" cartography. However, both civilian and military practices of using maps for measurement have roots in the administration of territory, resources and population that is associated with state systems. To understand the function that cartography and surveillance once performed for state power, it is useful to briefly consider other historical moments when maps and overhead perspectives first contributed to new ways of imagining and administer a state. Cartography and mapping were a way to condense long lists of information taken from geographic surveys that were increasingly being commissioned by modern states for the administrative control of land and resources (Kain and Baigent, 1993). Geographic information systems (GIS) are being used for the same thing by governments and increasingly by companies. Maps have traditionally been monopolized by the state and kept a state secret, at least since the rise of modern nation states between the 16th and the 18th centuries. Maps in the 18th century were used as representations for visualizing the state and its territory. The ownership and use of maps and globes in this period indicated direct territorial authority. Historians of cartography suggest that a new way of thinking, characterized by “the ability to think cartographically and to prepare sketch maps as a means of illuminating problems,” was already growing during this period (Barber, 1992). Associated with this history a new “map consciousness,” an idealized and moralized geography or “integrated cosmography,” and a more modern way of “seeing” the world and of thinking of the nation as a cartographic entity” (Marino, 1992). Considering this, perhaps the idea of using maps to illuminate problems has been key idea (besides transferring spatial information) from a very early point in time.

Generally research on maps is a very large field, considering the history and application fields in which maps are used. This extensive research field includes, for example, studies that have been carried out on maps in general (MacEachren, 1995; Wood, 1992), map design (Brewer, 2005; Krygier and Wood, 2005), the utilization of maps in political uses (Buisseret, 1992) and on the use of maps in the exploration of geographic data (Elzakker, 2004). Thematic maps can be regarded as maps that are created for a purpose (e.g., the average income in different countries). Within this research we extend the concepts of thematic maps (Slocum, 1999; Slocum, 2005) to task-specific maps. A thematic map (or statistical map) is used to display the spatial pattern of a particular theme or attribute. Task-specific maps are even more detailed, to the point where they might provide a very limited view relating to a specific problem. As Kraak (2001) states, maps are there to answer questions like "Where can I find...?", "How do I get to...?", "What feature can be found at...?", or "Where else do I find that feature?" Maps have to be well designed to be able indeed to answer questions like those above. If the translation from data to graphics is successful, the resulting maps are the most efficient and effective means of transferring geospatial information. The map user can locate geographic objects, while the shape and color of signs and symbols representing the objects inform him about their characteristics. They reveal spatial relations and patterns, and offer the user insight into, and an overview of, the distribution of particular phenomena (Kraak, 2001).

In this work, maps are the output of a geovisualization process and should provide users with task-specific information. This has to be done in a responsible way. Monmonier (1996) investigated how to lie with maps and illustrated this with many examples. He suggests maintaining a certain degree of skepticism about these easy-to-manipulate models of reality. In philosophy, skepticism refers more specifically to any one of several propositions. These include propositions about (1) the limitations of knowledge, (2) a method of obtaining knowledge through systematic doubt and continual testing, (3) the arbitrariness, relativity, or subjectivity of moral values, (4) a method of intellectual caution and suspended judgment, (5) a lack of confidence in positive motives for human conduct or positive outcomes for human enterprises (Keeton, 1962). All these points could be applied to the use of maps. In task-specific maps it might be easier to avoid these points, because they address a limited audience of experts and decision-makers, who are involved in the problem specific modeling process to obtain the task-specific maps. This might reduce the lack of confidence in the positive motives for human behavior, in this case the mapmaker. Wood (1994) points out that "a well produced map can cerate an impression of accuracy and neutrality far superior to its true quality". Perhaps this would also work the other way around; a map that contains valuable information, but is poorly presented may give an indication that this information is far less valuable than it actually is.

2.3.2 Mathematical Models

Within the framework of this research, it is useful to consider methods used in mathematical modeling to distinguish them from spatial modeling methods as geovisualization. Methods of constructing and using models in the mathematical world help to better understand real-world systems (Giordano, Weir et al., 1997). What is meant by a real-world system and why is it interesting to construct a mathematical model for a system? A system is an assemblage of objects joined in some regular interaction or interdependence. The modeler is interested in understanding how a particular system works, what causes changes in the system, and the sensitivity of the system to certain changes. The theoretical modeling system is shown in Figure 10.

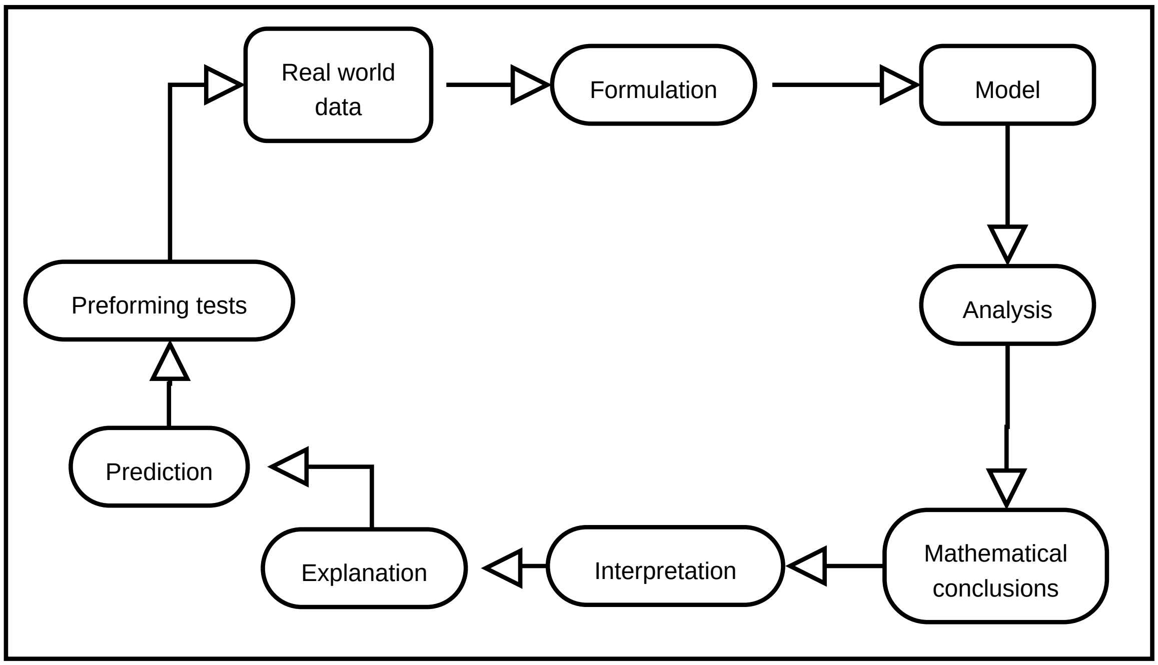


Figure 10. Modeling process as a closed system – based on Giordano (Giordano et al., 1997)

Given some real-world system, we gather sufficient data to formulate a model. Next we analyze the model and reach mathematical conclusions about it. Then we interpret the model and make predictions or offer explanations. Finally, we test our conclusions about the real-world system against new observations and data. We may then find we need to go back and refine the model to improve its predictive or descriptive capabilities. Or perhaps we will discover that the model really does not fit the real world accurately, so we must formulate a new model (Giordano, Weir et al., 1997). The formulation of a model needs knowledge, which can be based on experience, statistical analysis and/or spatial statistical analysis.

2.3.3 Representation Models

Representation models try to describe real objects, such as buildings, streams, or forests. Representation models can be created through a set of data layers and are sometimes referred to as cartographic models (Tomlin, 1990). Cartographic modeling is a general methodology for the analysis and synthesis of geographical data. It employs what amounts to an algebra in which single-factor maps are treated as variables that can be flexibly manipulated using small, but highly integrated sets of cartographic functions. Tomlin's cartographic modeling language (also known as 'Map Algebra') is one GIS modeling environment (Tomlin, 1991). Traditionally, the modeling capabilities of geographic information systems (GIS) have focused on analyzing data and transformations. This modeling accounted only for the organizations data and processes that interacted with data. Information technology extends computer use beyond geo-data processing into communication and coordination. Successfully integrating these methods into the activity involves a spatial modeling process (Burrough, 2003). In a presentation at the European conference on geographic information systems, Stinitz (1993) pointed out that data representation was presumed to provide an understanding of its underlying process. Data from several sources and of differing structures can be combined, but do we know more about the world because we can represent more data? Steinitz (1992) stated, “I do not believe that research on representation models is where major emphasis should be placed”. We now access multi-media systems and have the ability to generate perspectives in real time using combinations of computer and video technology, and, as a result, we can "walk through" and look at landscapes. Surely, we will see continued innovation, technical development, and increased efficiency in data capture, storage, and display, etc., and this is likely to be hardware-driven. But how much better should representations be while still only relying on the visual acuity and individually varied interpretations of the users? If this relationship is seen as a communications theory problem, then research on representation models should focus on the end-users (Steinitz, Wiley et al., 1993).

2.3.4 Process Models

A definition of process modeling and simulation by Mitasova[7] describes process models as theoretical concepts and computational methods that describe, represent and simulate

[7] Mitasova, H. and Mitas, L., 1998. Process Modeling and Simulations. NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u130/u130.html, posted December 2, 1998

the functioning of real-world processes. Computer simulations are becoming a way of performing research, thus expanding traditional experimental and theoretical approaches. This simulation can be regarded as a numerical experiment, but it often requires advancements in theory. They can provide information that is impossible or too expensive to measure, as well as insights that are not amenable or are too complicated for analytical theory methods. Process models can be regarded as simulations that run for certain initial conditions (real or designed). The purpose of modeling and simulations is the analysis and understanding of observed phenomena for testing of hypotheses and theories. They can additionally help the prediction of spatio-temporal systems behavior under various conditions and scenarios, existing and simulated, often performed to support decision-making.

Generally, within a process model a temporal component is added. Processes involve the changes over time, and different operations and functions running over time can be considered a process model. Many authors have noted that these problems are associated with the model-specific representations of space and time (Maidment, 1996; Peuquet, 2002; Wheeler, 1993). There are a number of operational constraints to consider, such as the practical feasibility of running simulation models in an environment that is not optimized for often computationally intensive programs. Hence, combining multiple process models can add complexity. A process model should try to be as simple as possible to capture the necessary reality to approach a problem, but since problems can be very complex, process models have to consider many parameters and turn out to be very complex as well.

2.4 Knowledge Discovery & Decision-Making

In the broader framework of modern thought an early formulation of knowledge was put forward by Descartes to relate "knowledge" to "models". It defined "real knowledge" as concerned with spatiality or extension, in the sense that what could be scientifically known was restricted to what could be called "things", meaning it can be seen (perhaps with the help of instruments) and measured. The world was divided into "thinking substances"--the phenomena of mind--and "extended substances"--the phenomena of bodies or matter, with extension, shape and dimensions. This formulation is called "Cartesian mind-body dualism" and was formulated by Rene Descartes (1637) in his "Discourse on Method", which is often described as the founding document of modern thought. In the creation of models, the "thinking substances" have to be related to the "extended substances". This early concept corresponds with the division of tangible and non-tangible attributes and the relation of these two (see chapter 2.2.5).

Due to knowledge, humans can solve many problems by using "common sense". Domain-specific knowledge is in the mind of an "expert" because of perception, learning and reasoning, but it can be difficult to communicate and use it. Increasingly, humans use computer technology to store existing knowledge in databases, digital libraries and on the web. Peuquet (2002) examined the background of spatial knowledge and its relation to the nature of space and time. She links the long tradition of human thought about space and time to the GIScience. Regarding knowledge acquisition she distinguishes between the cycles from the cognitive perspective and from the scientific perspective shown in Figure 11.

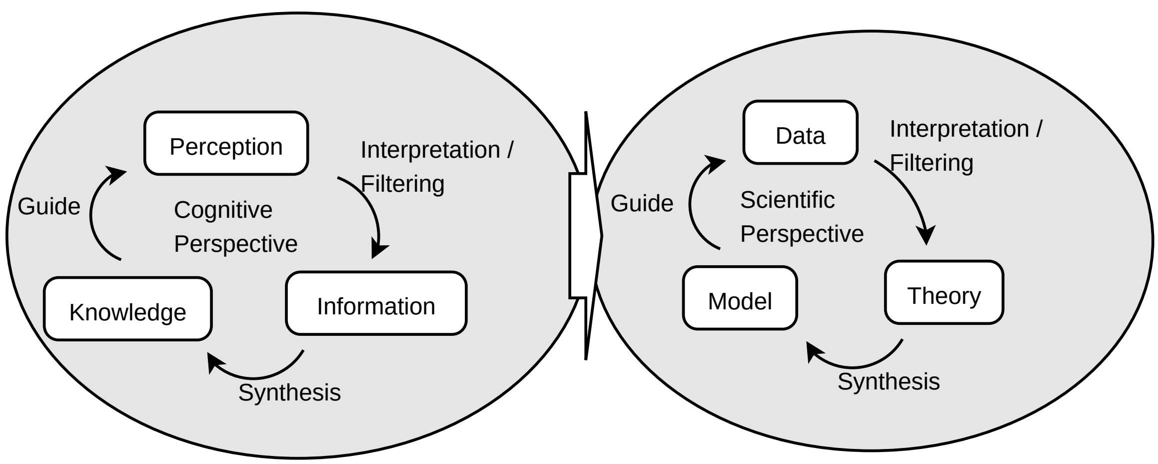


Figure 11. Cycles of knowledge acquisition from the cognitive perspective and from the scientific perspective, based on Peuquet (Peuquet, 2002)

Peuquet suggests that, "In the scientific context theories are formulated via filtering the data to select those observations considered relevant or "interesting". This selection tends to reveal patterns or consistencies in an observed phenomenon. […]. The key difference between the cognitive and the scientific perspective is, that data are externally recorded, and as such, are not subject to the fading of human memory. Data can be reexamined repeatedly without loss of detail and, perhaps more importantly, ban be shared with others. Data are the raw material of formal and scientific analysis" […]. The scientific perspective, as a formalization of this cognitive process, has, to a large extent, already been translated into the computing context. Computers and computer technology, after all, began as a scientific tool and they remain an essential tool for scientific leaning and discovery." (p. 219) (Peuquet, 2002). For this purpose, large amounts of (geospatial) data are collected and stored in digital form. These data sets include digital data of all kind. They are created or processed, and distributed by governments and the private sector. Datasets are available on landuse, socioeconomic data, infrastructure, georeferenced digital imagery high-resolution remote sensing data, like laser scanner point clouds, geographic and spatio-temporal datasets collected by global positioning systems, like Glonas, GPS or Galileo. Furthermore other devices can be used to acquire position information. These include cellular phones, in-vehicle navigation systems or wireless internet clients. The data volumes increase even more because data is stored continuously over time. To be able to research the changes, "old" data is not replaced. As in the cognitive perspective in human learning, the raw data and facts need to be filtered and selected, so that only the relevant data to a selected problem is taken into account and the rest is ignored. One concept from the scientific perspective, particularly in the computing context, has become knowledge discovery in databases (KDD).

2.4.1 Knowledge Discovery In Databases

Knowledge discovery in databases (KDD) has been defined as a process of discovering valid, novel, potentially useful and ultimately understandable patterns from data (Fayyad and Grinstein, 1996).

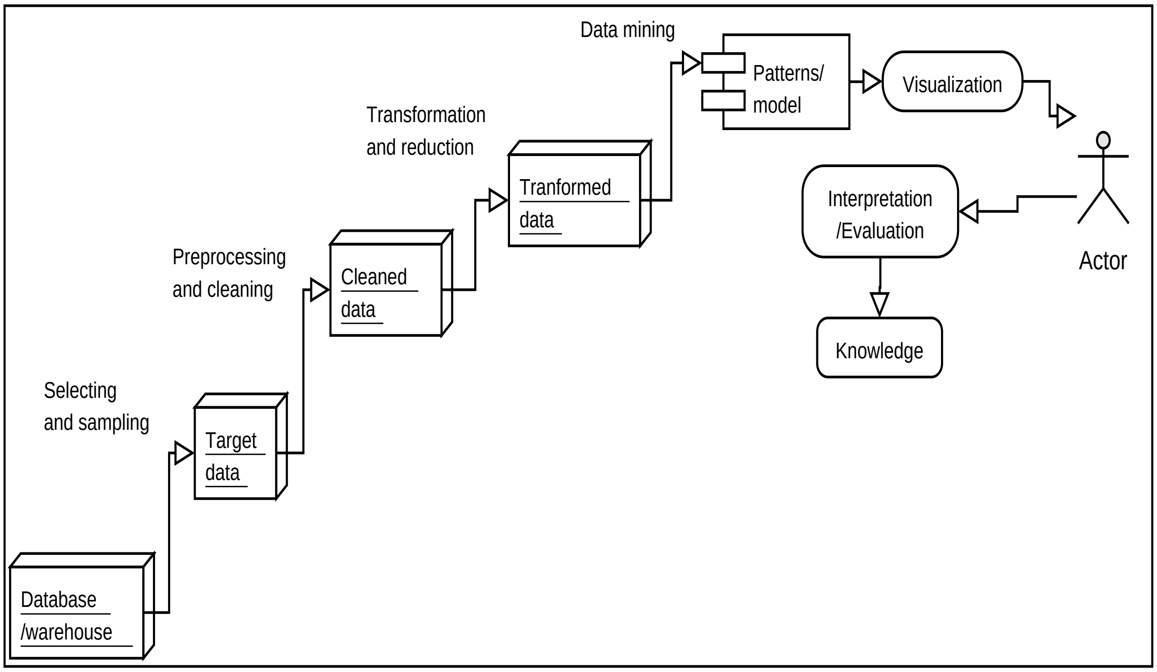


Figure 12. An overview of the KDD process - adapted from Fayyad (Fayyad and Grinstein, 1996)

Figure 12 shows an overview of the overall process of finding and interpreting patterns from data - adapted from Fayyad with the repeated application of the following steps:

- Developing an understanding of the application domain, the relevant prior knowledge and the goals of the end-user.
- Creating a target data set: selecting a data set, or focusing on a subset of variables, or data samples, on which discovery is to be performed.
- Data cleaning and preprocessing, including the removal of noise or outliers, collecting necessary information to model or account for noise, strategies for handling missing data fields, accounting for time sequence information and known changes.
- Data reduction and projection, with finding useful features to represent the data depending on the goal of the task and using dimensionality reduction or transformation methods to reduce the effective number of variables under consideration or to find invariant representations for the data.
- Choosing the data-mining task to decide whether the goal of the KDD process is classification, regression, clustering, etc.

- Choosing the data mining algorithm(s), e.g. selecting method(s) to be used for searching for patterns in the data, deciding which models and parameters may be appropriate and matching a particular data mining method with the overall criteria of the KDD process.
- Data mining, meaning searching for patterns of interest in a particular representational form or a set of such representations as classification rules or trees, regression, clustering, and so forth.
- Interpreting mined patterns.
- Consolidating discovered knowledge.

These steps, in particular, refer to the overall process of discovering useful knowledge from data, which involves the evaluation and possibly the interpretation of the patterns to make the decision of what qualifies as knowledge. It also includes the choice of encoding schemes, preprocessing, sampling, and projections of the data prior to the data-mining step. To achieve insight several methods using visual thinking have been investigated. The discovery of knowledge using geocomputational (and geovisualization) methods is driven by a specific problem. Perhaps the major defining difference between geocomputational and knowledge discovery methods thus far is that the major focus of geocomputation is on providing solutions to given problems, and not the discovery of knowledge per-se (Gahegan, Harrower et al., 2001).

2.4.2 Sense-making loop

Research in sense-making provides the theoretical basis for understanding what a planner does and, according to Thomas & Cook (2005), many reasoning tasks follow a process of

- Information gathering.
- (Re-) representation of the information in a form that aids analysis.
- Development of insight through manipulation of this representation.
- Creation of some knowledge product or direct action based on knowledge insight.

This process might be repeated several times as shown in Figure 13 and Thomas and Cook (2003) refer to this task as a “sense-making” or “knowledge crystallization task”.

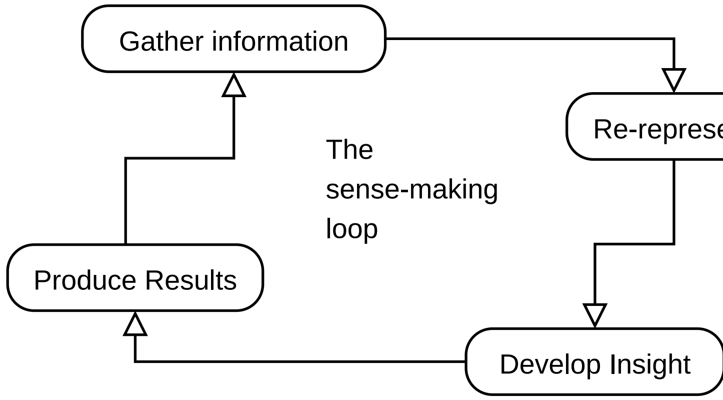


Figure 13. Sense-making loop (Thomas and Cook, 2005)

This loop shows that the representation and visualization of information is a crucial step in the knowledge creation process. Visualization has been traditionally seen as an output of a spatial modeling process. Within this research the modeling process is supported by visualization to select the right target data for the model (Thomas and Cook, 2005).

2.4.3 Decision-Making And Decision Analysis

OODA-loop

A classic concept is the OODA loop, which is the four-step Observe-Orient-Decide-Act loop shown in Figure 14, developed by John Boyd. The OODA Loop is now used as a standard description of decision-making cycles.

