Biotope and Biodiversity Mapping in Forest and Urban Green Space

Methodological Review and Developments

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Abstract

Forests play an important role in providing ecosystem services that support the ecological integrity of an area and also supply social benefits for humans. Many of the essential ecological and social benefits derived from forest are underpinned by its biodiversity. This thesis explores how biodiversity values of forest in urban and rural settings are expressed and how these values could be implemented in biodiversity-orientated forest management and planning.

Theoretical development work focusing on the application of biotope mapping methods resulted in a modified biotope mapping model integrating vegetation structure as a tool for collecting biodiversity values. The model was validated in a process beginning with a literature study on forest biodiversity indicators in order to test the rationality of vegetation structural parameters included in the model. Two case studies, carried out in an urban and a rural setting, respectively, were then used to validate the function of the modified mapping model in covering different aspects of biodiversity values (birds, mammals and vascular plants in the urban setting; bryophytes, lichens and vascular plants in the rural setting).

The results showed that the modified biotope mapping model, where temporal and spatial vegetation structural parameters are integrated, can be applied to collect biodiversity-orientated information, which can support decision making on forest landscape planning and policy.

Keywords: Biotope mapping, Forest, Vegetation structure, Biodiversity indicator, Mind mapping, Urban forestry, Urban settings, Rural context, Landscape planning, Landscape management.

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Dedication

This thesis is dedicated to everyone who has been a source of inspiration and knowledge for my doctoral research.

The landscape belongs to the man who looks at it.
Ralph Waldo Emerson

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Qiu, L., Gao, T., Gunnarsson, A., Hammer, M. & von Bothmer, R. (2010). A methodological study of biotope mapping in nature conservation. *Urban Forestry & Urban Greening* 9(2): 161-166.

II Gao, T., Nielsen, A.B. & Hedblom, M. (2015). Review of forest biodiversity indicators – taking stock and looking ahead. (Manuscript)

III Gao, T., Qiu, L., Hammer, M. & Gunnarsson, A. (2012). The importance of temporal and spatial vegetation structure information in biotope mapping schemes: A case study in Helsingborg, Sweden. *Environmental Management* 49(2): 459-472.

IV Gao, T., Hedblom, M., Emilsson, T. & Nielsen, A.B. (2014). The role of forest stand structure as biodiversity indicator. *Forest Ecology and Management* 330: 82-93.

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The contribution of Tian Gao to the papers included in this thesis was as follows:

I Carried out the literature search and analysed the collected data. Wrote the article with feedback and co-writing from the other authors.

II Carried out the literature search and analysed the collected data. Wrote the article with feedback and input from the co-authors.

III Planned the research project together with the co-authors. Carried out the field survey and data collection and analysed the collected data with the co-authors. Wrote the article with feedback and input from the co-authors.

IV Collaborated with the National Inventory of Landscapes in Sweden (NILS) programme. Conducted NILS data interpretation and statistical analysis. Wrote the article with feedback and input from the co-authors.

1 Introduction

Forests play an important role in providing ecosystem services that not only support the ecological integrity of an area, e.g. water and climate regulation (FAO, 2009), carbon storage (UNEP, 2007), pollution removal (Nowak et al., 2014) etc., but also supply social benefits such as recreation (Briffett, 2001), aesthetic enjoyment (Miller, 2007), physical health (Hill, 2002), psychological well-being (Orsega-Smith et al., 2004), social ties (Kearney, 2006), education (Chen & Jim, 2008), livelihoods and economic growth (UNEP, 2007) and so on. Many of these essential benefits derived from forest are underpinned by its biodiversity, which reflects the capacity of forest to adapt to pressures, such as human activity, climate change etc. (Seppala et al., 2009; Díaz et al., 2006; MA, 2005). Much recent work has demonstrated that the majority of relationships between biodiversity attributes and ecosystem service are positive (e.g. Harrison et al., 2014; Bastian, 2013; Cardinale et al., 2012; Mace et al., 2012).