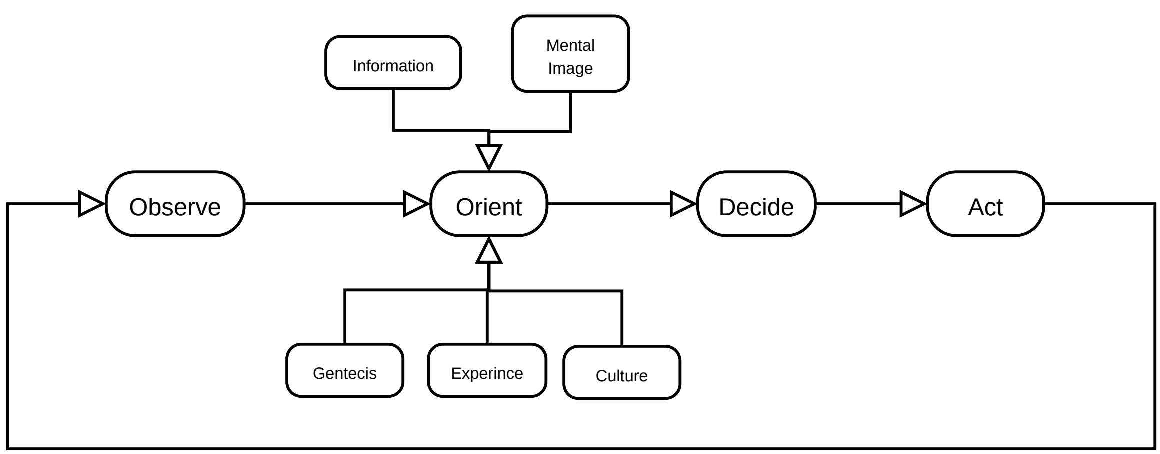


Figure 14. OODA loop adapted from Boyd

According to Fadok (1995), perhaps the best-known feature of Boyd's theory is that he states that all rational human behavior, individual or organizational, can be depicted as a continual cycling through four distinct tasks: observation, orientation, decision, and action. Using this construct from a military perspective, the crux of winning versus losing becomes the relational movement of opponents through their respective OODA loops. The winner will be he who repeatedly observes, orients, decides, and acts more rapidly and accurately than his enemy. Eventually the enemy reacts inappropriately to the situation at hand. The key to attaining a favorable edge in OODA loop is efficient and effective orientation (Fadok, 1995). It is referred in Greer (1985), to Boyd's words, the process of "examining the world from a number of perspectives so that we can generate mental images or impressions that correspond to that world." He implies this in the context of war and air combat, but this theory has been adapted into management and in this research it might as well be relevant to the use of geovisualization in decision making.

Early research by Simon (1960) suggests that any decision making process can be structured into three major phases (Figure 15). The intelligence phase recognizes a problem or an opportunity for change and the design phase identifies what the decision alternatives are. This is followed by a phase in which one chooses which alternative is best.

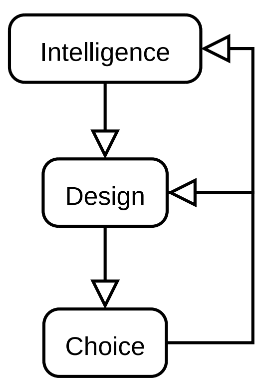


Figure 15. Phases of decision-making by Simon (1960)

Geovisualization (see Chapter 2.2) may provide support in each of the three phases of decision-making. The intelligence phase searches the environment for conditions calling for decisions. That may require an exploratory analysis of the situation. Geovisualization can play a vital role at the initial stage of spatial decision making, because of its ability to integrate and explore data and information. Therefore, it can effectively present information, in a general form, to the decision makers. The design phase involves inventing, developing, and analyzing a set of possible decision alternatives for the problem identified. Problem-specific models are typically used to support generating a set of alternatives. These models for generating decision alternatives operate in the background, detached from decision-makers insights and qualifications. The choice phase involves selecting a particular decision alternative from those available. Each alternative is evaluated and analyzed in relation to others in terms of a specified decision rule. The decision rules are used to rank the alternatives under consideration and the ranking depends upon the decision maker preferences, with respect to the importance of the evaluation criteria. It is sometimes very critical to incorporate the decision maker's preferences into the decision making process. It may be a disadvantage or an advantage to provide a model of the environment that may reduce the overall scope in decision support, especially in the context of problems involving collaborative decision making. The use of geographic information systems in collaborative decision making has been explored in detail by Malczewski, Jankowski and MacEachren, among others (Jankowski and Nyerges, 2001; MacEachren, 2001a; Malczewski, 1999).

Decision analysis

A book by Clemen & Reilly (2001) on making hard decisions sets the objective of decision analysis to help a decision maker think hard about the specific problem at hand, including the overall structure of the problem as well as his or her preferences and beliefs. Decision analysis provides both an overall paradigm and a set of tools with which a decision maker can construct and analyze a model of a decision situation. Figure 16 presents a flowchart for the decision making and analysis process.

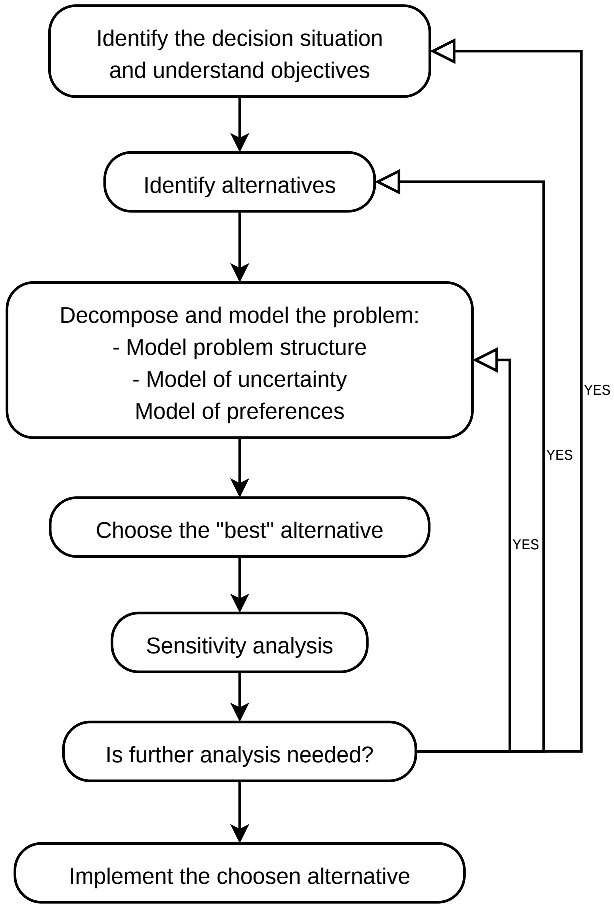


Figure 16. Decision-analysis process based on Clemen (2001)

The fist step in this flow-chart is for the decision maker to identify the decision situation and to understand his or her objectives in that situation. Getting a clear understanding of the crucial objectives in a decision situation must be done before much more can be accomplished. In the next step, knowledge of objectives can help in identifying alternatives, and beyond that the objectives indicate how outcomes must be measured and what kind of uncertainties should be considered in the analysis. Many authors argue that the first thing to do is to identify the problem and figure out the appropriate objectives to be used in addressing the problem. Keeney (1992) argues the opposite, that it is better to understand central values and objectives and to look for a way and for decision opportunities to achieve those objectives. The next step can be called "modeling and solution", as generally referred to in the literature (Clemen and Reilly, 2001). The idea of modeling is critical in decision analysis, as are most quantitative or analytical approaches to problems. A key advantage, from a decision making perspective, is that the mathematical representation of a decision can be subjected to analysis, which can indicate a preferred alternative. Decision analysis is an iterative process. If a model has been built, an analysis can be performed. This analysis might answer "what if" questions. The term *decision-analysis cycle* describes the overall process, which may go through several iterations before a solution is found. In this process, the decision maker's perception of the problem changes, beliefs about the likelihood of various uncertain eventualities may develop or change, and preferences of outcomes, if not previously considered, may develop (Clemen and Reilly, 2001). Decision analysis not only provides a structured way to think about a decision, but also provides a structure within which a decision maker can develop or change beliefs and feelings, which are subjective judgments that are critical for good decisions. Regarding the process to make spatial decision planning, in general, or, more specifically, ecological network planning, several problems can emerge. According to Malczewski[8] there might be a large number of decision alternatives, and the outcomes or consequences of the decision alternatives are spatially uneven. Each alternative is evaluated on the basis of multiple criteria and some of the criteria may be qualitative while others may be quantitative. There is typically more then one decision maker (or interest group) involved in the decision making process. In that case the different decision makers have diverse preferences with respect to the relative importance of evaluation criteria and decision consequences.

2.5 Selected Concepts In Landscape Planning

This chapter does not allow for a comprehensive review of work in landscape planning, but, with an introductory overview of selected concepts, it provides the theoretical background for ecological network planning as a tool that is used in landscape planning. Landscape planning is concerned with research on the allocation of resources on a small scale. It links human goals with an analysis of landscape features, processes and systems. Landscape planning is distinguished from land-use planning by the emphasis on

[8] Malczewski, J., 1997. Spatial Decision Support Systems. NCGIA Core Curriculum in GIScience, http://www.ncgia.ucsb.edu/giscc/units/u127/u127.html, posted October 6, 1998,

landscape resources and environmental attributes as the primary determinants in decision making.

2.5.1 Ecological Networks

The concept of ecological networks emphasizes that nature reserves should contain sufficient, high quality areas of habitat, which are connected by corridors (Figure 17).

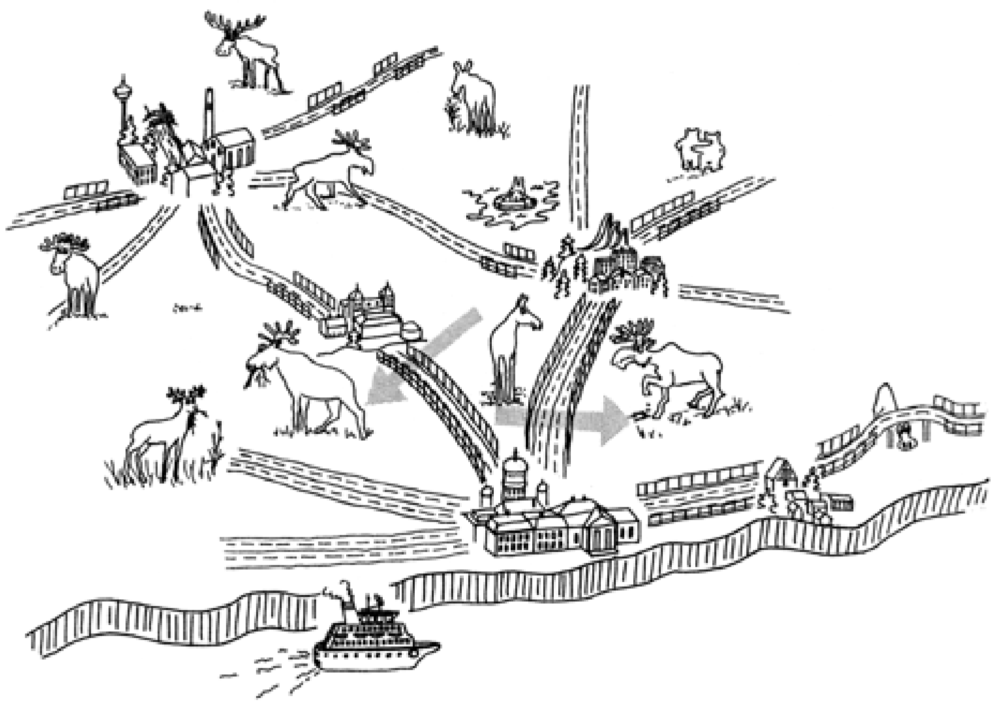


Figure 17. Illustration showing moose separated by traffic infrastructure (Väre, 2001)

Development of ecological networks is an important tool in the field of landscape planning and landscape ecology. Habitat networks may be essential for the survival of populations of species that are poorly adapted to human-dominated landscapes. Networks provide opportunities for an efficient migratory route, as well as to alter the flow of nutrients, water and energy across the landscape (Forman and Godron, 1986). According to Langevelde et.al. (2002) this can be viewed as the basic principle in landscape planning for nature, at any scale and in any context. In land development projects the concept of ecological networks is gaining importance. For this reason, there is a need for a deeper understanding to use the spatial concepts of ecological networks in landscape planning.

2.5.2 Landscape and Urban Ecology

The term landscape ecology was introduced by the German biogeographer Carl Troll (1939). Subsequently, several definitions of landscape ecology were published. According to Grillmayer (2002) the main aspects of them can be formulated as the study of

- Spatial relationships among landscape elements or ecosystems.
- The flow of energy, material nutrients, and species among the elements.
- The ecological dynamics of landscape mosaics trough time.

Landscape ecology has rapidly emerged in the past decade to become usable and important to practicing land use planners and landscape architects (Darmstad, Olson et al., 1996). For the field of landscape and urban ecology it can be stated that landscape ecology is a study of complicated systems that needs to be referenced to an organism to be better understood (Turner, Arthaud et al., 1995). The landscape ecology is a direct response to human activity within ecosystems (Kent, Gill et al., 1997). Niemelä (1999) defines urban ecology as a science that studies ecological phenomena and processes in areas with dense human populations. Urban ecological research provides basic findings but also applicable data for land use and green area management in cities. Langevelde (1994) has suggested an approach of a conceptual integration of landscape planning and landscape ecology and introduces this as landscape ecological planning. He concludes that landscape planning for nature became landscape ecology based. Landscape ecology provides planners and designers with a conceptual framework within which they can include knowledge about relevant patterns and processes.

2.5.3 Habitat Fragmentation

In the case of habitat networks, which form a part of the spatial concept of ecological networks, the theory of metapopulation dynamics and connectivity are useful as substantive planning theories. In a fragmented landscape the habitat of many native species is dissected into small isolated patches with sharp boundaries, separated by unsuitable areas for the species concerned. Each habitat batch may contain a population of these species, but local extinctions appear and can lead to empty patches. As long as dispersal is frequent, local extinctions will be prevented or the empty habitat will be recolonized. Ecologists, conservationists and land managers refer to habitat loss and habitat isolation as "habitat fragmentation" (Collinge, 1996). Habitat fragmentation as a result of the construction and the use of infrastructure is a major cause of deterioration in the quality of the natural environment in Finland. The splitting of natural ecosystems into smaller and more isolated patches causes habitat fragmentation. Various authors have explored measures for habitat fragmentation (Cook, 2002; Luoto, 2002; Olff and Ritchie, 2002). Figure 18 illustrates the relation between the size of a natural habitat and the effect on a rabbit population.

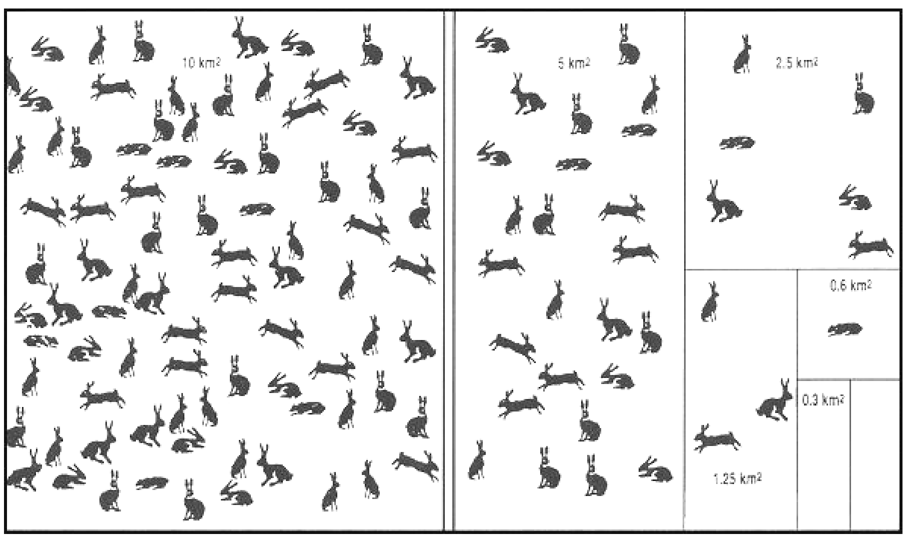


Figure 18. The size of a habitat and the effect on a population (Lähde, 2001)

As habitat fragmentation increases, moose and other wildlife need suitable areas to be preserved in their natural condition. In addition, they need ecological corridors, which connect isolated patches of different animal habitats and enable diverse populations to interact with each other.

2.5.4 Metapopulation Theory

A system of spatially and functionally structured populations in a heterogeneous landscape is identified as metapopulation. Metapopulations are defined as any set of spatially defined local populations, which are demographically affected by the spatial arrangement of habitat patches and the resistance of the non-habitat of the landscape matrix. Extensive research has been done on the dynamics of metapopulations (Opdam, Van Apeldoorn et al., 1993). In Finland, Hanski (2005) has carried out extensive research and has established a metapopulation research group, which is very active in publishing on the biology of species inhabiting fragmented landscapes (Hanski, 2005; Hanski and Ovaskainen, 2003; Laine and Hanski, 2006; Ovaskainen and Hanski, 2003). In many cases this detailed research from the perspective of biological accuracy, results in very specific information for the distribution and migration patterns for a particular species. Results from this research should be applied and integrated with the core concepts of metapopulation biology to management and conservation of landscapes and biodiversity.

2.5.5 Ecological Barriers

Spatial objects that are obstacles to wildlife movement can be defined as ecological barriers (Krisp, 2004). They represent a varying restricting influence of certain land use or land cover on animal movement. In particular, infrastructure, like road constructions, are regarded as ecological barriers and cause fragmentation. Others include intensive agriculture, industrialization and urbanization. The spatial concept of ecological networks may motivate landscape planners to plan landscape structures that enhance the natural processes, especially the movement of particular species, and avoid habitat fragmentation due to ecological barriers (see also case study II, chapter 4.3).

2.6 Limitations

The practical approach in this research is to use existing Geographic Information Systems (GIS) and its current capabilities in geovisualization. Modeling represents a complex interaction of human and instrumental factors; acquiring the raw components of each model, the data itself, is subject to a host of uncertainties (Zhang and Goodchild, 2002). As far as data uncertainty in all case studies is concerned, within this research the data is supplied by the data providers (mainly city and municipal administrations), and no information of its original acquisition quality has been made available. Furthermore geographical data recorded are only realizations of the underlying phenomena; they can only approximate the truth. This research does not focus on such developments as the use of non-cartographic devices, such as the parallel coordinate plot, and the exploration of visualization technology, in general. The links and differences between the display of non-spatial and the display of geographic information has been previously discussed by Fabrikant (2000), among others. To further limit the scope of this research, the wide field of cognitive and usability issues, which are considered by several authors (Nielsen, 1993; Slocum, Blok et al., 2001) have been provided with only a limited review. Ecological network planning is a process. This research does not attempt to review all possible factors and provide a ready-made model for the Finnish national ecological network. This is an attempt to advance the planning methods and processes that might eventually lead to a national ecological network. Even in that capacity, the emphasis here is more on the process of furthering the idea of ecological networks into spatial planning, rather than on attempting to provide a directive.

3 Chapter 3 – General Background For The Case Studies

This chapter provides an overview of the natural setting in Finland related to this research. The circumstances might significantly differ in other countries, therefore this chapter briefly describes the Finnish environment with a scope on the situation for the Finnish moose population, which is a subject in the case studies. This is followed by a review of previous research, regarding the development of ecological networks, and its representation in cartographic products.

3.1 Environmental Setting In Finland

Finland is a relatively small country, but is also amidst a trend of increasing urbanization, particularly in the metropolitan area of the capital, Helsinki. Finnish cities are relatively young. Turku, the oldest town in Finland, is known to have been a small town in the 13th century, and remained small for many centuries (Niemelä, 2001). Several wildlife species immigrated after the last ice age, around ten thousand years ago, and larger urban settlements have existed for only a few hundred years. Although urban wildlife is disturbed, cities are surprisingly rich in species.

Development of natural areas in Finnish cities

Urban wildlife is valuable, because it is the nearest daily link between the inhabitants and nature. This urban nature that people encounter daily has been called *lähiluonto* (in Finnish), literally, "close nature"[9]. In 2002 approximately 80 per cent of the population in Finland lived in cities or urban communities (Statistics-Finland, 2002). Figure 19 illustrates the urbanization in recent years, population growth, and decline of forest areas in Vantaa, in the years 1900-1990.

[9] Laurila, J., 1998. Löytöretkiä lähiluontoon, Suomen Luonnonsuojelun tuki oy.

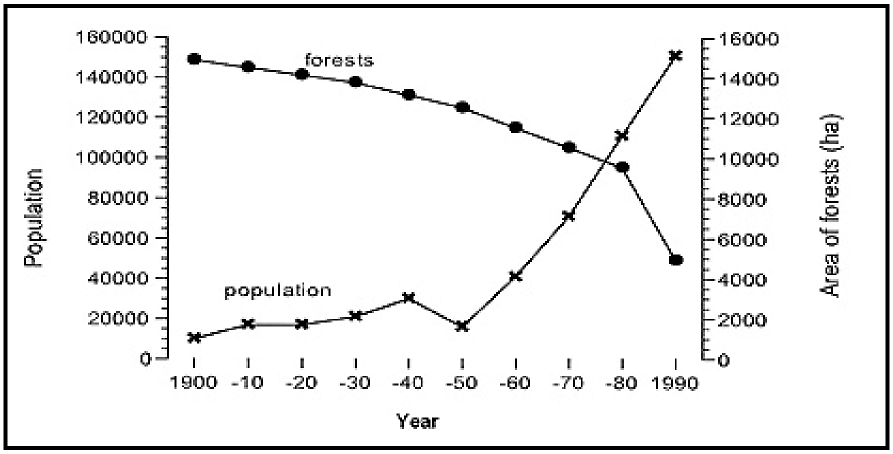


Figure 19: Population Growth and decline of forest areas in Vantaa, Finland 1900-1990, adapted from Ranta (Ranta, Tanskanen et al., 1997)

Vantaa is part of the Helsinki metropolitan region and we can identify a trend, causing an increase in population with decrease in the forested areas. Finnish cities still have a reasonably large amount of green area, but people moving into the area need to be housed and the construction of housing, roads and services reduces the green areas (Niemelä, 2001).

Landcover and wildlife population

The Finnish people live typically in a close relationship with nature. In Finland a high number of holiday houses exist in the countryside--roughly half a million, in a country with just over five million inhabitants. Almost all of these cottages or cabins are by lakes or the seashore, and about half of them are suitable for use in the winter. Finland is the most forested country in Europe. Figure 20 shows the estimated land coverage (Hallanaro and Pylväläinen, 2001).

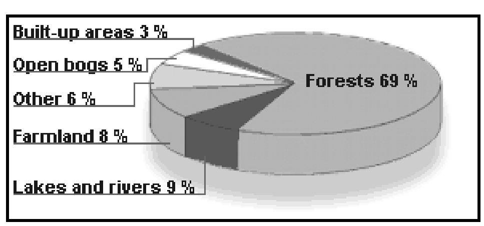


Figure 20. Land cover in Finland (Hallanaro and Pylväläinen, 2001)

There is a wealth of information about Finland's plants and animals by surveys about the status of threatened species. The last was published in 2000 and covered almost 19,000 species. Like similar surveys in other countries, this report revealed that many species are indeed under threat and about a tenth of all species in Finland were officially red-listed as threatened species. Sixty-five mammal species are resident in Finland. Large animals, like moose and white tailed deer, are able to exist here since there is both enough room in undisturbed forests and enough prey to allow them to thrive. But these animals have suffered over the years from persecution in Finland, particularly during the 19th century. Within case study one (see chapter 4.2) the moose population is used as an important indicator species that is affected by ecological barriers. Figure 21 shows a female moose photograph, which was taken in winter 2004 close to the Helsinki metropolitan area.

Figure 21. Photograph of a Finnish female moose

The moose population size in Finland has varied greatly during the last few decades. In the past few years, the population size has once again increased (Nygrén, Tykkyläinen et al., 2000). Recently, the populations have been deliberately encouraged to recover, and are now generally stable[10]. Research work by Luoma (2002) illustrates the change in the moose winter population from 1930 till 2000 (Figure 22).

[10] based on Hallanaro, E.L., 2002. Nature in Finland, http://virtual.finland.fi, Helsinki.

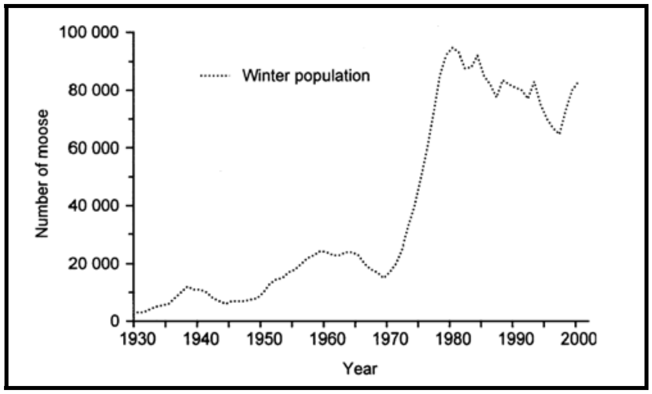


Figure 22. Changes in moose winter population size in Finland during 1930 – 2000 adapted form (Luoma, 2002)

Recent studies estimate the winter population size of approximately 120 000 animals in 2001 in Finland (Ruusila, Pesonen et al., 2002). To keep a stable number of moose and other wildlife populations, a functional ecological network is important.

3.2 Previous Research on Habitat Fragmentation due to Ecological Barriers

On a global scale, green areas within cities grow smaller or become more isolated. Infrastructures, business districts, shopping centers as well as industrial areas, etc., demand space. Natural rates of population growth and the demand for space are high in many urbanized areas. There is a strong trend of net migration into towns, as a result of both the 'pull' of apparent economic opportunity in towns and the 'push' of different factors, like insufficient employment in rural areas (UN, 1996). Urbanization can cause severe challenges to wildlife living in an environment within highly populated areas. Without adequate planning and control, rapid and increasing urbanization may lead to the development of informal settlements and development in inappropriate, (e.g., contaminated, flood-threatened or ecologically valuable) areas. In addition to that it can cause excessive pressures on available services in poorly-serviced and planned residential areas, and cause problems of sanitation, air pollution, over-crowding and social problems. Among these problems, infrastructure and construction can limit the natural migration patterns for wildlife within these areas and can cause considerable barriers to wildlife (Seiler, 2001; Seiler and Rudin, 1998).

Many European countries have become aware of the need to carry out research on the effects of human infrastructures on bio-diversity and to implement the results to minimize the impact (COST341, 2003). The COST341 states that, despite the general awareness of the problem and the urgent request for planning tools, empirical data on the actual impact of infrastructure on wildlife is still scarce. Major gaps in ecological knowledge have been identified concerning, for instance, the width and quality of the disturbance zone along infrastructure, the barrier effect of roads, road traffic, and the associated mortality in wildlife, differences in the impact between road and railroad, and methods to predict potential hotspots of ecological conflicts during the planning phase (COST341, 2003; Seiler, 2003; Seiler, 2004). Concepts for ecological impact evaluation have been presented by various authors (Eriksson and Skoog, 1996; Seiler and Eriksson, 1995).

Renewing connections between separate protected areas is a problem. Solving this would significantly improve conservation and free migrations of animals. Various authors have studied the different possibilities, like passageways, tunnels and green bridges. (Ahern, 1995; Grillmayer and Woess, 2002; Jordán, 2000; Serrano, Sanz et al., 2002; Taylor, Paine et al., 1995). These efforts can help to increase the sustainability of populations and ecosystems, in general. Therefore, the establishment of ecological corridors is very important and it has to become one of the priorities of environment protection activity (Heslenfeld, Liévin et al., 1999). A great variety of studies have been initiated to produce quantifiable data for the development of indicators and evaluation tools. In the COST341 report these studies are distinguished into the following categories:

- Project-related follow-up or monitoring studies of impacts and/or mitigation measures - Follow-up studies are linked to project specific problems and mainly financed within the road or railroad project. These studies are not designed to answer to general questions about impacts and effects, but may add to the collection of empirical background data.

- Problem-oriented field studies or simulation models. These studies are generally designed to answer a specific question and develop new empirical knowledge on effect thresholds and relationships. They are thus not (necessarily) related to a particular road project or location. Some of these studies are however combined with other scientific research projects.
- GIS-studies with remotely sensed landscape data--spatial analysis of existing empirical data combined with remote sensing provide a new approach ecological impact evaluation at landscape scale. So far, only few studies have involved GIS and more basic research is needed to validate potential indicators and evaluation criteria.
- Implementation/test in actual infrastructure projects (planning and/or construction)--several attempts have been made to apply the existing knowledge (and concepts) and through that helped to raise (practical) questions related to the planning procedures and specify the need for more detailed research.
- Development of indicator systems and evaluation methodology--critical to the development of techniques and methodology for an ecological impact assessment is the translation of empirical data, models and field experiences into measurable criteria. Such criteria are to be defined through environmental policies and mitigation plans and quantified in GIS studies or field inventories.

Research by Grillmayer and Woess (2002) considered the impact of road constructions on the fragmentation of landscapes. According to their research road planners should consider the aspect of fragmentation in their planning processes. A fragmentation value should make visible the importance of continuous wildlife habitats as a limited resource worthy of preservation (Voelk and Woess, 2001). Landscapes without roads of a daily traffic amount of 2000 vehicles or more and without highly frequented railway lines should be defined as continuous. Every road with a higher daily traffic amount going through a wildlife habitat divides this continuous habitat in two areas; a larger and a smaller one remain. Grillmayer and Woess (2002) suggest a simple formula to get the percentage of fragmentation caused by a road project. This percentage of fragmentation depends on the difference between the remaining larger and smaller area of living space. The lower the percentage of fragmentation, the smaller the area that is cut off of from a continuous living space. A high value usually will have to be valued more negatively, because it indicates a strong reduction of continuous living space. But if a small part of habitat is completely cut off and stays isolated, a low value of percentage of fragmentation may also have very negative effects when no measurements of compensation are taken (e.g. green-bridges).

Very few cases with previous innovative research with an emphasis on cartographic representation of ecological networks can be found. Hehl-Lange (2001) used a GIS-based analysis and later a three-dimensional visualization to show spatial-functional relationships. She visualized the cumulative barrier effect and possible dispersal, using the common toad (Bufo bufo in Latin). To visualize the data, they assumed the barrier effect of the land cover subjectively and in dependence on Häflinger (1996). Additionally she demonstrated the flight patterns of bats in small towns around potential barriers. Three-dimensional visualizations are mainly applied in relation to project assessment or for visualizing landscape changes. Hardly any work is done in relation to landscape ecology, landscape planning and nature protection purposes. Prelaz-Droux and Vuilleumier (2000) build up an ecological network map by adding different constraint maps (highway, main road, secondary road and buildings and their influence distances), to generate the movement limitation map corresponding to the major constraints affecting the wildlife dispersal. In a landscape processes are interrelated; for example, a road constitutes a barrier to wildlife dispersal processes. To integrate this kind of spatial relationship, spatial analysis with GIS is needed. Landscape is represented by the habitat quality of the studied species, dispersal functions, distances and limitations of species dispersal by human activities. The models can be developed to obtain understanding maps of the potential fluctuation of the concerned species. First, a qualitative value is given to every landscape component that is a function of the studied species. Usually, except for water areas, the value is low for natural elements and high for habitations and roads networks. Figure 23 illustrates the spatial analysis of dispersal for wildlife and constraints present in a landscape. This map represents the movement limitation (Prelaz-Droux and Vuilleumier, 2000) and this concept has been taken as a starting point for the further development of ecological barriers in case study III (see chapter 4.4).

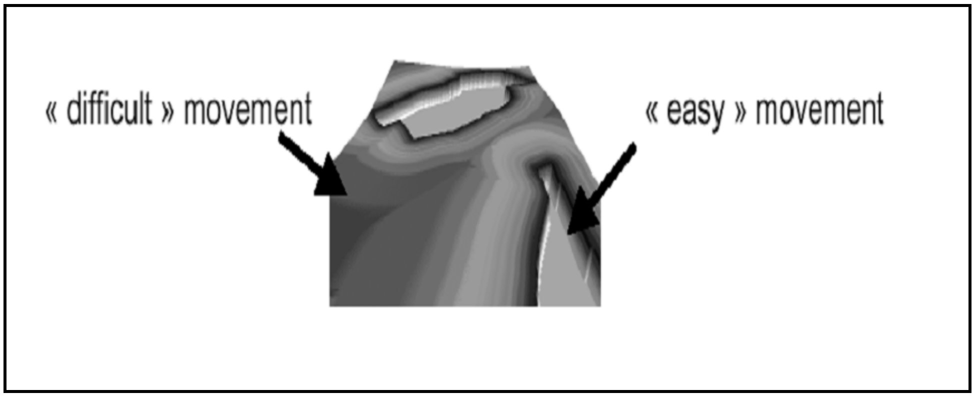


Figure 23. Spatial analysis of dispersal for wildlife and constraints present in a landscape (Prelaz-Droux and Vuilleumier, 2000)

In Finland early urban ecological studies were made in the 19th century (Westerlund, 1897), but urban ecology research is relatively young in Finland. According to Niemelä (2001) the reason urban ecology has been studied so little in Finland might be because scientists have regarded cities as man-made environments that cannot possibly be of any interest to ecological research. In recent years, however, the situation has changed and several urban ecology research projects have been launched in Finland. Human activities (such as large-scale agriculture, energy projects, construction, water resources, or agricultural projects driven by increasing resources consumption with increasing population numbers) considerably affect the natural environment. Research by Häggman (1999) used moose population data, which was collected as individual moose observation points to interpolate a density surface. Figure 24 shows the results for the greater Uusimaa area.

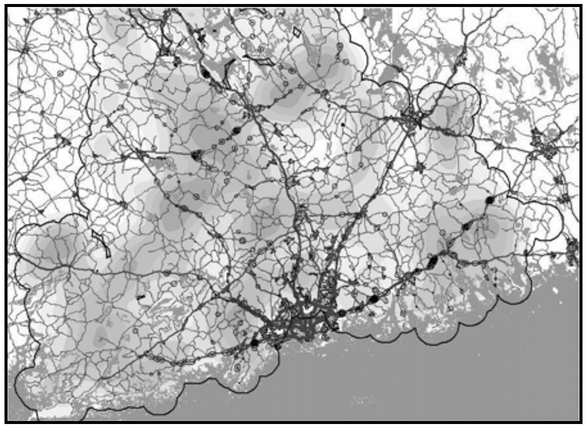


Figure 24. Potential moose habitats in Uusimaa, based on Häggman (1999)

Additionally he used point data from wildlife traffic accidents to calculate an accident density surface. By using this information as a background, it is possible to simulate potential moose migration patterns from their winter into their summer habitats. Furthermore potential moose traffic/vehicle accident sites were evaluated (Häggman, 1999). Road construction in Finland causes significant changes in the natural behavior of moose populations. Where possible, all major roads are protected by fences to minimize the danger of traffic accidents. The decrease of natural areas is problematic in urban land use planning, as the continuity between different protected areas is crucial to maintain the endurance of wildlife. Moose tend to migrate between their summer and winter habitats to different locations (Helldin, Seiler et al., 2002). Without proper investigation and integration of animal crossing structures into the infrastructure, the natural migration patterns and habitats of moose and other wildlife are distorted.

3.3 Current Maps Used In Ecological Network Planning

The classic network approach in landscape ecology distinguishes nodes, associated with hospitable habitat patches and links associated with corridors between theses habitat patches. A conventional approach to visualize landscape ecology is based on the patch/matrix conceptualization of landscapes (Forman and Godron, 1986). This approach is rooted in island biogeography theory (MacArthur and Wilson, 1967), where patches are considered islands and the matrix is represented as an inhospitable "sea" (Wiens, 1994; Wiens, 1996). The approach is considered to be straightforward and accessible because it corresponds to human scales of perception of the landscape. It integrates with traditional cartographic representations of landscapes using categorical maps (Gustafson, 1998). Furthermore, analysis of these landscape maps can be accomplished through existing geographical information systems tools (Haines-Young, Green et al., 1993). As a result this approach has been popular with practicing landscape ecologists, especially those in the planning field (Collinge, 1996; Darmstad, Olson et al., 1996).

A common cartographic example for the representation of urban green areas in Finland is the *Helsingin Viheraluerakenne kartta* (in Finnish), the master plan for green areas. Figure 25 shows a part of the Helsinki city area, which is an example.

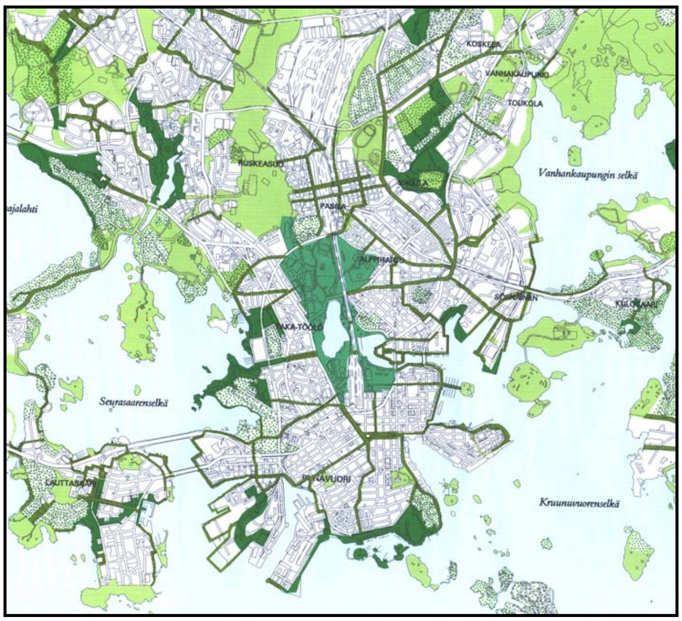


Figure 25. Selected part of the master plan green area map for the city of Helsinki

The map is part of the master plan 2002 and shows the green areas, including parks, city forests and connecting green ways. In Helsinki this map is used to integrate ecological questions and ecological matters into planning considerations. It is published by the city of Helsinki, Department of environment. The scale of the original map is 1:40.000. Commonly used for regional planning is the "*Helsingin Seudun Seutukaavat*" (in Finnish), shown in Figure 26. The map represents the regional plan for the green areas of the metropolitan area of Helsinki. The regional planning authorities publish this map.

Figure 26. Selected part of the regional plan for Helsinki metropolitan area

The map shows changes in the planning decisions for agricultural, recreation, nature-protected and forest areas. The original map has a scale of 1:100.000.

These examples stand for a type of maps that are well known among city planners and they are in practical use. In the common mapping approach, regions are classified and represented as a thematic map, which highlights areas that are considered valuable for animal movement. Usually a green color is used to represent the habitat areas and their connecting corridor area. A different method proposes to visualize the landscape considering the impact of infrastructures to the movement behavior of wildlife (Krisp, 2004). This assumes the original landscape in Finland is free from disturbance for animal movement, despite natural barriers such as water or mountainous areas. An interruption to this freedom is caused by human construction of infrastructure. Geovisualization can be utilized to enhance the identification and representation of these areas that are a significant problem for animal movement. These areas can be referred to as “ecological barriers” (see also case study III, Chapter IV).

4 Chapter 4 - Case Description And Analysis

4.1 Summary of the case studies

- Case I: This case describes an investigation of moose population density changes in southern Finland for the years 1999 to 2003. Data is available as points representing moose observations in the hunting districts located in the southern county of Uusimaa. Fences to minimize the danger of traffic accidents protect major roads within this area. Proper investigation of moose habitats is necessary to integrate animal crossing structures into the infrastructure. Such structures preserve the natural migration patterns and habitats of moose or other wildlife. Additionally, they may avoid the danger of traffic accidents at other locations. By using kernel density estimations, the data is interpolated into moose density surfaces for the years 2001-2003. The results are displayed as density maps in a four-dimensional explorative visualization to visualize and highlight changes in moose habitats that might be caused by the road and rail network.
- Case II: Current placement of wildlife warning signs by the Finnish road administration is based on suggestions from hunting associations and individuals. The problem within this practice is, that the placement process of warning signs is not based on any statistical or spatial statistical analysis and is therefore not transparent. Regarding wildlife crossings and vehicle accidents there is no evaluation of spatial indicators in place to find an optimal location for wildlife warning signs so far. Within this case study we investigate the current placement of wildlife warning signs in the Uusimaa region in southern Finland. Moose and white-tailed deer accidents are evaluated in relation to the road sections that are marked with warning signs. A method is developed to optimize warning sign locations using kernel density estimations, which are based on existing accident records. The contour lines of these densities can indicate the road sections to be marked with warning signs. To apply a well-documented computational method, based on these moose and white-tailed deer accident locations, assists the Finnish

road administration in their task to place or replace wildlife-warning signs along specific road sections.

- Case III: Ecological barriers represent the restricting influence of a certain land use or land cover (like infrastructure and urban areas) on animal movement. These land covers can split natural ecosystems into smaller and more isolated patches. As this fragmentation increases, moose and other wildlife need suitable areas to be preserved in their natural condition. In addition, they need ecological corridors, which connect isolated patches of different animal habitats and enable diverse populations to interact with each other. This case study defines the ecological barriers, using experts' knowledge in classification of spatial objects. The objects are visualized representing ecological barriers in maps by using the third dimension for selected cities in Finland. These maps can assist to define corridors or networks, especially in urban areas, where it is important to preserve animal habitats and avoid threats to traffic safety. In addition the results of this work can be used to adapt the existing means of transport to ecological requirements. It can also be used to integrate this subject within the planning procedures for new infrastructure. This case is evaluated using a questionnaire. Eleven experts from the field of land use planning have commented on the maps and are largely in agreement that these kinds of maps are useful for planning.

4.2 Case I – The Use Of Geovisualization For Changing Moose Densities

Articles published relating to this topic:

Krisp J.M., Väre S. (2006) Explorative Visualization of kernel density estimations and their application for habitat monitoring, manuscript submitted to *Ecological Modeling*

Krisp J.M., Väre S., Dame J., Virrantaus K. (2004), Visualizing moose habitat change due to infrastructure construction in southern Finland, *Proceedings on the 20th ISPRS congress*, 12. -23. July, Istanbul, Turkey, pages pending

4.2.1 Background For Case I

Habitat fragmentation is a severe problem in much of Europe. Although southern Finland, a landscape of forest and wilderness, is still relatively sparsely in habited, the problem also exists here. The major roads cut through forest and join adjacent developed areas, and this can cause isolation of animal populations. Species of deer family are common animals in Finland; there are about 100 000 moose, 30 000 white-tailed deer, 10 000 roe deer and 200 000 reindeer in the Finnish forests and the amount of animals will almost double every spring due to reproduction. The foraging behaviour of moose allows them to survive in the hard northern climate, but these movements bring them into contact with road vehicles. Animal accidents have forced the road authorities to built wildlife fences along major roads to protect drivers from sudden, unexpected and disastrous contact. Information on moose habitats is essential to any investigation of their migration patterns, i.e. for effective planning and management of conflicts with road users.

Moose natural habitats in southern Finland

Moose undertake seasonal migration from winter pastures to summer pastures and vice versa. The distances they move when changing pastures are 10-20 km and quite often they have to cross major highways (Väre and Grenfors, 2004). In southern Finland the main winter pastures grazed by moose are located in large, undisturbed forest areas inland, and the summer pastures are to the south, along the seashore or amongst the archipelago of lakes. The mean density of moose can be 2.5-3.5 animals/1000ha in summertime over all the forested areas, but 13-16 animals/1000ha in wintertime in the best winter pastures. A standard gravel or quiet tarmac road is no hindrance for moose or deer, but it does affect the movement of middle-sized animals. The road channels, the movements, the dispersal of the middle sized animals and the traffic affects animal mortality. According to a research by Väre and Grenfors (2004), within the

Monimuotoisuuden Tutkimusohjelma[11] research project, where animal movement was monitored at "highway environments," about 50% of the animals that approach the highway will cross it, 30% move along the highway for more than 2.5 kilometres (in the case of a moose), and fewer than 20% turned back away from the highway. Moose accidents have spatial differences according to season and animal densities. The movements of moose follow the same pattern every year. In wintertime the number of accidents is low and they are concentrated near winter pastures. In the spring, when winter populations start to scatter, the accidents tend to occur in places where moose routes cross major highways. The moose use the same familiar routes every year to move to summer pastures and their calves are born in traditional breeding areas. In the summer moose-motor vehicle accidents occur in the coastal areas near the places where the yearlings begin their independent lives. The accidents happen every year at the same 1.5-2 km section in the highways. Accidents occur also in the Metropolitan area of Helsinki, where the inexperienced young moose try to reach the seashore. The moose have also learned to find the weak spots in the wildlife fences and to take advantage of intersections, where the fence is open for the crossroad. The study area for this case I (as well as for case II) is the Uusimaa district, shown in Figure 27.

[11] Maa- ja Metsätalousministeriö and Ympäristöministeriö, 2003. Monimuotoisuuden Tutkimusohjelma (MOSSE) - Project description, Helsinki.