Forest is one of the most biodiverse ecosystems on this planet, representing about 70% of terrestrial biodiversity (FAO, 2010; Schmitt et al., 2009), and directly supporting 1.6 billion human livelihoods (FAO, 2010). Depending on the location, forests can be categorised as urban, e.g. urban parks, remnant green spaces, even street/residential trees, or rural, e.g. national parks, forest reserves, managed plantations etc. However, in both urban and rural environments, the pressure on forest to service biodiversity nowadays is greater than ever (Qiu, 2014; Forest Research, 2010; Young et al., 2005), because of e.g. population and consumption growth, growing demand for forest products, expansion of human settlements and infrastructure, climate change, etc. (UNEP, 2011; DeFries et al., 2010; IUCN, 2010; FAO, 2009; Slingenberg et al., 2009).

Urbanisation is considered to be one of the main driving forces of habitat and biodiversity loss, together with biological homogenisation in the developed and developing world (Gaston, 2010; McKinney, 2008; Chace & Walsh, 2006; McKinney, 2006; McIntyre, 2000). Many studies have demonstrated that both the richness and abundance of species, including plants (Thompson & Jones, 1999), mammals (McKinney, 2008), insects (McIntyre et al., 2000) and amphibians (Riley et al., 2005), change in response to urbanisation. With the growth of cities, valuable habitats within and outside these cities become destroyed and fragmented. The surviving forest remnants and other green patches are a key element in maintaining biodiversity in urban areas (e.g. Mörtberg, 2001). In addition to urbanisation, other human activities that are detrimental to biodiversity include overexploitation of natural resources, which may primarily occur in a rural context. Forest biodiversity loss has continued worldwide because of deforestation and forest degradation, e.g. in South America, Africa and Australasia. Most of this is occurring in tropical forests that are especially rich in biodiversity. Forest monoculture is also decreasing forest biodiversity, e.g. in Europe, North America and Asia (CBD, 2010; FAO, 2010).

Owing to the biodiversity losses associated with various human activities, finding the balance between: (1) The need for more built-up areas and natural resources, e.g. timber products; and (2) the need to maintain viable ecological functions of forest in urban and rural contexts has become a major challenge in current research. Maintenance of viable ecological functions is fundamental to sustainable urban and rural development that secures viable biodiversity values (e.g. Forest Research, 2010). These values in turn benefit people's health and well-being (e.g. Bezák & Lyytimäki, 2011; Niemelä et al., 2010).

The reasons for studying biodiversity in urban and rural areas are many. Besides the research perspective mentioned above, perhaps the most obvious reason in the view of ordinary people is aesthetic or ethical considerations. Nature and its living creatures always attract humans. Wilson (1984) called this phenomenon "biophilia", i.e. an inherent tendency to affiliate with beauty and life. A sense of peace and joy can be felt by many people when surrounded by attractive plants and beautiful animals (Frumkin, 2001). For example, many of us have house pets and we like to grow flowers on balconies or trees and shrubs in gardens, attract birds with feeders etc. It does not matter whether these plants and animals have an ecological function (although most of time they do, e.g. birds help control harmful insects as an extra benefit), people just like having them around (Szlavecz et al., 2011). Therefore, improving landscape planning for biodiversity conservation purposes has become an important issue.

Against this background, this thesis set out to explore how the biodiversity values of forest in urban and rural settings are primarily expressed, and how these values are implemented in biodiversity-orientated management and planning. The work was conducted in the context of Sweden, but many parallels can be drawn with the situation in other countries.