Figure 27. Overview map with the Uusimaa study area indicated in red

The amount of moose and the amount of traffic has been growing during the decade and the animals have actively searched and found places to cross the highway, in spite of the fences. The annual movements attract moose to the same favourable locations in the forest areas, where there is enough food to overwinter successfully. Developed areas, especially roads, cut these areas into smaller fragments, and the effects are clearly seen in the decreasing size of moose populations in these small areas. Previous research (Clevenger, 2003; Finch, 2000) has shown, that the animals are adaptable, and they use the suitable technical solutions provided for them, for example green-bridges and animal underpasses, to cross the highways, especially if these are situated in the right places. To find a suitable location for crossing places, the moose density is one of the determining parameters. Research by Häggman (1999) used moose population data based on the information from regional hunting associations to calculate moose densities. The data was based on the hunting districts from 1997. This provides the basic information to monitor the moose habitats. The density maps were adapted to aid the definition of the ecological networks and ecological barriers utilized for land use planning for the regional plan in Uusimaa (Väre, 2001). The concept of ecological barriers has been investigated by Krisp (2004).

Motivation for the case study

The decrease of natural areas is a concern in urban land use planning, as they endeavour to maintain continuity between different protected areas. Links between habitat patches are crucial to wildlife. Moose tend to migrate between their summer and winter habitats to different locations within southern Finland. Without proper investigation and the integration of animal crossing structures into infrastructure, the natural migration patterns and habitats of moose and other wildlife are distorted. Changes in infrastructure planning and construction involve a complex political process. In making decisions in a democratic system, politicians and planners generally have to consider public attitudes.

In this case, geovisualization may help to support the decision making process and may help the general public to understand the issue. Peuquet and Kraak (2002) state that using geographic visualization to aid knowledge discovery in large spatial databases and to aid interactive analysis and complex problem solving can be a potentially powerful tool. Research by Elzakker has shown that the use of maps in regional exploratory studies seems to be very much of a supply driven nature, and users do not want to spend much time on retrieving or generating a map. Furthermore users ignore the nature and characteristics (i.e. metadata) of the geographic data visualized. They are also careless with maps legends (Elzakker, 2004). These aspects have to be considered when using geovisualization for moose habitat monitoring.

Aim for this case

This study concerns meta-population changes of moose in southern Finland. Any changes in the migration patterns of these animals might lead to increasing traffic accidents in new locations or cause greater damage to forestry in sampling stands. Within this study the aim is to

- display changing moose density.
- attract the public participation in the planning procedures for future infrastructure.
- assist the overall ecological network planning.

Therefore the core research question in this case is:

- How can we offer this information to planners and decision makers in an efficient and informative way?

To answer this question we need to investigate methods of how to describe point patterns and how to visualize this information over time.

4.2.2 Material And Methods - Determination Of The Moose Density

Data points representing moose locations

The material processed and analyzed are point patterns based on data from hunting associations. Finland is divided into 15 game management districts. They govern hunting associations, which are usually same size as local communes. In Uusimaa district there are over 30 associations, which are further divided into over 300 hunting clubs or parties. Data about big game animals (moose, white-tailed deer, roe deer, wild boar, wolf, bear etc.) is gathered at the beginning of March by a track index. The track index gives the number of animal crossings a previously defined set of transect lines in the study area over a time period of 24 hours (Högmander and Penttinen, 1996). The Finnish Hunting Association provided data, available as points representing moose counts in the individual districts. The inventory took place every year at the beginning of March, representing winter habitats of moose. Datasets for the region, i.e. the Uusimaa game management district, are available from 1997 – 2003. Starting from 2001 the locations have x/y coordinates. Additionally, road network data and wildlife accident records for 2002 from the Finnish road administration[12] have also become available.

Kernel density

Using spatial statistical methods, available in existing GIS analysis tools, the data can be interpolated to create density surfaces for different years to highlight changes in moose habitats. Based on previous research experience, a kernel estimation method was used to calculate the moose density for the research area. Generally density is a continues function, and in order to present an effective and accurate impression of its distribution, a

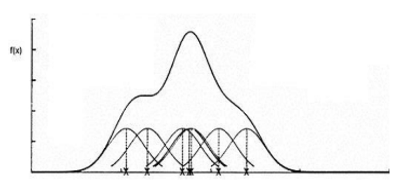
[12] FinRA, 2003. The animal accident statistics 1996-2003, Finnish Road Administration, Helsinki.

scheme that recognizes this continuity is needed (Langford and Unwin, 1994). To determine changes in the habitats of moose, we calculate the moose density for different years using a kernel interpolation method described by Bailey & Gatrell (1995) and O'Sullivan & Unwin (2003). Kernel estimation was originally developed to obtain a smooth estimate of density from an observed sample of observations. The idea is that the pattern has a density at any location in the study area, not just at a location where there is an event (O'Sullivan and Unwin, 2003). Selecting an appropriate search radius is a critical step in kernel estimation. The search radius determines the amount of smoothing of the point pattern and defines the radius of the circle centered on each grid cell, containing the points that contribute to the density calculation. In general, a large search radius will result in a large amount of smoothing and low-density values, producing a map that is generalized in appearance. In contrast, a small search radius will result in less smoothing, producing a map that depicts local variations in point densities (Bailey and Gatrell, 1995).

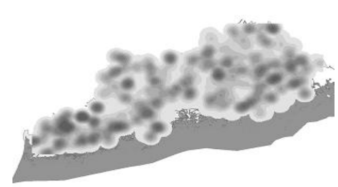
- The search radius for moose density habitats is set to a radius of 7.5 km. It is based on an estimated moose movement radius in the wintertime.

Calculating the density provides a output map, which shows the moose density for the study and is based on the individual moose locations reported by the hunting associations. The results of the density calculation can be displayed in different ways. The stages of the process are illustrated in Figure 28, a, b, c.

a.) Individual moose locations from the Finnish hunting association



b.) Kernel estimate showing individual kernels



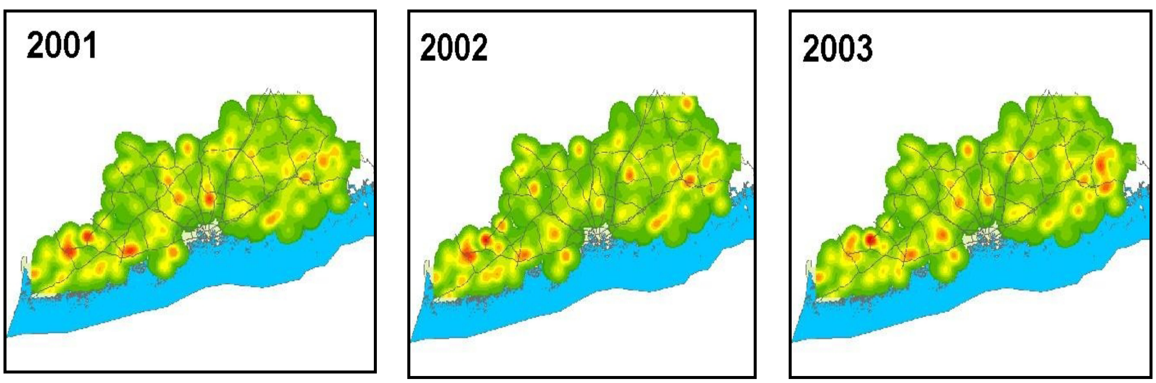
c.) Moose density map

Figure 28. a, b and c show the process for a output map representing the moose density calculation

The challenge in using the kernel density methods is having enough expert knowledge to determine the correct search radius and to visualize the correct information. To extract this domain expert knowledge and incorporate it to the modeling process is the core expertise of a GIS expert. The maps provided using geovisualization, in this case density maps as a geovisualization methods, are meant for the planners and decision makers. The decision makers themselves are not able to create these maps.

4.2.3 Visualizing The Changing Moose Densities Over Time

The individual density maps for the years 2000 to 2003 can be overlaid on the road network. The road network data is available from 2002 from the Finnish Road Administration. Figure 29 a,b,c shows the moose density maps for the years 2001 to 2003 combined with the road network and water polygons for better orientation in the study area. We take the calculated moose density as an indicator for the moose habitats in the winter season.



a.) March 2001 b.) March 2002 c.) March 2003

Figure 29. Moose density in march 2001 to 2003

Contours can be calculated based on the moose density classification and a triangular irregular network (TIN) can be constructed using these contours. TINs are widely used to represent terrain surfaces in geographical information science. They have been investigated by numerous authors (Lee, 1991).

The TIN is visualized as a three-dimensional density surface, shown in Figure 31. “Hills” indicate a high moose density while “valleys” indicate a low amount of moose. The map stresses this information further by a color scale. The scale adopted shows changes along a continuum from red to dark green, via yellow. From a cartographic point of view this is made ambiguous by the adoption of "hill-shading", for example the yellow categories that fall into the "shadow" regions are now longer shown their true color. Nevertheless it is suggested here that users are able to distinguish between areas of "high" and "low" moose density, even without identifying the exact color classification from the legend. The use of colors in map design has been considered in detail by Brewer (1994) among others. In these example cases a color scale from red – orange - yellow - dark green - light green is applied. Figure 30 shows the moose density for Uusimaa in 2003.

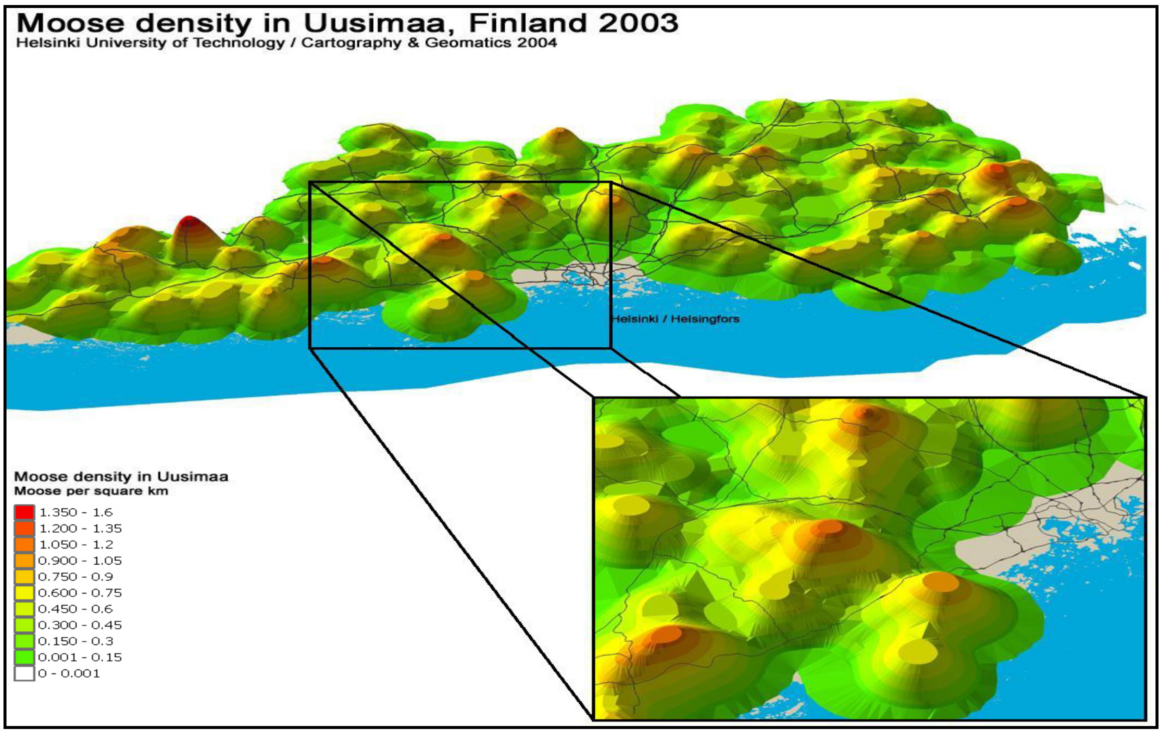


Figure 30. Moose density in winter 2003 for Uusimaa in a three-dimensional map

The density map is overlaid with the road network showing the major roads and the water areas. Additionally a transparency effect can be used to make the shoreline visible. The shoreline is an important feature and during the summer time, when the water is not frozen, it has a natural barrier effect on moose habitats. A four-dimensional map integrates the x, y locations as well as a z variable over time. To create a four-dimensional animation we generate three-dimensional maps for all available years (2001-2003) and combine them into an interactive system illustrated in Figure 31.

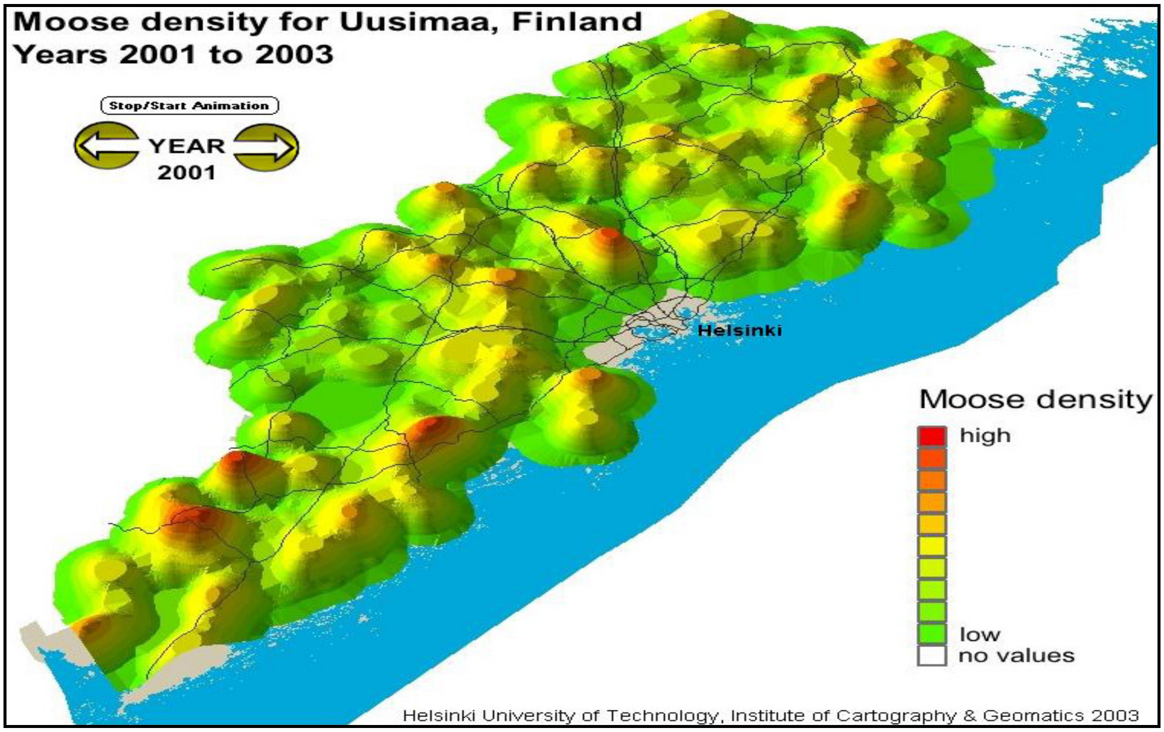


Figure 31. Interactive animation of the 3D moose density maps for Uusimaa including the years 2001-2003

The interface is easy to use, allowing the user to navigate between the different years, which are also displayed in the upper left corner. By clicking through the different time stamps (at various speeds) the user can visually explore the changes in the moose density.

4.2.4 Conclusions

The identification and visualization of changes in animal habitats is a first step in planning the defragmentation of landscapes and the establishment of fully functional corridors and wildlife crossing structures, e.g. green bridges. Calculations of the moose density for different years provide the basic data to indicate changes in the moose density, which might be partly caused by these fenced roads. The kernel method proves to be a good tool to calculate the density patterns of the individual moose locations. By creating a smoothing of density values in with the density at each location, which reflects the concentration of points in the surrounding area, analysts are able to identity how densities vary across a study area. Overlaying the moose density map onto the road network map can help to identify wildlife traffic accident “hotspots” and plan more effective control measures. Future research might use these methods to aim at the deeper identification of relations between the moose habitat changes (including traffic accident patterns) and modifications in the infrastructure.

4.3 Case II – Task Specific Maps and Wildlife Warning Signs

Articles published relating to this topic:

Krisp J.M., Durot S., (2006) Segmentation of lines based on point densities—An optimisation of wildlife warning sign placement in southern Finland, *Accident Analysis & Prevention*, In Press, Corrected Proof, Available online 20 July 2006

4.3.1 Background - Wildlife As A Threat To Traffic Safety

A large number of moose populations can be a threat to traffic safety. In Finland there are six species of animals that belong to the deer family. Most significant, from a standpoint of road safety, are moose (Alces alces), white-tailed deer (Odocoileus virginianus) and reindeer (Rangifer tarandus). Because of its weight and size the moose is particularly dangerous in road accidents (Beilinson, 2001). The Finnish national museum has re-enacted a possible moose accident and its consequences, which are shown in Figure 32.

Figure 32. Moose accident consequences (Reconstruction in the Finnish national museum)

About 1500 - 2800 moose accidents and 1300 -1700 deer accidents occur in Finland each year. Beilinson has estimated the cost to society in 1999, which was about 48 million EUR (4534 elk and deer accidents). About 4000 reindeer accidents happen each year, but, because of the small size of the animal, they are usually not as serious. The migration of moose in Finland is a significant threat to traffic safety. From 1992 to 1999 moose and deer accidents account for approximately 20 percent of all traffic accidents reported to the police (Beilinson, 2001). The percentage of wildlife accidents causing injuries increased from 5.1 percent in 1998 to about 6.8 percent in 1999 (Finnish-Road-Administration, 2003). The increased number of white-tailed deer, particularly in southern Finland, caused a rise in the number of deer accidents

To avoid wildlife accidents, warning signs and other precautions are important. The warning sign, shown in figure 33, informs of a possible wildlife crossing danger ahead and admonish drivers to be careful. The sign does not require drivers to slow down to a particular speed, unless there is a speed limit sign adjacent to it. The cautioned road section starts with a warning sign. Below the sign is a plate showing the length of the cautioned section in kilometres. There is no sign indicating the end of the dangerous road section.

Figure 33. Wildlife warning sign in Finland

The warning signs should influence the attention of the driver in a way that the drivers' safety increases by being more alert or reducing speed. To lower the accidents on hotspots on the road, administrations place warning signs. This process may result in an uncritical use of the warning sign. Too many warning signs might have the effect that the warning signs do not influence the driver, because the drivers may ignore them, with moose or white-tailed deer visible only occasionally (Hedlund, Curtis et al., 2004; Jorgensen and Wentzel-Larsen, 1999).

Warning signs are located according to the suggestion of hunting associations, local authorities or individuals. If a wildlife-traffic accident has happened and a crossing hotspot has been identified, moose warning signs can be put in place. This process does not include any computational analysis of statistical parameters. Consequently, the wildlife warning signs in Finland are installed in places where hunters or individuals observe many moose or white-tailed deer tracks crossing the roads or to locations where wildlife-vehicle accidents have happened and are reported to the authorities. There are no systematic control measures in the placement of the warning signs. The problem within the placement process is the lack of transparency. There has been no identification of indicators and systematic evaluation so far. The quality of the placement of wildlife warning signs has to be investigated, and a method to optimize warning sign placement needs to be developed. These optimized sign locations are based on the density analysis of existing wildlife accident records and its spatial distribution. The aim is to assists the Finnish road administration in their task to place or remove warning signs. To apply a well-documented computational method, based on moose and white-tailed deer accident locations, helps the administration to argue for or against specific locations for signs, because they have information based on spatial analysis of accident records.

4.3.2 Material And Methods - Accident Data Analysis

The study area for this case is Uusimaa. The Finnish Road Administration has provided the data of the road network as well as the location of wildlife accidents, fences, warning signs sections, and background data (e.g. water polygons). The road network database includes information about the amount of daily traffic per year, speed limit and road sections. The overall length of the road network in Uusimaa is about 4653 km. Public roads include national highways, and regional and local roads managed by the county municipalities. The vehicle traffic is usually concentrated on national highways that carry between 6.000 to 80.000 vehicles per day at a speed mostly above 70 kmh^{-1}. In 2002, 274 km (6 %) of the total road network had warning signs and 153 km (3 %) of the road network were fenced. The wildlife accident data includes the moose and the white-tailed deer accidents on all public roads within Uusimaa. They are reported for the years 2000 to 2004 and include place, time and day, and occurrence of injured or dead individuals. Not all deer accidents are reported to the police. Researchers estimate that the number of accidents might be twice as high (Hedlund, Curtis et al., 2004; Seiler, 2005). Accident records for the study area from 2000 to 2004 include 4719 accident points, representing 1417 moose- and 3302 deer-vehicle collisions. The average per year shows 283 moose and 660 white-tailed deer collisions. Moose-vehicle accidents indicate a decrease from 2001 to 2004, but white-tailed deer-vehicle accidents do not show a general trend in the annual numbers. To have a larger database, the moose and white-tailed deer records are used together as a general accident dataset. Table 1 shows the distribution of the accidents within fences and warning sign road sections for the years 2000 to 2004. In the years 2000 to 2004, 4719 accidents are reported, overall.

Table 1. Amount of the accident within the accident in the special warned roads

Year	Total amount of accidents	Accidents within fenced or warned road sections (%)	Accidents within warned road sections (%)	Accidents within fenced road sections (%)
2000	944	285 (30)	239 (25)	46 (5)
2001	991	309 (31)	265 (27)	44 (4)
2002	1026	314 (31)	272 (27)	42 (4)
2003	865	249 (29)	207 (24)	42 (5)
2004	893	281 (31)	256 (28)	25 (3)
2000 – 2004	4719	1438 (30)	1239 (26)	199 (4)

Out of these, 1438 accidents (about 30%) are within the warning signs and fences section of the road network. Focusing on the warning signs (in table 1 marked in light gray), 1239 accidents (about 26%) are within road sections that are marked with a warning sign. The numbers show roughly the same distribution over each year.

Accident density as an indicator for warning sign locations

Wildlife accidents are recorded as individual points on a road network. To apply a kernel density estimation on these points seems to be inadequate, because it represents a continues function. Nevertheless this method is chosen to give an efficient visual impression for the spatial distribution of moose and white-tailed deer accidents along the road network. A kernel density estimation replaces each point with a kernel (Silverman, 1986), giving the surface a “spatial meaning”. The determining factors are the bandwidth and the output grid size. If the bandwidth is too large, the estimated densities will be similar everywhere and close to the average population density of the entire study area. If the bandwidth is too small, the surface pattern will be focused on the individual population records. Experimentation is required to receive the optimal bandwidth to get satisfactory accident densities along the road network.

For the area of Uusimaa a search radius of 2000 m has been applied to the accidents dataset. After consultation with the Finnish road administration authorities, this has shown to be suitable to represent a realistic amount of accident hotspots along the road network. Figure 34 shows the accident densities aggregated for the years 2000-2004.

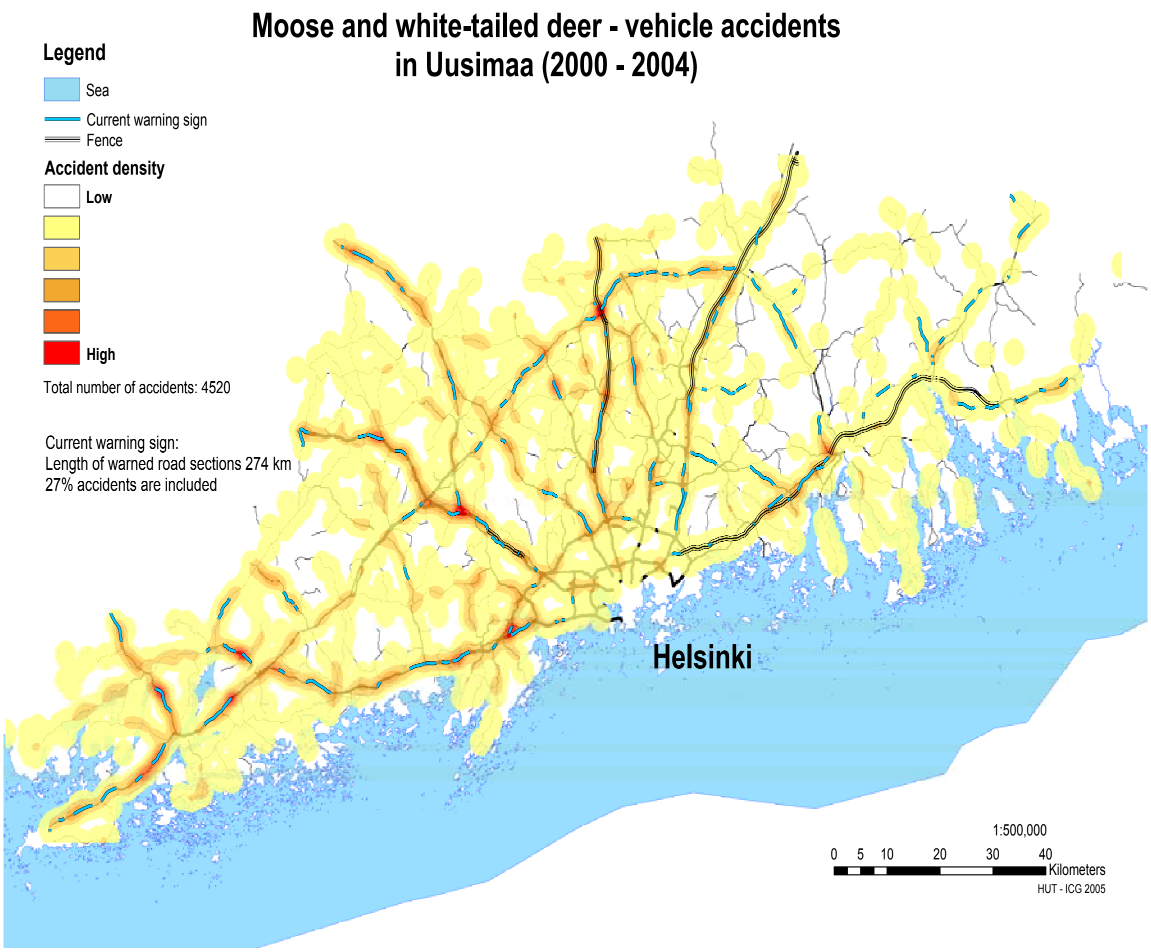


Figure 34. Moose- and white-tailed deer-vehicle accident density and current wildlife warning sign road sections

The dark (red) colors represent a higher accident density and show specific incident hotspots in the study area. Additionally the current locations of warning sign section and fences are plotted over the density surface. Warning sign sections are platted in blue, which might cause confusion with the water areas and will be changed in the future. This map makes it possible to visually compare the hotspots and the locations of existing signs and fences. By exploring this map, one can identify certain points where warning signs seem to be on the "wrong" spot.

Optimizing wildlife warning sign locations

The process of optimizing the warning sign locations is based on the contours calculated from the wildlife accident density surface (Figure 35).

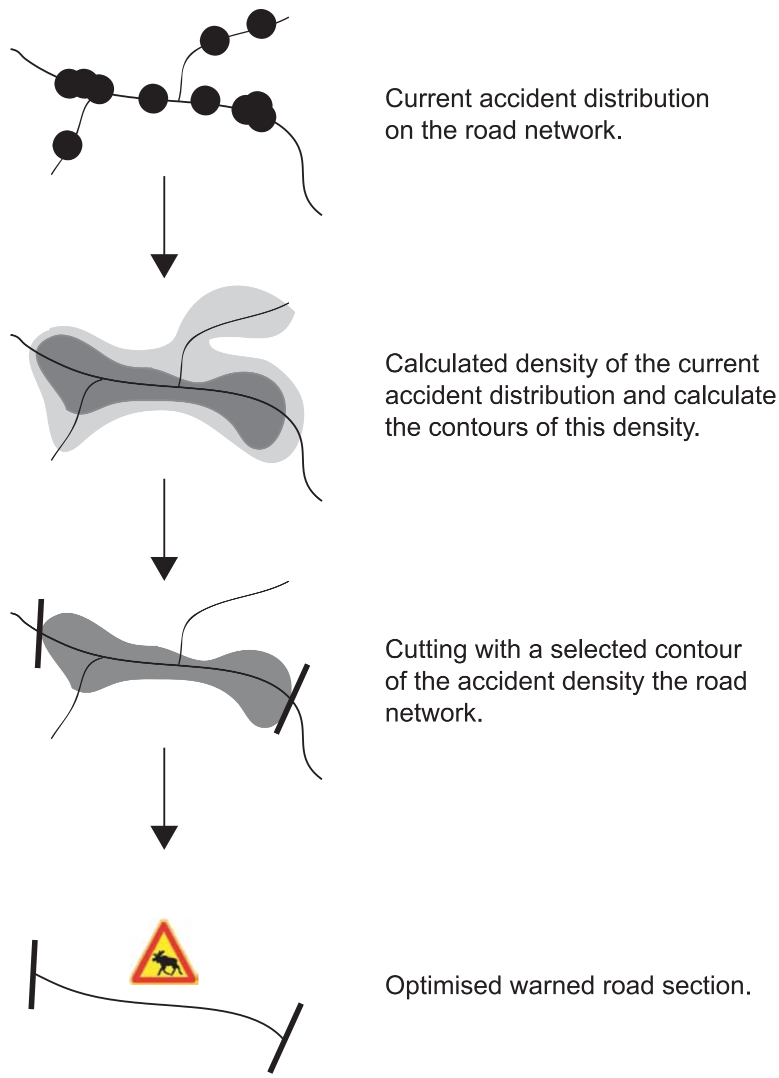


Figure 35. Process of optimizing the warning sign locations based on accident densities

A density surface is calculated for the original accident data points for the years 2000 to 2004. The density is estimated applying a 2000 m bandwidth and 100 m-output grid size.

This grid is used to calculate contours within different contour classifications. Selecting the number of accidents to be included in the contour class will give a specific contour line. This line can be used to specify the road section that should be signaled with a warning sign. The contour classifications, meaning the number of accidents that are considered in selecting the appropriate contour to define the road section, are changed. A changing amount of road kilometers covers a specific amount of accidents. The relation between the road kilometers and the amount of accidents that can be covered by these warned sections is shown in table 2.

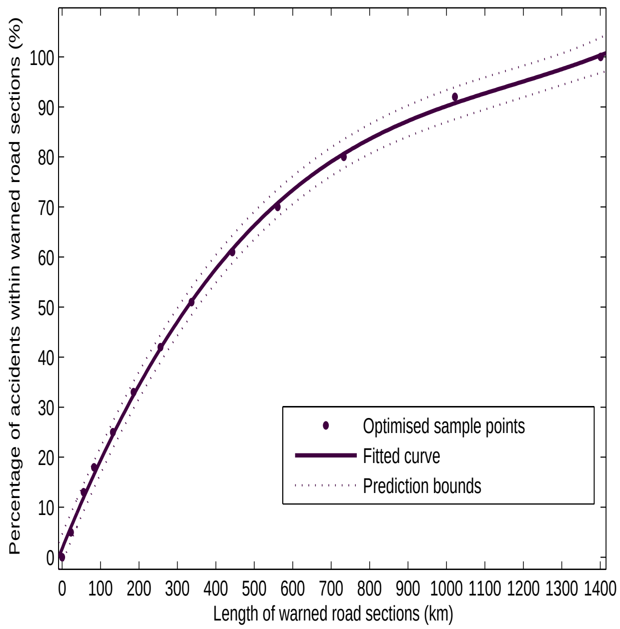
4.3.3 Optimized Wildlife Warning Sign Road Sections

To indicate the relation, 13 points--including start and end points--are calculated. The numbers in table 2 show the amount of warned road sign kilometers that are needed to cover a specific percentage of wildlife accidents. The 100 percent (4520 accidents) of accidents within the warned road sections exclude the accidents within the fences.

Table 2. Relation between the km of warned road sections and accidents covered

Length of the warned road sections (km)	Percentage of accidents within the warned road sections
0	0 %
23	5 %
56	13 %
83	18 %
132	25 %
186	33 %
256	42 %
337	51 %
443	61 %
561	70 %
733	80 %
1022	92 %
1401	100 %

These sample points can be used to estimate a function that describes the relation between the signed road kilometers and the amount of accidents that can be covered with these sections. The software MATLAB provides functions for standard polynomial operations, such as polynomial roots, evaluation, and differentiation. Additionally, functions for more advanced applications, such as curve fitting and partial fraction expansion. To fit the curve based on the 13 manually calculated sample point relations, a linear model polynomial third-degree curve fitting function is applied. The curve is shown in figure 36.



$$f(x) = p_1 * x^3 + p_2 * x^2 + p_3 * x + p_4$$

using the coefficients (with 95 % confidence bounds):

$p_1 = 4.049*10^{-8}$ $(2.857*10^{-8}, 5.242*10^{-8})$

$p_2 = -1.423*10^{-4}$ $(-1.666*10^{-4}, -1.179*10^{-4})$

$p_3 = 0.1902$ (0.1775, 0.2029)

$p_4 = 1.699$ (0.2134, 3.184)

MATLAB generates a goodness of fit with:

SSE: 11.05

R-square: 0.9992

Adjusted R-square: 0.9989

RMSE: 1.108

Figure 36. Relation between the amounts of warning sign kilometers to the accidents covered

The curve shows that by entering a specific number of kilometers that are marked with a warning sign, it is possible to cover a particular amount of accidents. The process of calculating warning sign road sections, based on accident densities, involves a margin of error for the outcome. This uncertainty needs to be included somehow, to indicate the uncertainty of the process. One way of doing this might be to add prediction bounds to the curve (Figure 36). The prediction bounds are graphical measures, while the confidence bounds are displayed numerically. The prediction bounds are more beneficial than numerical measures because they show the entire data set at once. The MATLAB curve-fitting tool provides the possibility to add the prediction bounds to the curve plot. These are non-simultaneous bounds for new estimated points. What does this mean?

Suppose a new sample point needs to be estimated on the curve. A new point has its own error, so it satisfies the equation. What are the likely values for this new point? The prediction bounds may suggest the answer. The interval is a 95% prediction bound. Figure 36 contains the following three curves: the fitted function, the lower prediction bounds, and the upper prediction bounds. These are the default bounds calculated using the default MATLAB functions.

Table 3 summarizes the results and shows the warning sign section kilometers and the percentages of covered accidents for the current and the optimized warning sign sections.

Table 3. Summary of selected results for the optimized warning sign sections to accident points

	Amount of road kilometers with a warning sign sections	**Percentage covered of accidents**
Current warning signs	274 km	27 %
With optimized warning signs	150 km	27 %
With optimized warning signs	274 km	44 %

Currently 274 kilometers of warning road sections with warning signs cover 27 percent of reported accident locations. This is already a fairly good value as shown by a verification measure, using a random point distribution, which covers "only" 6 % of these potential accident points. With the optimization method applied, 274 kilometers of warning sign sections can cover 44 % of the accident points. Increasing (or decreasing) the number of kilometers changes the number of covered accident points. Basing the calculation on the density estimation of the accident points, Figure 37 shows the optimized road sections that should be warned within the study region.

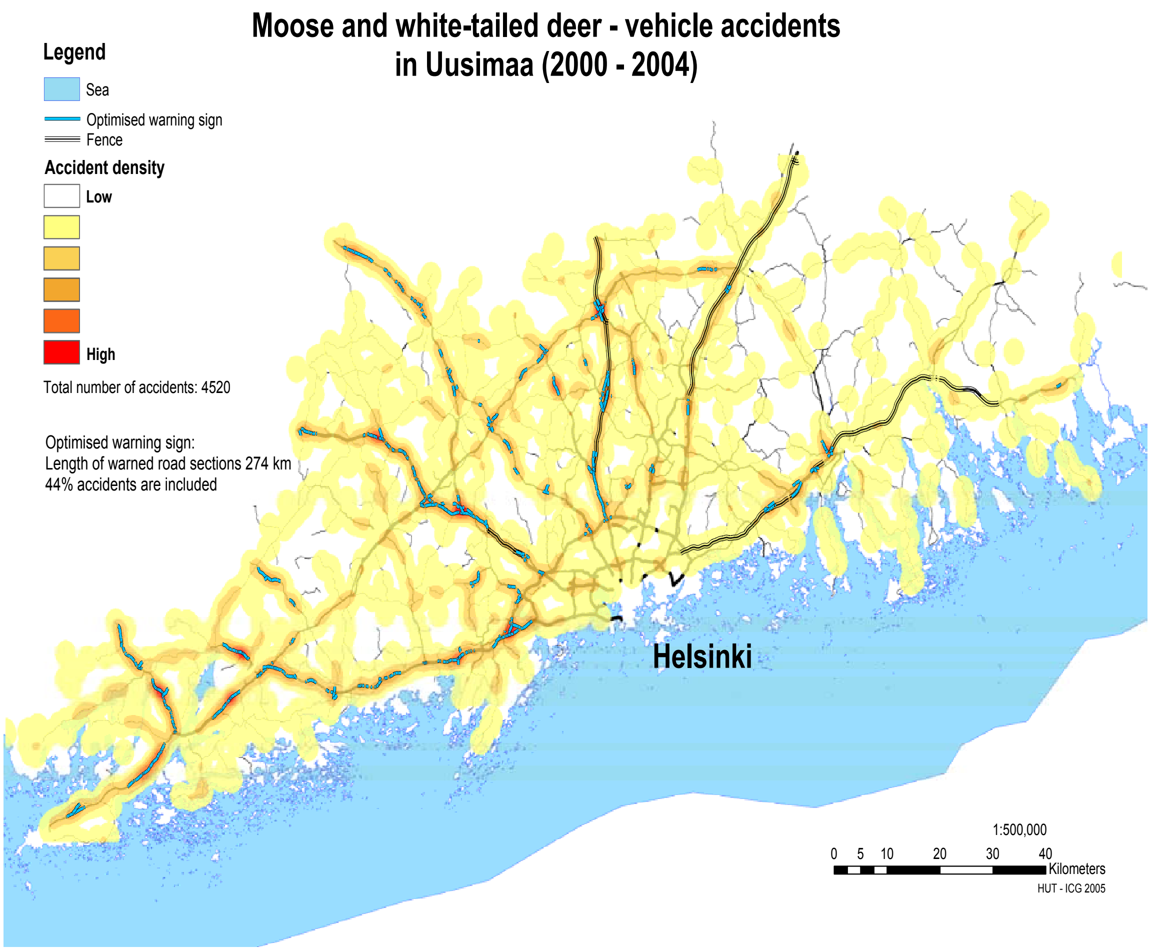


Figure 37. Moose- and white-tailed deer-vehicle accident density and optimized wildlife warning sign road sections

Unlike the current warning signs (see Figure 34), the optimized locations (Figure 37) are more concentrated in accident hotspot areas. Certain warning sign sections disappear, because the accidents are well distributed along some roads, and no specific hotspots can be identified.

4.3.4 Conclusions

This case investigates wildlife-vehicle accidents data. In these road sections an intensity value does not necessarily exist. Applying a density-interpolation technique does not help to estimate the number of wildlife-vehicle accidents that have occurred between the existing wildlife-vehicle accident locations. In these road sections no wildlife-vehicle accidents have been recorded. Therefore this method should be understood to create hypothetical estimated intensity values in the gaps between the points. The surfaces that are created represent the distribution of wildlife-vehicle accidents and are intended to illustrate wildlife-vehicle accident patterns. This method, therefore, represents a continuous surface, which reveals the relationship between wildlife-vehicle accident point distributions. The optimization of the warning sign location is based on the density of moose and white-tailed deer-vehicle accidents. This method assumes that in most cases the occurrence of accidents marks the location of a potential hotspot and the need for a warning sign. In some cases "known" wildlife crossing locations where no accidents have happened should be considered separately.

Applying spatial statistical methods to wildlife accident data assists the Finnish road administration in their task of replacing warning signs. Appling a well-documented computational method, based on moose and white-tailed deer accident locations, helps the administration suggest locations for signs, based on spatial analysis. Current placement of warning signs (Figure 34), based on suggestions of hunting associations and individuals, has proven to give reasonably good results as investigated by Krisp and Durot (2006). The optimization approach presented in this case refines the current method and bases the placement on a spatial analysis. The process of placing warning signs has to go hand in hand with an identification of potential hotspots, based on accident records and the suggestions by hunting associations. The road administration should continue to collect information on wildlife-vehicle accident locations. A database over a long period of time can help to identify accident hotspots more accurately. The analysis made for the relation between the warning sign kilometers and the amount of accidents covered by these is specific for the study area of Uusimaa. Further research in this case needs to consider this relationship on a smaller scale, e.g., for all of Finland, or on a larger scale, like specific hunting districts. This would help to derive a general relation and perhaps give a more general recommendation for the optimal placement of wildlife warning signs.

4.4 Case III – Geographic Visualization for Ecological Barriers

Articles published relating to this topic:

Väre S. , Krisp J.M. (2005), Ekologinen verkosto ja kaupunkien maankäytön suunnittelu (Ecological Networks and Landuse Planning in Urban Areas), Ympäristöministeriö, SY780, Edita Ltd, Helsinki, ISBN 951-731-323-5 (PDF), ISBN 951-731-322-5 (printed)

Krisp J.M., (2004) Three-dimensional visualization of ecological barriers, *Applied Geography,* 24, p. 23-34

Krisp J.M., Väre S. (2003). Ecological Barrier Model for Järvenpää (Finland), *ESRI's Map Book*, Volume 18, p. 9

Krisp J.M., Fronzek S. (2003). Visualizing thematical spatial data by using the third dimension, *Proceeding of the 9th Scandinavian Research Conference on Geographical Information Science* ScanGIS, 04. –06. June, Espoo, Finland, p.157-166

Krisp J.M., Ahonen-Rainio P. (2003). Combining real and virtual components for visualizing ecological barriers, *Proceedings 21st International Cartographic Conference (ICC)*, 10. -16. August, Durban, South Africa, pages pending

Krisp J.M. (2002). GIS supported visualization of ecological networks. *Proceedings on the 1st International Symposium on Geographical Information Systems*, 23. -26. September, Istanbul Turkey, pages pending

4.4.1 Background - Case Description

Case study III describes a process of modeling "ecological barriers" that lead to habitat fragmentation, by means of a list of land use and land cover elements and their impact on animal movement. The model is build upon assumptions by various experts. To create a model and visualize the barrier effect, we assume that different land cover or manmade structures have different impacts on the movement of animals. Bennett describes the relationships between roads and their environment (Bennett, 1991). He identifies the creation of barriers by roads as an extra disturbance, which causes fragmentation of the landscape and its populations. One aim of this case study is to indicate the restrictions on animal movement, by finding a barrier value for many different land cover types (Figure 38).

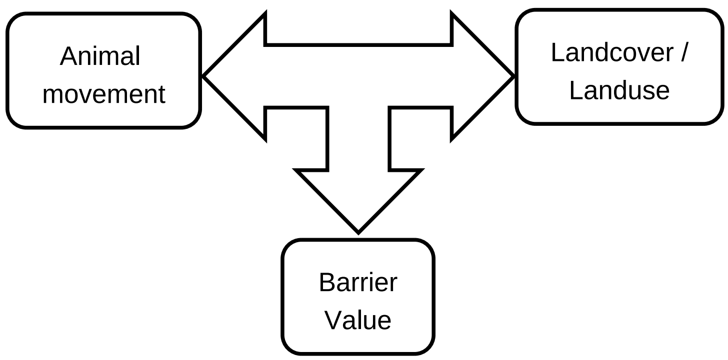


Figure 38. Barrier Value as a measure of the restriction by a specific land cover or landuse on the movement of specific animals

Different spatial objects, like different types of land cover (e.g., fields, lakes, etc) and land use (e.g., infrastructure, build-up areas, industrial areas, etc.) can significantly restrain migration patterns of wildlife. To achieve our goal, concerning the modeling of the ecological barriers, the following questions arise:

- What are the determining elements of land use and land cover that restrict the free movement of animals?
- What animal types do these land use and land cover elements affect?
- Can we derive a numerical value to describe the ecological barrier effect?
- Can we make use of the third dimension to visualize this thematic data?
- Does the third dimension provide new insights concerning the model?

- Does a three-dimensional visualization approach offer an informative, aesthetic and appealing way to represent the ecological barrier effect?

4.4.2 Material And Methods - "Ecological Barrier Values"

Expert Survey On Ecological Barrier Values

The goal is the development of an ecological barrier model. For each landscape element, a barrier value (negative function for wildlife mobility and barrier elements, like motorways, fenced areas, etc.) is created, according to its function for certain animals.