1.1 The challenges of biodiversity conservation in urban and rural areas

Since acknowledging the significant impacts of urbanisation and overexploitation of forest resources on biodiversity, in recent decades many countries have adopted various methods and strategies for long-term preservation of biodiversity according to the Rio Convention on Biodiversity (UNEP, 1995). These methods include implementing species-specific conservation (Michaels et al., 2014), maintaining habitat ranges (Buffum et al., 2011), creating protection for natural and human-dominated landscapes (Kingsland, 2002), building connections between habitats and landscapes (Heller & Zavaleta, 2009) and organising land management methods (Lindgren et al., 2006). However, these methods tend to operate on a 'macroscopic' level as regards biodiversity conservation, and therefore the difficulties in measuring biodiversity and evaluating the outcome of preservation strategies still remain (Millennium Ecosystem Assessment, 2005).

According to McCarty (2001), current plans and assumptions about establishing protected areas or maintaining existing habitats need to be reconsidered, because it is no longer safe to assume that the historical growing range remains suitable for all species due to changes in e.g. matrix environments, climate etc. Some studies have concluded that strategies solely targeting individual spaces, preserving land parcel-by-parcel or only considering green infrastructure are unable to provide effective protection of habitats from the encroachment of human activities (Hostetler et al., 2011; Shih et al., 2009). In general, lack of basic data on ecological characteristics and on effective conservation measures concerning urban and rural landscapes is the most significant obstacle hindering the process of biodiversity conservation (Hong et al., 2005). Therefore, a 'microscopic' scientific and political focus and revised strategies for protecting forest biodiversity in urban and rural settings are needed, in order to offer new understanding, insights and opportunities for responding more effectively to biodiversity decline (UNEP, 2011; Gardner et al., 2010; Maris & Béchet, 2010; Pfund, 2010). It is thus imperative to understand in detail whether and how patterns or structures of different forest represent biodiversity or, more specifically, which aspect(s) of biodiversity and at which scale(s).

1.2 Forest biodiversity in urban and rural landscapes and its different scales

Forest biodiversity is the variability in living organisms in forest ecosystems. It comprises diversity within and between species and within and between terrestrial and aquatic components of forest ecosystems (Millennium Ecosystem Assessment, 2005; Groves et al., 2002; Purvis & Hector, 2000). In undisturbed ecosystems, interpretation of this definition is relatively straightforward (e.g. Holt, 2006; Noss, 1990). In human-disturbed systems, however, interpretation can be controversial, especially with respect to exotic species (Dearborn & Kark, 2010). While various values are associated with urban vegetation or timber forests, exotic species are often excluded from such evaluations (Szlavecz et al., 2011).

However, this point of view may now need revision. For example, some studies have found e.g. that the climate is becoming less suitable for native trees in some areas of the prairie provinces in Canada, so that retention of the environmental and economic values associated with forest may require introduction of exotic species that are adapted to the warmer and drier climate (Henderson et al. 2002; Thorpe et al., 2001). In addition to the climate change effect, the presence of exotic species in urban systems may be due to many native species not being able to thrive in highly urbanised areas and only a subset of native species being able to cope with the associated environmental shifts (Williams et al., 2009; Kark et al., 2007). Consequently, it may be impossible to protect or restore a viable ecosystem that functions in the same way as the native system that the urban area replaced. Therefore, this thesis primarily focused on the species level of flora biodiversity in terms of species richness/diversity and ignored whether the vegetation was indigenous or exotic. Bird and mammal species were also studied to some extent.

Mapping forest biotopes for biodiversity purposes in urban and rural settings requires knowledge from spatial planning, ecology and biology, as well as suitable tools for integrating these different aspects. Patterns in vegetation are the result of variations in physical conditions, e.g. soil type, hydrological conditions, land use etc., and can be viewed at different spatial scales ranging from the wider landscape scale to the regional and on to the smaller habitat scale (Werner & Zahner, 2010). Viewed at the landscape scale, forest and other biotopes can appear as a mosaic of patches and linear strips embedded in the surrounding environment or matrix, e.g. built-up areas in urban settings or agricultural fields in rural settings. At the habitat scale, patches, i.e. individual forest biotopes, become the focus of the landscape design process. The quantity and size of vegetated patches are important factors determining the biodiversity value of new developments. Some studies report that species diversity increases with patch area (Nielsen et al., 2014; Muratet et al., 2007; Cornelis & Hermy, 2004). In the case of smaller vegetated patches, Godefroid and Koedam (2003) indicated that these can serve as stepping stones or corridors between larger patches for the movement of species. Other key factors for vegetated patches, such as diversity, naturalness, typicality, rarity, fragility and history, also define habitat quality (UCD Urban Institute Ireland, 2008).