To realize efficient spatial analysis, functionality and properties have to be integrated and assessed. To find appropriate barrier values, we sent a survey to different experts on animal movement. Six surveys were returned. The experts were requested separately to fill in a "barrier evaluation table", which contained the selected animals and land use elements. The participants filled in the table with values between 1 and 100, representing elements, which, according to their opinion, restrict the movement of animals. The experts were provided with sample verbal descriptions, so that they were able to evaluate the different kinds of barriers. An overview of the descriptions is listed in table 4.

Table 4. Verbal description of ecological barrier values

Barrier value	Verbal description of the barrier
100	Absolute barrier, no crossing possibility
80	Hard conquerable barrier
60	Conquerable barrier
40	Easy conquerable barrier
20	Very easy conquerable barrier
1	No barrier, crossing possible
0	not classified

The word "percentage" was used to describe the barriers effect. The value 100 (percent) for a certain land use would restrict the movement of an animal completely, while a low value (e.g., 20) would be a minor barrier. This has been done for the selected sixteen different animal types separately, which leads to a maximum sum value of 1600. Within case study III, the questionnaire to obtain ecological barrier values is limited to six expert opinions. The survey has been answered for the conditions in southern Finland during the summer time. Other landscapes and other seasons would surely result in different ecological barriers values. In addition to that, the framework of this research covers only a small amount of existing wildlife in Finland; only a limited number of land cover and land use classifications are included.

Calculating The "Ecological Barrier Value" Based On The Survey

We included a weight factor (w) into the equation, which is not used in the following examples. It can be used to stress certain animals of land use classes or help us to increase or decrease the estimation of particular experts. The mean barrier value (BV) is calculated according to the following equation.

Calculating the mean barrier value (BV)

$$\overline{BV} = \underbrace{\left\{ \sum_{e=1}^{E\max} \underbrace{\left[\sum_{l=1}^{LU\max} \left(\underbrace{\sum_{a=1}^{A\max} BV_{ael} \cdot \frac{w_a}{A\max}}_{\overline{BV_l}} \right) \cdot \frac{w_l}{LU\max} \right]}_{\overline{BV_e}} \cdot \frac{w_e}{E\max} \right\}}_{\overline{BV}}$$

where:

Variables:
BV= BarrierValue
A = Animal
LU= LandUse
E= Expert
w= weight factor

Subscript:
a = animal
e = expert
l = landuse
max = maximum value of the subscript
$\Sigma w = 1$

The following graphs (Figure 39) illustrate the result of the evaluation table. Each graph represents one returned survey, indicating the barrier values for all Line and Polygon features (fenced major highway, major highway, major roads, etc.).

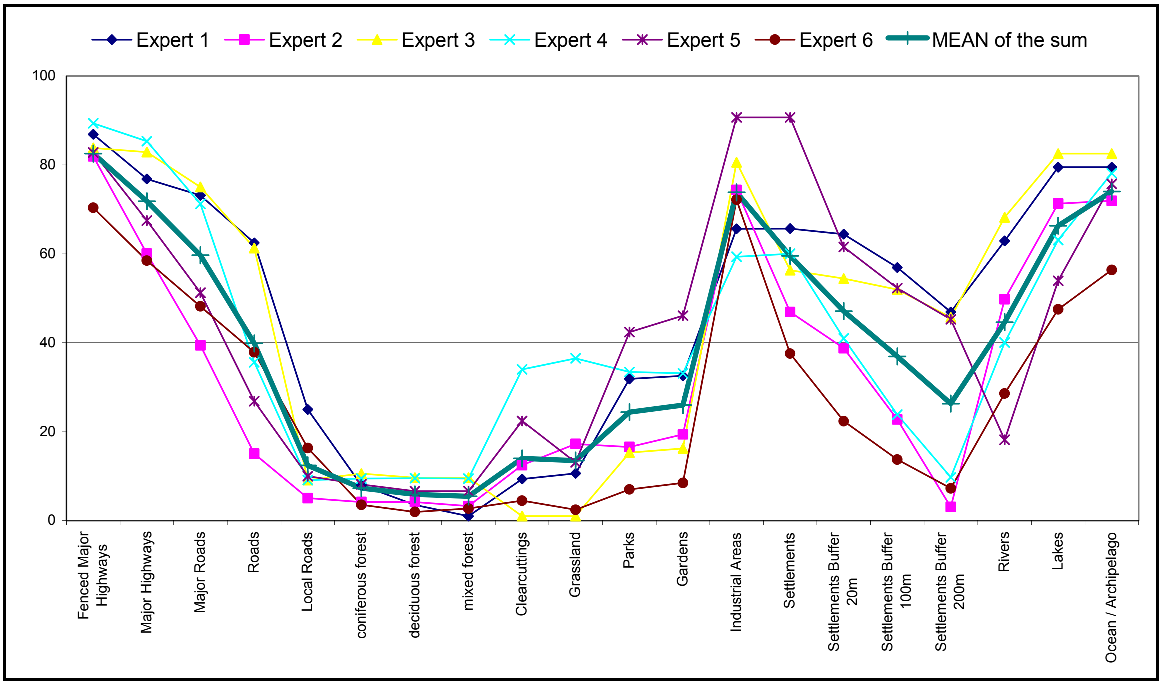


Figure 39. Barrier values for all selected animals of all returned surveys

Building up an extensive survey allows us to take out barrier values for only a certain species. We can adjust the model to single out barrier values for a particular animal or animal group, such as moose. Additionally we can remove certain landuse items. In the following Figures 41-48 the barrier value for the water bodies has been not considered (and set to 1). In the interaction with the data providers (mainly the city planning departments) the extruded water bodies have caused confusion. There has been no formal investigation to this mater, but perhaps water bodies are very important for the orientation and should not be extruded as barriers.

4.4.3 Visualization Of Ecological Barriers

Ecological barriers indicate the barricade effect on animal movement for different land cover types. In this study, the "land use polygons" and "line data" have two meanings. They represent "tangible" (directly tangible attributes) and "non-tangible data" (not directly tangible attributes). Ecological barriers are regarded as non-tangible attributes, because this barrier effect cannot be directly measured in the field, but has to be modeled and visualized. They are defined as obstacles to animal movement, based on the land use information. By using the third dimension we are able to both visualize both of these aspects at the same time, without overloading the map, and to emphasize the barrier information. Figure 40 shows the two-dimensional map of Jyväskylä, using data provided by the city of Jyväskylä (2001). The numbers in the map indicate the barrier effect value of every specific polygon and line. No other annotation has been added to this map.

Figure 40. Two-dimensional map of Jyväskylä, Finland including the ecological barriers value as label values

This map seems to be very difficult to understand, because of the large number of land use features, with their different barrier values.

4.4.3.1 Using The Third Dimension

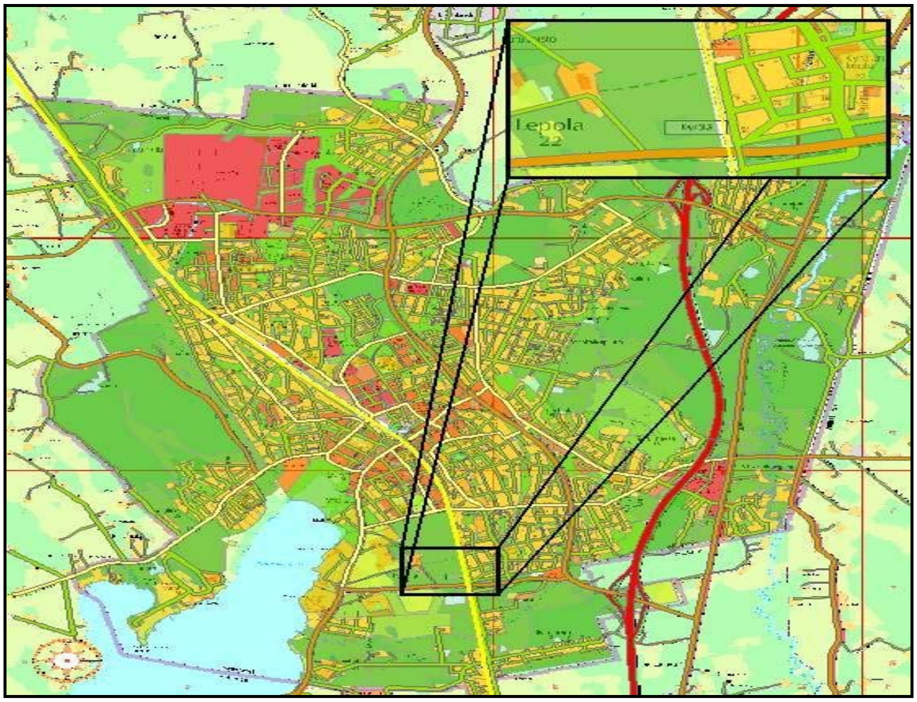
In Figure 41 the same information (the land use map and the ecological barrier effect) is visualized. In this case, barrier values are used as z-values to give the model a third dimension. The illumination is set with the azimuth to the North West (315 degrees). The altitude of 30 degrees provides a sufficient shadow for all objects.

Figure 41. Three-dimensional map using the ecological barrier value as z values

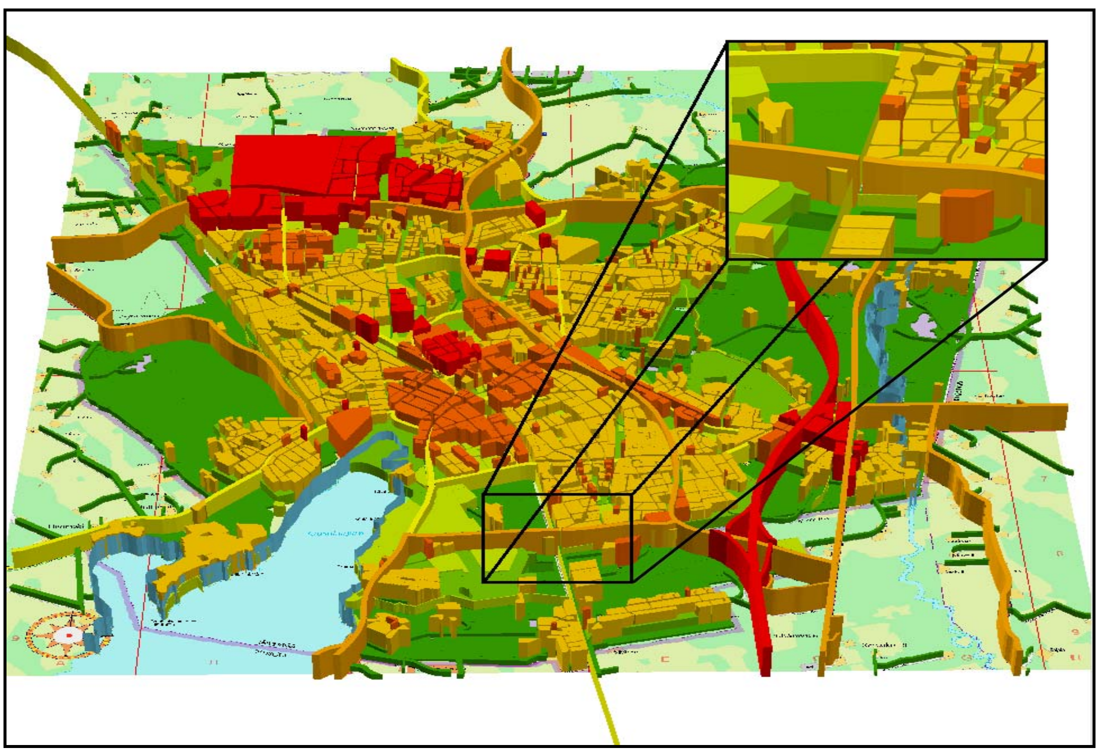
In Figure 42 the perception of the barriers is stressed by using different colors. The same classification is applied for the colors as for the z values. Changing the color settings can help to stress the ecological barrier effect. The range of the colors is set from green, indicating low barriers, to yellow, and to red, for high barrier values. Polygons and lines with the same barrier value have the same color.

Figure 42. Three-dimensional using the ecological barrier values as z values with a color range from green-yellow-red

Modeling barrier effects three-dimensionally can help to identify ecological corridors, networks or bottlenecks that might be underestimated in the two-dimensional visualization. It can also help to provide appealing visualizations that can be understood easily and encourage the public to participate in the development processes. Thereby, it can also be used to integrate this subject within the planning procedures for new infrastructures. The barrier values can change over time, which can give this model a fourth dimension. To visualize this change over time, a series of maps has to be calculated be used in an animation, as was done in case study I.



a.)



b.)

Figure 43. Ecological barriers in the city of Järvenpää showing zoomed detail a) two-dimensionally and b) three-dimensionally

Figure 43 shows the ecological barrier model for the city of Järvenpää as a two-dimensional and a three-dimensional map. The ecological barriers are based on the vector data with a detail zoomed-in to illustrate the flexibility of the model, concerning the scale. Järvenpää is located in the Helsinki Region, along the Helsinki-Lahti freeway, a 30-minute drive from downtown Helsinki. It also runs along the main railway line to the north. It has a population of 36,000 and advertises itself, to a great extent, as a garden city that offers excellent recreational and leisure time opportunities. The data has been provided by the city. Feedback from city authorities, during the research, was generally positive, regarding our three-dimensional representation of the information. Utilizing geovisualization methods--in this case the three-dimensional visualization of the ecological barrier model--would appear to have advantages over the two-dimensional map with the same information.

4.4.3.2 Combination Of Realistic And Virtual Components

The application of the concept of augmented reality (see chapter 2.2.2) can illuminate ecological barriers and show their locations in the landscape. To demonstrate the concept, combined visualizations of the model are applied using aerial photographs and photographs of landscapes. According to the reality-virtuality continuum (see Figure 7) the application follows a four-category organization of the levels of abstraction for reality to a case study of visualization of ecological barriers where spatial datasets are combined and visualized in a three-dimensional environment. In the following, we are using combined data from the city of Järvenpää, Finland to exemplify and illustrate our classification.

Figure 44. An aerial photograph as an example of a realistic representation for ecological barriers

Realistic representations are intended to display data in a way that reflects reality, using videos, photos or aerial photographs. On this level of abstraction, every object within the representation is specific. Every object has its own identity. Figure 44 shows an aerial photograph with a five-meter resolution (provided by the city of Järvenpää).

Figure 45. An extended realistic representation for ecological barriers

Augmented reality showing extended realistic representations generates a composite view for the user. It is a combination of the real image viewed by the user and a virtual reality (Virtual Reality) image generated by the computer, which augments the original image with additional information (Figure 45). These representations abstract reality by combining photos with virtual objects; the aerial photograph from Järvenpää is used as a background for the visualization of ecological barrier effects.

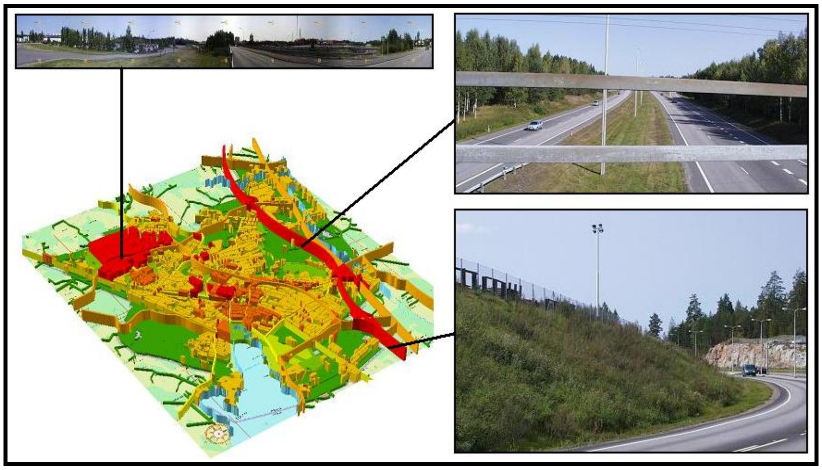


Figure 46. An extended virtual representation for ecological barriers

Extended virtual representations combine in a virtual environment to model and shape reality. They explain their model further by realistic representations like photos or videos. In Figure 46 we illustrate the virtual model of ecological barriers further with actual photographs taken from selected spots that are represented in the model.

Figure 47. A virtual representation for ecological barriers

Virtual Representations describe reality only by virtual models. Virtual models use general symbols for more than one specific object. In our case, real objects (like streets, rivers, etc.) are classified into several abstract ecological barrier classes. The model shown in Figure 47 illustrates virtual reality's potential for identifying and analyzing spatial problems in reality.

4.4.4 Conclusions & Further Research

In general, research about fragmentation is very complex and difficult to quantify and compare. The impact of fragmentation is specific to one species. Effects can be measured at different levels. However, we have introduced a model to quantify ecological barriers leading to habitat fragmentation by way of a list of land use elements and their impact on animal movement. Since the whole model is based on assumptions by different experts, it is not a precise model. It is not necessary to build up a very accurate model, because the nature of animal movement cannot be an exact one. Higher traffic flows do not always lead to more road kills, because a bigger barrier-effect can prevent certain species from trying to cross the road. This could work the other way around as well; lower traffic flows, leading to a smaller barrier effect, could encourage species to try to cross the road more often, which could lead to more road kills.

Generally, landscape ecology is very concerned with the scale of measurement and the scale of process. How appropriate the land cover data is for mapping ecological barriers will affect the results. This is of concern if the approach is to be applied elsewhere with different land cover data and other species. A number of cities have been included in this study to verify our visualization technique with different datasets from diverse sources. The interpretation of the results is not the intention of this research. A report by the Finnish Ministry of Environment (Väre and Krisp, 2005) takes the ecological aspect into account and interprets the results from an ecological network planning point of view. Considering all potential movements from all habitats is unrealistic. In a landscape, a rough idea of habitats and activity sites suggests a lot of potential movements. Most people like to see still images or moving sequences of landscapes, animals or plants. If we would like to encourage nature protection plans, a medium is needed that is understood more easily than an abstract two-dimensional plan, so that the public can participate in the planning process. This relates particularly to less visible and often complex matters, such as spatial-functional relationships in the landscape. Three-dimensional visualizations for nature protection purposes could help to highlight the importance of this topic. Modeling barrier effects three-dimensionally can help to visually identify ecological corridors, networks or bottlenecks. The ecological barrier model can be analyzed further using grid analysis functions and visibility graphs. It can help to provide appealing visualizations for the problem of a fragmented landscape. Whether or not these maps can be understood easily is yet to be empirically proven. If their effectiveness is proven, perhaps they could be used to help encourage the public to participate in development processes and, thereby, they could be used to integrate this subject with the planning procedures for new infrastructures. Plans for the future are to exceed the number of participating cities and provide them with the information of ecological barriers within and across the borders of their administrative areas. Within our studies we are able to extract a series of species barriers or a series of land covers from our survey. That enables us to change the species focus to suit wildlife-specific policies. Furthermore, we suggest verifying the model with individual experts, different combinations of experts, “good” and “bad” experts and other ecological problems. The barrier values can change over time, which can give this model a fourth dimension. For example the barrier value of a lake can change over different seasons. In Finland, lakes are frozen during the wintertime, so they have a low barrier effect on animal movement. To visualize this change over time, we can create a series of models and visualize them over time, creating an animation, as we have done in case study I. Then models and visualizations might help to predict changes over time in the research area, for example the impact of a new road on its environment, concerning the movement of animals.

4.5 Questionnaire On Expert Opinions On The Results Of Case III

A questionnaire gives an indication of the usefulness regarding the maps produced in the case studies. It is based primarily on expert opinions. The expert opinion questionnaire was conducted to get positive or negative feedback on the maps created within case study II. These maps have been published by the Finnish ministry of environment (Väre and

Krisp, 2005) and is taken as a basis for the opinion survey. The questions are formed in both open and closed formats. Closed format questions offer advantages in time by restricting the answer set. It is convenient to calculate percentages and other statistical data over the whole group or over any subgroup of participants. The open format questionnaire opens a variety of responses, which should be wider and more truly reflect the opinions of respondents. Case study I and case II have been not evaluated via a questionnaire. There are too few users that have these maps in use. In these cases feedback has been asked directly from the potential map users.

4.5.1 Expert Background

Information about the experts includes the organization they work in and their position or field of expertise within this organization. Based on that information, it is assumed that all participants have worked with common maps used in land use planning and similar tasks. Table 5 shows the type of position and the number of experts who returned the questionnaire.

Table 5. Questionnaires returned listed by organization types

Type of organization	Number of returned opinion questionnaires by organization type
Research Institutions	4
Marketing	2
Public Administration – Land use planning	4
Private Environmental Consulting	1

The organizations include a diverse number of institutions, including: Helsinki University, the Helsinki Technical University, Software Vendor (ESRI), the Finnish Defense Forces, the Uusimaa regional council, the Helsinki city administration, the Finnish environmental research institute (SYKE), Jaako Pöyry Consulting and the Finnish Topographic Society.

4.5.2 Closed Format Section

Eight different statements, shown in table 6, are written and the participants are asked to indicate their agreement or disagreement with these statements. Two statements (2.1.1 and 2.1.3) are of a more general nature, while the other statements are directed at the participant's opinion of the specific maps and their usefulness in planning, communication and decision-making procedures. The experts were asked to indicate their opinions by yielding their agreements with the statements. The level of agreement is ranked by 1=Strongly Disagree, 2= Disagree, 3= Neither Agree nor Disagree, 4=Agree, 5=Strongly Agree. The statements are shown with the average results in table 6.

Table 6. The results of the closed question statements in average and the level of agreement

Question	Result in average	Level of agreement
2.1.1 There is a need to analyze ecological networks in urban areas.	*4.4*	*[Agree]*
2.1.2 The maps can be used to explain an audience the concept of "ecological barriers".	*4.6*	*[Strongly Agree]*
2.1.3 It is important to visualize the data to get people to understand the plan better.	*4.8*	*[Strongly Agree]*
2.1.4 The maps are understandable with little verbal aid and without a legend.	*3.4*	*[Neither Agree nor Disagree]*
2.1.5 The maps show the intended information immediately.	*3.8*	*[Agree]*
2.1.6 The three-dimensional representation of the information used in the maps makes it easier to understand the map and interpret the barrier effect on animal movement.	*4.5*	*[Strongly Agree]*
2.1.7 The color range represents the information correctly.	*4.0*	*[Agree]*
2.1.8 The digital version of the maps is more useful than the paper print.	*3.8*	*[Agree]*

The two strongest average agreements to the statement are shown in dark gray while the two lower agreements are shown in light gray.

4.5.3 Open Format Section

Questionnaire Part 2.2 - Do you think that the maps presented (see attachments) are useful for planning?

YES NO

All opinions concerning this question answer YES to this question. The open format is used for giving unenclosed opinions and examples of the real cases.

Questionnaire Part 2.3.1 - If yes, who are the main users?

Table 7 lists the various answers to this question. It shows the number of times this specific user type has been mentioned in the questionnaire by the other experts. Additionally, the suggested users are classified into administration, research or public.

Table 7. Suggested main users named in the questionnaires classified into potential user groups

Suggested main users named in the questionnaires:	**In the number of times this user type is suggested in the questionnaires**	**Classified into a group**
City (Urban) planners	5	Administration
Land-use planners	5	Administration
Architects / Landscape architects	3	Administration
Decision-makers (municipal and regional)	2	Administration
Politicians	2	Administration
Regional planners	2	Administration
Authorities	2	Administration
Road-Engineers	1	Administration
Transportation planning	1	Administration
Wildlife managers	1	Administration
Land surveyors	1	Administration
Researchers	2	Research
Biologists	1	Research
Animal geographers	1	Research
Students	1	Research
Layman citizens (?)	1	Public

Questionnaire Part [2.3.2 -] What benefits will they get from these maps? This questions aims to investigate the usefulness of these maps and the benefits an expert might gain from them. The answers are listed in the following list (partly translated from Finnish).

- Estimation of more "dangerous" areas (traffic etc.)

- A better overview of the actual ecological barrier effect and ecological networks, help & support for future land use planning
- A good overall picture of the ecological network and challenges related to it. It also helps to target actions and regional planners and find planning practices
- To see how to add to the infrastructure with minimal adverse effect on ecosystems
- A new dimension for decision-making and land use planning. A vital aid for planning, wildlife conservation & research. Useful information for improving the safety of traffic.
- Planning "not blocked" areas, paths for animal movements
- They can see where it is necessary to preserve ecological pathways
- Demonstration of ecological networks; simulation if the data available
- Ecological planning in areas has to based on sustainable grounds (meaning sustainable development)
- Identify corridors that are important for nature conservation

Questionnaire Part [2.3.3 -] Please, give some cases in which these maps can be used. With this question the intension is to find some practical areas in which these maps could be used. The answers are listed in the following list (partly translated from Finnish).

- Infrastructure Planning
- When considering building new roads (motorway), exploiting areas, which so far have been in a natural state, etc. The maps could, in fact be something, "good to know" for everyone involved in decision-making in important/large building projects.
- To examine cases in which it is necessary to decide on the use of green areas. These kinds of maps can help in deciding whether to develop or leave an area in a natural state and, if the decision is to build, what kind of construction best suits the area.
- Housing planning; road planning
- Planning of green area corridors in urban areas, wildlife conservation & research, managing urban wildlife species, land use planning with an ecological dimension,

a variety of research purposes, traffic safety – to improve traffic infrastructure and to avoid moose accidents & traffic accidents with other wildlife as well.

- Building of moose fences; building of noise fences; removal of unnecessary conservation areas, e.g. the ones that animals cannot access properly
- To ease or prevent animal movement; recreational route planning for areas
- Land use planning; traffic-infrastructure planning; The area should not be built or blocked so that the areas are full of high obstacle values; good land use planning for areas/recreational areas
- To identity possible isolated populations; To identify needs to develop corridors

Questionnaire Part 3 - Suggestions/Opinions/Additional Information

This is an open area to invite comments on the maps or further remarks of all kind. The answers are listed in the following list (partly translated from Finnish).

- It would be useful to add more information about different species in different areas.
- Road tolls to Helsinki
- Very nice work indeed
- Estimation of moose warning sign areas by vegetation and elevation model, seasonal changes; moose detection distances according to different seasons
- Select the appropriate scale – region size is important (not only city centers); plus natural causes; elevation model and land cover

4.6 Review Of The Questionnaire Findings

Most of the experts provide quite similar answers. Generally the survey has received positive feedback, when considering the agreement to the provided statements. The highest concurrence seems to be with the statement that it is important to visualize the data to get people to understand the plan better. Concerning the potential users for these maps, the city or urban planners and the land use planners are on the top of the list. Overall the public administrations dealing with land use planning are identified as the main users for these kinds of maps. The research side (e.g., geographers or biologists) might also be included as a user group. Surprisingly, only one expert suggested the general public or layman citizens as potential users and that even with a light question mark behind the answer. This is a surprise, since it might have been expected that at least some would consider the maps preferable as a tool for communication. Perhaps the term planning in this question has been chosen too generally, but there has been overwhelming feedback that these maps are, in fact, useful for planning.

5 Chapter 5 - Discussion And Conclusions

5.1 Application of the theoretical framework

This dissertation is the first study to attempt to include and investigate the use of geovisualization in maps that are used in the field of ecological network planning. One of this dissertation's basic findings is that geovisualization can assist the modeling process and the interaction process between the GIS-expert (or Geoscientist) with domain experts. Figure 48 illustrates this process based on experiences gained from case study II.

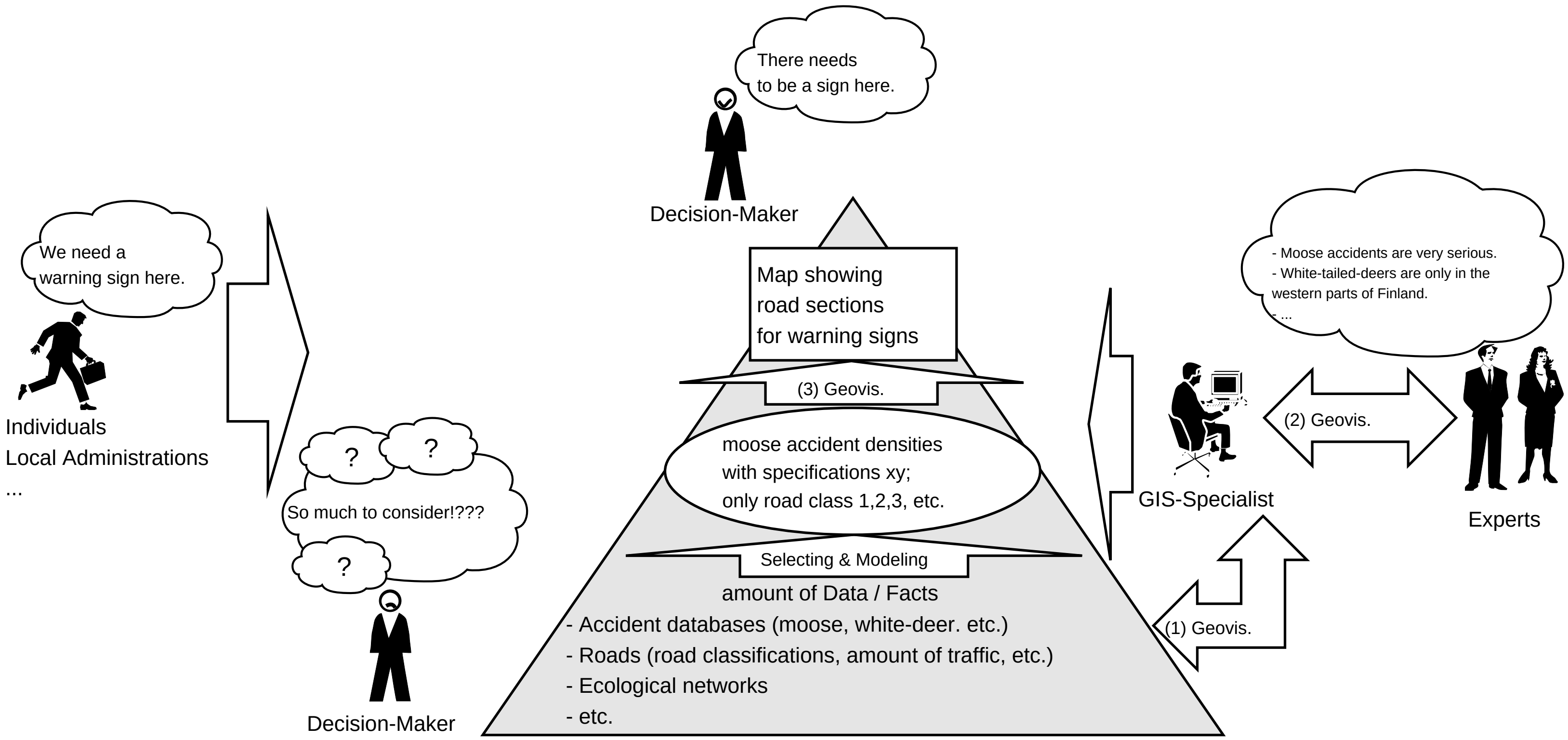


Figure 48. Application of the theoretical framework to case study II

In this example the local administration of a district requests a new warning sign at a specific location. The Finnish road administrations frequently get this kind of request, but have limited resources to place new signs and, as a result, aim at placing warning signs only at significant locations. After this request the decision maker at the road administration takes a look at the geospatial information at hand and finds there is a lot available. The road administration has stored numerous files on specific animal-vehicle accidents, including moose, white-tail-deer, reindeer and other, road-datasets in different classifications, amount of cars, pavement, etc. Additionally there is data from other sources (like hunting societies, nature protection organizations) on ecological networks, wildlife habitats etc. This amount of data confuses the decision maker (indicated in the Figure 48 with the questions marks), so he/she decides to bring in a GIS-expert (or Geoscientist). In the following process geovisualization can assist the knowledge discovery and decision making in three ways. (1) The GIS-expert is aware of different tools and processes and formulates ideas and hypothesis based on the available data with the support of geovisualization. (2) Then the important interaction process with different domain experts begins, and maps and applied geovisualization methods can significantly assist the negotiation process. The domain experts give statements in this process based on their knowledge (e.g., moose accidents are the most significant, white-tailed-deer are only in western Finland, reindeers exist only in Lapland, etc). The GIS-expert incorporates this information into a spatial model. (e.g., data concerning reindeers is left out, only moose accidents are considered, density maps are used, only specific road classes are included, etc). This consulting process with domain experts is the key to a problem specific model. (3) Based on this problem specific model the GIS-expert can use geovisualization methods to create a problem-specific map (or a map series, or an information system) for the decision maker. Now the decision maker can verify the incoming requests with the problem specific map. Similarly, this process can be applied to case study I and III.

Visualizing the meaningful is important for the planning and decision making processes. The principle can be extended as has been done in Figure 49. This shows the process involving more detail and outlining suggested methods for the tangible and non-tangible data collection, as well as for the data selection processes.

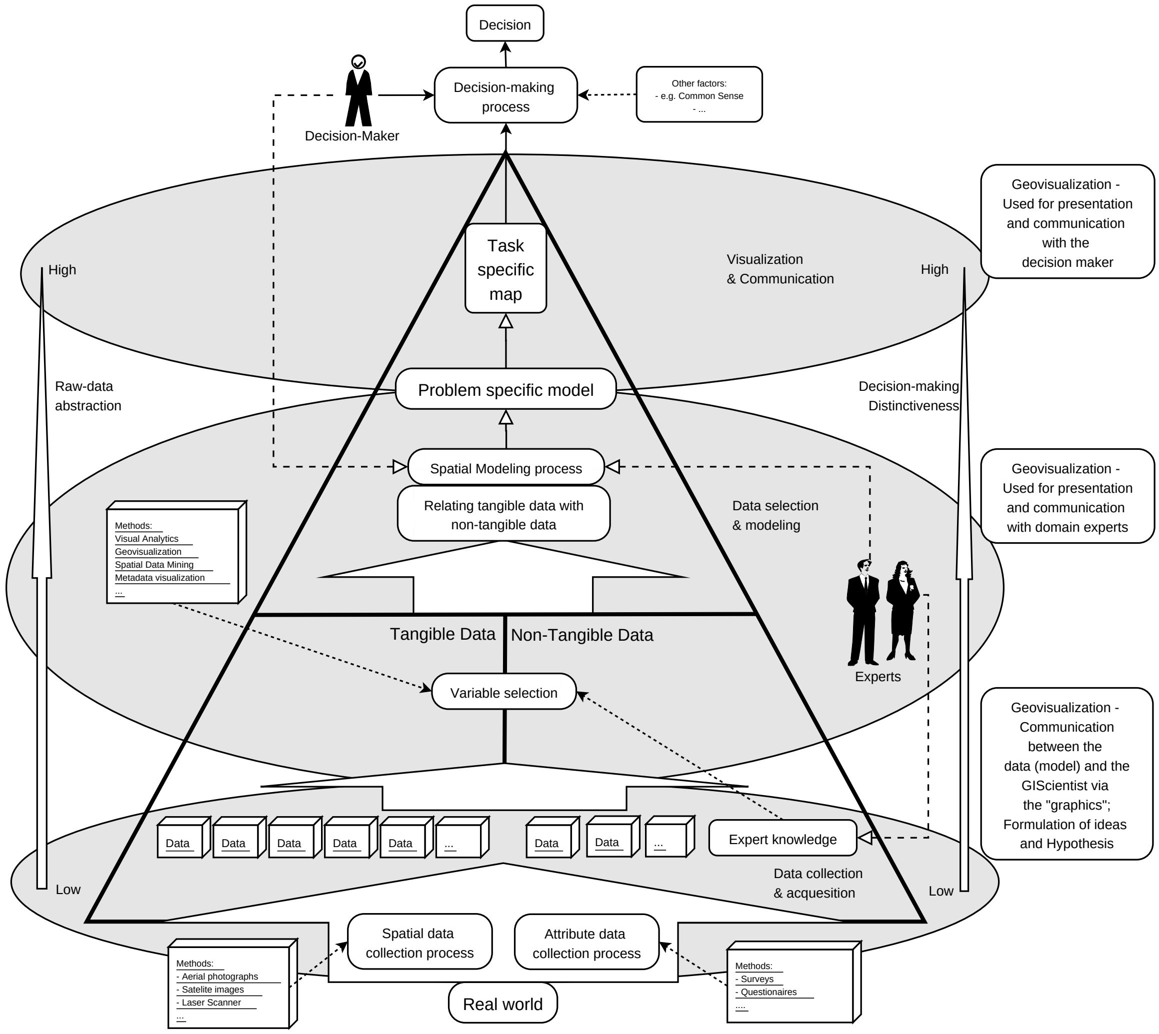


Figure 49. Theoretical framework for the process from data and facts to problem specific models and task specific maps

The collection process for data is divided into a process to collect tangible spatial data (e.g. the road network, land-use, etc.) and non-tangible attribute data (e.g., real-estate values, ecological barrier values, etc.). “Tangible data” refers to “real-world” objects. These objects are to a certain degree directly measurable (e.g. length, volume, location etc.). “Non-tangible data” refers to data that is indirectly measurable and defined (e.g., administrative areas). Other non-tangible data might be collected via measurable indicators (e.g., high-class living areas). In the case study III (see chapter 4.4), ecological barrier values are evaluated via an expert survey. These values are based on expert opinions, which is another way to acquire this non-tangible attribute data. These values could be also based on a measurable indicator (e.g., number of dead animals along a road section), as done in case study II, where the wildlife accidents densities are used to find the “dangerous” road sections. Large amounts of data have been collected and the methods to collect spatial data (e.g., satellite images, laser scanners, etc.) and non-tangible attribute data expand constantly. To assist the decision making process, a situation or a problem has to be explained and understood. There might be a risk involved in the overall process. Usually the decision-maker wants transparent processes, that can be understood easily to justify his/her decision. But the decision maker might already be active in the modeling process or in providing pre-selected data. This would influence the decision into a direction that intentionally or unintentionally is preferred by the decision-maker.

5.1.1 Need For GIS Specialists

Models are being increasingly used for integrated studies of landscapes, (e.g., for modeling landcover change, for running hydrological models, etc). An important question raised by Burrough, is whether the current tools have sufficient theoretical underpinning to support the uses to which they are put. How does a user decide whether the standard tools are sufficient for his/her purpose, or whether to call in a specialist to help? (Burrough, 2003) Figure 50 illustrates one possible framework for the spatial modeling process. The user cannot use explorative analysis tools. The help of an expert is needed, as is, most likely, the development of methods and tools.

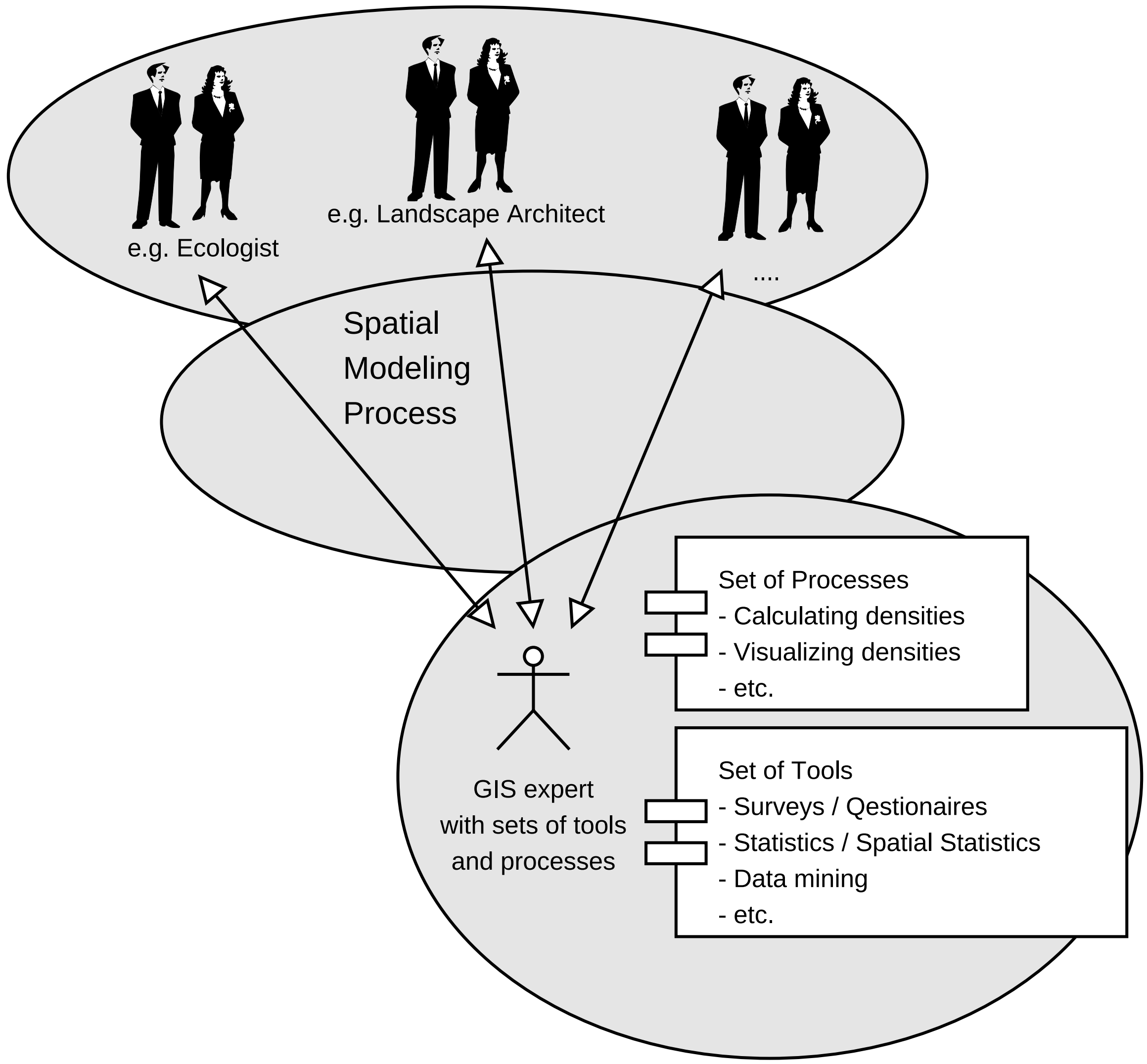


Figure 50. Interaction framework for the data selecting and modeling process

A GIS expert has the knowledge of a set of tools and processes related to geo-referenced data. Domain experts from an organization have their knowledge regarding the processes and experience dealt with in the specific field. Within the spatial modeling process the actors have to find ways to integrate the knowledge from the experts into a spatial model. This requires interaction and an understanding between actors. Geovisualization can have a crucial role in creating this understanding. Domain experts are the most important information source in the problem-specific spatial modeling process. We suggest bringing in expert knowledge as one of the crucial points in developing the problem-specific spatial models and finally the problem-specific maps that assist the decision making. But how can we extract this expert knowledge? It has been done by interviews or questionnaires in social sciences. When it concerns the spatial distribution of the phenomena, maps are needed. In this case we need to create initial draft maps first. This might be a sketch of ideas of what is important, and these can be based on very controversial variables. These maps can be printed or presented on the screen in order to communicate with experts and determine their opinion and knowledge about the phenomena, extract the knowledge, and incorporate them into a problem-specific model. This model is needed to provide the final task specific maps.

5.1.2 OODA Loop and Insight Generation for Decision-Making

Several data collection methods assist the observation phase. Using geographic information analysis tools, it is possible to derive information from this data collection. The interpretation of this information provides us with knowledge. When this knowledge is used and applied, it can provide insight to a problem and decisions and actions can be done appropriately. Figure 51 shows a possible relation between the OODA loop and the process of producing insight from spatial data to generate information, to provide knowledge and subsequently insight, and to support the decision making process. This process is accompanied by planning steps that exemplarily illustrate this procedure.

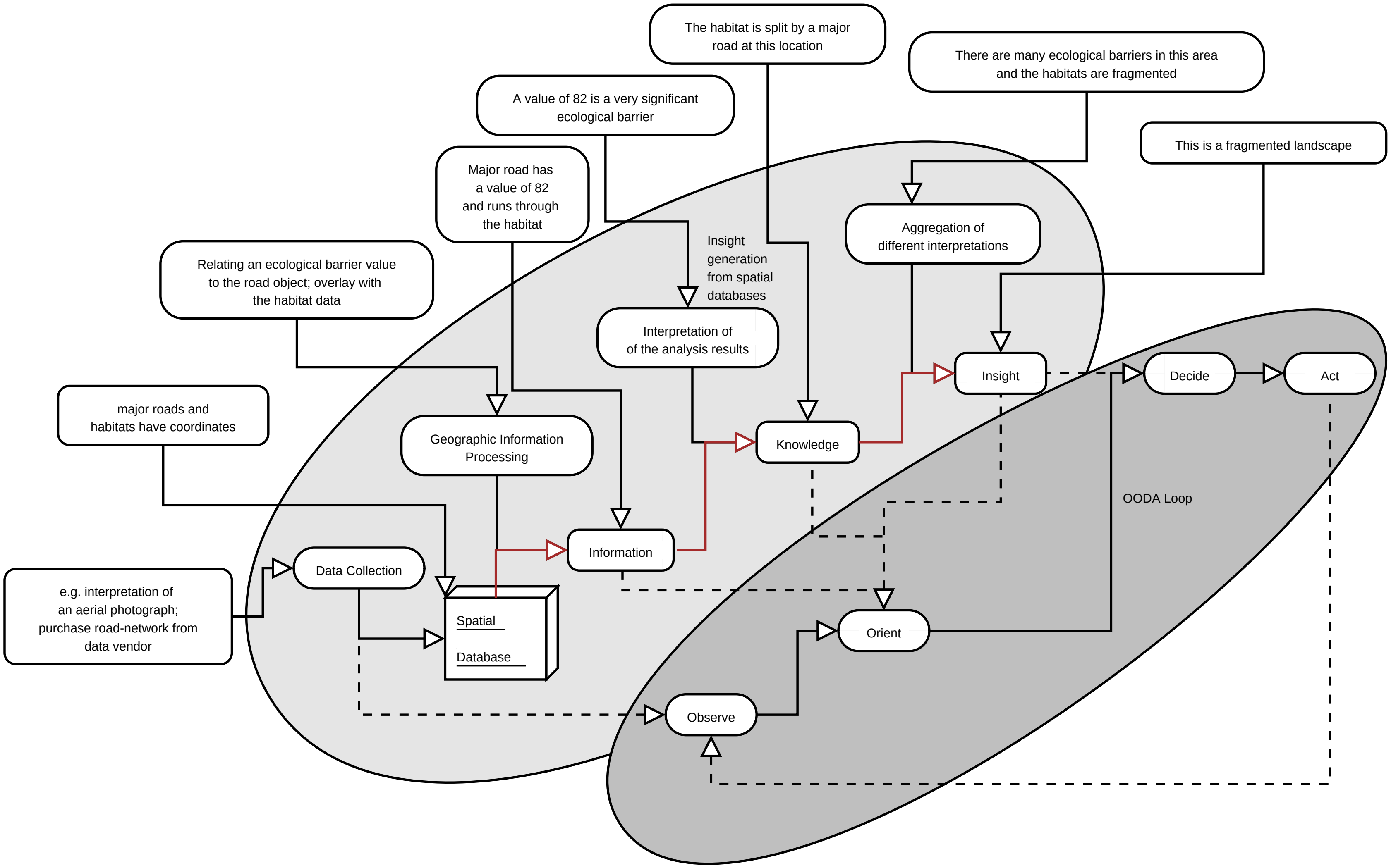


Figure 51- OODA loop & Insight generation process with example work steps in ecological network planning

The OODA loop is illustrated in dark gray, showing the Observe-Orient-Decide and Act phases. Related to these steps are the key stages from the process of producing insight from spatial data, starting from the (geo)spatial database. This data is used in geographic information processes to obtain information. This information requires interpretation to acquire knowledge. The aggregation of knowledge provides insight, which can be used to make a decision and perform action. Related outside the gray shading are some exemplary steps which relate to case study III. These are not real case steps, but are intended to explain the thoughts that might occur during this process. This process involves:

- *Data:* The real-world data is collected and stored in a geospatial database—for example, roads and moose habitats (objects) are stored with their coordinates.
    - *Geographic Information Processing:* This step involves a geographic information-processing step, such as relating an ecological barrier value (obtained from a problem specific model) to a particular road object and e.g. the overlay of roads and habitat areas.
- *Information:* This provides the information that a particular road section has a barrier value of, for instance, 82 and it is located in a moose habitat
    - *Interpretation of Information:* This information requires interpretation; one can surmise that a value of 82 is a significant ecological barrier.
- *Knowledge:* A road, which is a significant ecological barrier, splits the moose habitat.
    - *Aggregation of knowledge:* To develop insight, knowledge from different work steps (and different interpretations) has to be aggregated; e.g. there are many ecological barriers in this area and the habitats are fragmented.
- *Insight:* This is a fragmented landscape.
    - *Decide & Act*– With significant insight planner & decision-makers can make profound decisions and act accordingly. This might be accompanied by a monitoring procedure that leads to new observations and repetition of the OODA and KDD processes.

Amount of available geospatial data

In all three case studies, building up the use of geovisualization is limited to the data, which is available in digital format. It seems to contradict the theoretical framework, which states that the increasing amount of data makes it difficult to build a problem-specific model. This is the case in all case studies. The models in these cases are limited to available amount of data, but still there is a large amount available, though, unfortunately, not standardized. In recent years, most cities in Finland have been very active in building up a database for their area in digital form. The data is accurate enough for the purpose of visualizing ecological relationships. Nevertheless combining datasets is problematic. Up to this point, we could not find a standardized method of how these diverse city-databases have been built up. They vary in their software format, projection and labeling. This problem has been recognized and several international standards, such as the INSPIRE directive to establish an infrastructure for spatial information in the EU-Community (EU-Commission, 2004), and national standards have been developed. This will allow harmonized data models and standardized data quality including metadata. With an increasing number of participating cities it is problematic to combine the datasets and analyze the ecological network on the border of city areas or on a larger scale between different regions. When it comes to analyzing the ecological network, this is a major problem; animals do not care about city or regional borders. To analyze a potential ecological network, we have to consider that animals might move outside the city area and re-enter it somewhere else to reach their destination. Combined datasets would help to analyze the ecological network despite city borders. In practice, building up the models is limited to the data, which is available in digital format. The cities have been very active in building up a database for their area in digital form. The data is accurate enough for the purpose of visualizing ecological relationships. Concerning the expert survey in case study II, it has been successful to model ecological barriers (leading to habitat fragmentation) by a limited list of land use (and land cover) elements and their impact on animal movement. Since the whole model is build up on assumptions by different experts, it is not a precise model. From our point of view it is not essential to build up a very accurate model, because the nature of animal movement cannot be an exact one.

5.2 Research Questions Answered

Can geovisualization methods enhance the selection of meaningful variables from spatial data that is used in planning and decision making?

This research question appears to be too general for the scope of this research. We might suggest that the geovisualization methods applied have to be reviewed case by case. It seems there is no general answer to this question. A general answer is approached, though not comprehensively given in this research. The problem seems to be specific to different fields and therefore this research approaches this question with three case studies all related to the ecological network planning.

Do geovisualization methods and their application in task-specific maps assist decision making and decision distinctiveness?

In general, research about fragmentation is very complex and difficult to quantify and compare. The impact of fragmentation is specific to one species and effects need to be measured at different levels. Concerning the case studies, this can be answered yes. Creating task-specific maps has, in all cases, proven to enhance the planning and decision making. The decision making distinctiveness in case II (moose warning sign placement) was considerably improved by the application of geovisualization and task specific maps.

Do the applied geovisualization methods bring advantages in the field of the case studies?

The results from the case studies have found their way into some use applications at this point in time. Case study I have been presented to the Finnish hunting associations and they have indicated an interest in these kinds of maps. They are not used for a particular planning purpose yet, but they help the communication between landuse planners and hunting associations regarding the formulation of ecological networks. There is a strong indication that visualizations like this should be not restricted to the Uusimaa area, but should consider the whole of Finland.

Concerning case study II, the Finnish road administration, in particular the road safety planning authority for the Uusimaa region, is consulting the optimized warning sign location map, when checking the placement for a new wildlife warning. The maps are not used as the only planning tool, but they are considered as information resources, which are limited to a certain purpose and to a certain region. Hunters and local police approach the decision maker at the Finnish road administration with a request for a new warning sign at specific location. There are many requests and only limited resources per year. Up to this point the decision maker has had no task-specific maps at hand to inform him/herself further. This map provides a road section that is based on indicators. This is a great advantage for the placement process, because the decision maker can reason the proposed action.

Concerning case study III - Some of the maps have already found a practical interest among planners (summer 2006), as a result of this research. The ecological barrier model is, at the moment, used for the determination of the ecological network in Finnish urban areas. A publication by the Finnish ministry of environment (Väre and Krisp, 2005) documents this model. Planning offices (like SITO and YS consultants) are consulting the three-dimensional barrier map (where available) when identifying ecological networks. Figure 52 shows a regional map including the concept of ecological networks. This map has been produced with the consultation of the ecological barrier model for the area of Espoo as a result of case study III (see chapter 4.4).

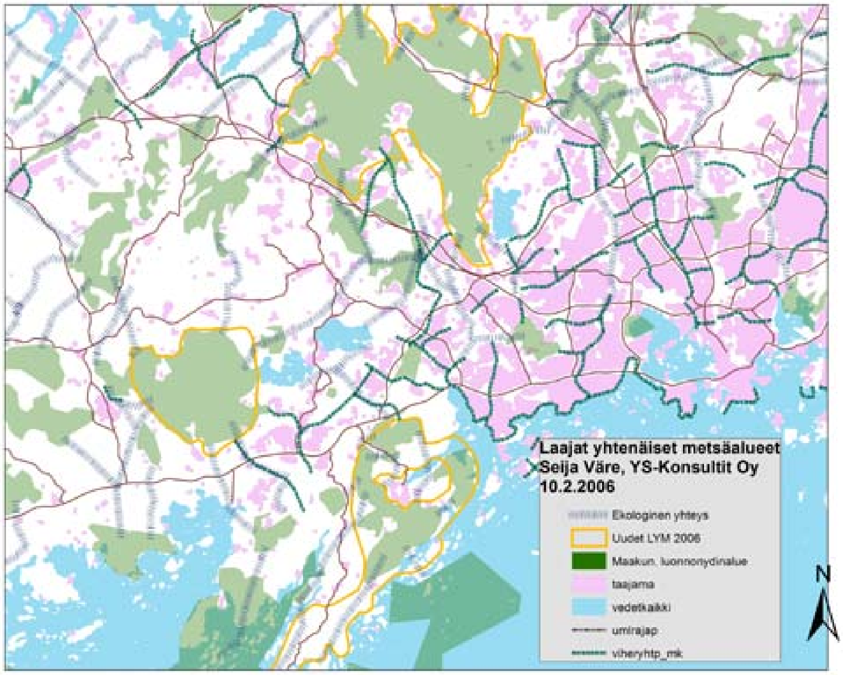


Figure 52. Map including suggestions for the ecological network corridors in the Espoo region (with courtesy to SITO OY)

The interconnected ecological network is sketched with blue stripes. City planners intend to use this map as a basis for integrating the ecological network into the regional plan for the metropolitan area of Helsinki.

Can we integrate animation into maps as a meaningful feature?

Four-dimensional interactive animations can help to visually analyze the moose density patterns over time. Integrating the individual three-dimensional visualizations into an interactive system makes it easy to navigate between the different maps created for each point in time. In our example (see Figure 31) the time span from 2001 to 2003 appears to be too short to identify significant changes in the moose density. It is important to integrate data from a longer time period. The Finnish hunting association will continue to record moose data points with individual coordinates, so future research will be able to consider longer time spans. To visualize this change over time we can create a series of models and visualize them over time creating in an animation, as was done in case study

I. Animation can be useful for creating “what if” scenarios that can help us to predict changes in the research area, for example the impact of a new road on its environment concerning the movement of animals. In this case the animation has proven to be a useful tool for visualizing the changing moose densities for different years.

Can we integrate augmented reality into maps as a meaningful feature?

The classification of different representations into the four categories proves to be functional as we can categorize all our representations accordingly and each category based on the reality-virtuality continuum is occupied. In our case, the usefulness of the categorization would be verified in the future by guidelines for the use of the different visual components. From a technical point of view, GIS software and graphic tools enable us to freely combine real and virtual representations of reality. This is a great advancement in the technical development, but so far we do not see many maps or other cartographic representations making full use of this possibility. Tools for exploratory visualization should also be combined in this context. The reality/virtuality continuum helps us to organize our visualizations. These needs can include the promotion of a region, the description of an area, or the analysis of the wildlife network for a certain district. The combination of realistic and virtual components can aid in understanding and exploring the problem represented in the map. Based on the result of case III, there is an indication that most users will demand maps that combine virtual models with realistic representations as a further explanation of the ecological barrier concept.

Can we integrate density information into maps as a meaningful feature?

To calculate the moose density for different years provides us with the basic data to show us changes in the moose density, which might be caused by the roads. The Kernel method proves to be a good tool to calculate the density patterns of the individual moose locations. By creating a smooth representation of density values in which the density at each location reflects the concentration of points in the surrounding area, analysts are able to identify how densities vary across a study area. The overlay of the moose density and road network map can help to identify “hotspots” concerning the location of a traffic wildlife accident. Wood suggests making use of the landscape metaphor in understanding population data (Wood, Fisher et al., 1999). That would include, for example, the calculation of slopes to show the control of physical features on the distribution of moose. The calculation and visualization of slopes on population densities might result in "channels" between the steep changes in the density of moose. The visual identification of these "channels" assists the placement of wildlife crossing structures over (and under) roads and other infrastructures.

Do we gain further information from a map, when visualizing data in a three-dimensional environment?

Why do we need to visualize these areas in a three-dimensional environment? Generally three-dimensional visualizations are mainly applied in relation to project assessment or for visualizing landscape changes. Case study I and II explored a "new" way of representing this topic. Most people seem to like appealing images or moving sequences about landscapes, animals or plants. If we would like to encourage nature protection plans, a medium is needed that is understood more easily than an abstract two-dimensional plan. It enables the public to participate in the planning processes. Unlike other two-dimensional visualizations, our maps approach the problem from a different perspective. Two-dimensional maps that show ecological patches and corridors have highlighted these areas (usually in green) and outlined a connection between them. In our three-dimensional approach we highlight the barrier effect of existing infrastructures. In case II, the aim of visualizing ecological barriers to the general public is to gain their attention and get them interested in the ecological aspects of land use planning. In this respect visualization must be attractive and thought-provoking; reading of the details of the actual information is not necessary. The combination of photographs and three-dimensional maps can result in an appealing visualization. However, the usefulness and usability of these combined three-dimensional maps needs to be proven. Generally we got positive feedback on the appearance of the maps from our data providers who received three-dimensional maps that have been created from what they had delivered. People seem to like the three-dimensional maps. Three-dimensional visualizations for nature protection purposes can help to highlight the importance of this topic. Modeling barrier effects three-dimensionally can successfully help to identify ecological corridors, networks or bottlenecks. That enables us to recognize ecological barriers and corridors, by “valleys” of easy movement or “hills” as high barriers.

5.3 Propositions & Directions For Further Research

Consideration of the user

User groups suggested within the questionnaire (chapter 4.4) for task specific maps might be the general public, the political decision makers in land use planning and the land use planners. The planners need to have an insight of the ecological environment. They need exploratory geovisualization tools for studying the ecological landscape and alternative approaches for land use. Generally we might state that in some cases the available data exceeds the capability of the decision maker to use this data. In these cases, a problem-specific model is needed. This can be derived using an extensive interaction process with domain experts. Maps with applied geovisualization methods can assist in this process. Having a problem-specific model helps to create task-specific maps for the decision maker.

Interaction is the key

Interaction and expertise are key issues. An interpretation of abstract phenomena requires expertise that cannot be expected in decision makers. Decision makers are not motivated in exploring the situation in detail, but they prefer to hear reasons for the proposed actions. Therefore the planners produce specific maps for them in order to convince them of the proper actions. The choice of the variables used in the problem-specific model affects the overall message. To select meaningful variables, interaction between domain experts and the GIS-expert (or Geoscientist) is essential.

GIS software as a valuable tool

From a technical point of view, GIS software and graphic tools enable us to freely combine real and virtual representation of reality. One off-the-shelf package of software, ESRI's ArcGIS package, has proven to be a very useful tool for visualizing three-dimensional data, even though it has limits in the amount of data that can be used. Its analysis functions for this purpose are to be investigated further. This particularly relates to less visible and often complex matters such as spatial-functional relationships in the landscape. Overall, the software has great advancements in technical development, but so far we cannot see many maps or other cartographic representations making full use of this possibility. Tools for geovisualization can aid the understanding and exploring of problems represented in the map. It seems that in the future special applications (like specific density estimations) will not be provided by the initial software package, but individual functionalities have to be developed (or purchased) on a case-by-case basis. This might have advantages for users who are interested in a limited number of functionalities and do not need the full capabilities; this might be the majority of users. For researchers who seek a special function, this might involve an initial survey phase to find, design, and implement or purchase "exotic" functionalities. To a certain extent this is already the case, as many utilities for ArcGIS are available via user forums and user communities. We predict that this practice will increase in future systems.

The use of more maps

Perhaps the decision makers (and researchers) in landscape planning and ecological network planning underestimate the importance of maps, particularly of task specific maps. Geovisualization provides a wide set of tools and processes to create all kinds of maps, and this research indicates that making use of these tools helps the interaction between decision maker, general public and domain experts. Interaction with domain experts essentially assists the development of models and the creation of task-specific maps. Visualizing results is a crucial point in getting the message across. Appropriate planning requires political backing. Visualizing spatial-functional relationships is a problem of growing importance for several research fields. City planners might be more interested in the relationship between inhabitants and their living environment. Major roads and big industrial areas cause disturbances for inhabitants. To achieve the support of a proposed planning action it is necessary to get the attention of the public. In spatial planning, maps are very often used to demonstrate the intentions of a plan. The choice of the visualization, the orientation of the geographic space in relation to the viewer, as well as the selection of the spatial area portrayed all similarly affect the overall message in these cases. Some people tend to think that mapping data is very precise. There has to be an indication that will make users aware of the reliability and quality of the task specific map. Concerning the case studies, there might be a tendency that all maps describing non-tangible concepts are better treated as fuzzy sets rather than crisp sets. Insight based on knowledge has to be integrated into legislation and planning procedures. When using geovisualization with planning purposes, including, for instance, property rights and directing money into ecological planning, it seems that the models themselves as well as the ecological parameters are insufficient. For applying the ecological barriers into legislation the models would have to be re-evaluated and based on a larger amount of experts opinions. Furthermore the models would have to be verified more carefully. The case studies show that within the development of a model, it is one possibility to transfer expert knowledge into planning procedures regarding to the field of natural protection. Within existing GIS technologies this is one approach to integrate expert knowledge into planning procedures. To get inter-subjective planning essentials from experts and produce task specific maps for decision makers is one of the most important tasks for scientists.

Further research

Further research might be required in three-dimensional visualization techniques, color schema, shading, three-dimensional visualization angles and output formats. Furthermore studies will focus on the adaptation of this kind of methodology and on the understanding of these kinds of maps, with the aim of obtaining operational information for land use planning. Furthermore, the output of the model might be analyzed further using grid analysis functions and spatial visibility graphs. The results can be used to adapt the existing means of transport to ecological requirements. It can also be used to integrate this subject within the planning procedures for new infrastructures.

From an ecological network planning point of view the model itself can change over time. In case study III, for example the barrier value of a lake can change over different seasons. In Finland, lakes are frozen during the wintertime, so they have a low barrier effect on animal movement. The changing barrier values in an animation over time gives an informative picture of the situation at hand when planning the comprehensive ecological network. These models can be useful for creating “what if” scenarios that can help us to predict changes in the research area, such as the impact of a new road on its environment, concerning the movement of animals. Thematic relationships of objects interact and influence each other. In some cases we might be able to measure this influence. For example, the modeling of ecological networks shows that certain spatial objects have a very strong impact on the movement of animals, while others are less important. Generally we might say that every spatial object has an influence value that depends on its impact on other spatial objects. To measure and visualize this value as a potential fifth dimension could be investigated in further research. This “influence” can also change over time. An object distends in topological dimensions (length, width, height, time and “influence”) in a defined spatial area. It is a more artificial variable that can be measured only by “soft” indicators; but, according to the mathematical definition, the “influence” can be described as a fifth dimension. We propose to model the influence of each spatial object on its environment, which might be a great challenge for cartographic representations.

Within this research the individual case studies have been reviewed separately, but future research might follow an integrative approach to advance ecological network planning. We suggest combining the moose habitat (and their changes) with the ecological barrier map for this area and to review them together with the identified moose accident hotspot locations. This line of inquiry might result in some interesting correlations. Some efforts to do so have been attempted already, but they need further investigation.

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Expert Opinion questionnaire on three-dimensional maps representing the ecological barrier effect in Finnish urban areas

HUT Department of Surveying –
Institute of Cartography and Geoinformatics

Expert Opinion questionnaire
on three-dimensional maps representing the ecological barrier effect in Finnish urban areas

1.General Information

Name:____

Position:____

Organisation:______________________________________

Contact Information (e-mail):___________________________

2. Expert Opinion

2.1 Indicate your agreement with the following statements by circle your answer. (1=Strongly Disagree, 2= Disagree, 3=Neither Agree nor Disagree, 4=Agree, 5=Strongly Agree); If you have no opinion to a specific statement please don't circle anything.

	Strongly disagree			*Strongly Agree*	
2.1.1 There is a need to analyse ecological networks in urban areas.	**1**	**2**	**3**	**4**	**5**
2.1.2 The maps can be used to explain an audience the concept of "ecological barriers".	**1**	**2**	**3**	**4**	**5**

2.1.3 It is important to visualize the data to get people to understand the plan better.	**1**	**2**	**3**	**4**	**5**
2.1.4 The maps are understandable with little verbal aid and without a legend.	**1**	**2**	**3**	**4**	**5**
2.1.5 The maps show the intended information immediately.	**1**	**2**	**3**	**4**	**5**
2.1.6 The three-dimensional representation of the information used in the maps makes it easier to understand the map and interpret the barrier effect on animal movement.	**1**	**2**	**3**	**4**	**5**
2.1.7 The colour range represents the information correctly.	**1**	**2**	**3**	**4**	**5**
2.1.8 The digital version of the maps is more useful than the paper print.	**1**	**2**	**3**	**4**	**5**

2.2 Do you think that the maps presented (see attachments) are useful for planning? YES NO

2.3.1 If yes, who are the main users?

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2.3.2 What benefits will they get from these maps?

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2.3.3 Please, give some cases in which these maps can be used.

References

3.Suggestions/Opinions/Additional Information