Forest biotopes in urban and rural settings were the main focus in this thesis, but other green spaces in the urban context (including lawns, gardens etc.) were also included. Vegetation in public or private ownership was not included. The primary subject of study was biodiversity at species level within habitats, particularly forest biotopes. However, different patterns of habitats were also considered as a whole in order to explore the biodiversity attributes at larger scales.

1.3 The idea and inspiration for this thesis

It has been shown that the prerequisite for a successful strategy in terms of biodiversity-related management or planning is good knowledge of the individual biotopes, their ecological characteristics, locations and distributions, and the configuration of flora and fauna communities (Yilmaz et al., 2010; Sukopp & Weiler, 1988). Knowledge of the interactions between biotopes and their surrounding neighbourhood is also important (Hostetler et al., 2011). Biotope mapping has the potential to provide the necessary information relating to biodiversity in urban and rural settings. However, traditional biotope classification for mapping is based mainly on vegetation physiognomy and phytosociology, with little attention being paid to conditions inside biotopes, so that a subset of biodiversity information could be overlooked (e.g. Gyllin, 2004; Freeman & Buck, 2003).

The aim of this thesis was thus to develop a biodiversity-orientated biotope mapping model and then examine its rationality and validity by a series of literature and case studies. The overall objective was to devise a modified biotope mapping model that could be applied to collect information on biodiversity values in order to support decision making within forest landscape planning and policy.

2 Objectives of the thesis

The hypothesis tested in the thesis was that a biotope mapping model in which temporal and spatial vegetation structural parameters are integrated can be applied to collect biodiversity-orientated information needed to support decision making in forest landscape planning and policy.

Specific objectives were to:

- Develop a biotope mapping model that integrates temporal and spatial vegetation structural parameters, to be used for identifying detailed forest biodiversity characteristics in urban and rural settings.
- Relate the modified mapping model, more specifically the temporal and spatial vegetation structural parameters, to forest biodiversity indicators to test their rationality.
- Test the modified biotope mapping model in both urban and rural settings, targeting different species groups (i.e. birds, mammals and vascular plants in the urban setting and bryophytes, lichens and vascular plants in the rural setting).

The work was guided by the following research questions:

- How can biotope mapping be developed and applied for effectively collecting information on forest biodiversity characteristics in urban and rural settings?
- Which aspect of forest biodiversity do indicators actually indicate and are the vegetation structural parameters included in the mapping model reasonable indicators?
- How can the species diversity/distribution of birds, mammals and vascular plants in urban settings and of plants in general in rural settings be represented using the modified biotope mapping model?

3 Ecological understanding of forest biotopes in urban and rural settings

This chapter provides an overview of forest development in urban and rural settings, with the focus on biodiversity conservation issues.

3.1 Dynamic landscape change accompanying urbanisation and (de)forestation

The world is becoming increasingly urbanised, with about 50% of the global population living within cities and towns in 2008. This proportion is continuing to grow and is estimated to reach 70% by 2050 (UN, 2008). Due to the rapid pace of urban expansion, two opposing patterns of urban development have emerged, particularly in Europe: Urban sprawl into the wider countryside (Zhao et al., 2006; Johnson, 2001) and urban densification through development of vegetated urban spaces (EEA, 2006; CEC, 1999). Urban sprawl and urban densification have both severely affected green spaces within and around cities, and consequently have had profound impacts on biodiversity and ecosystem services.

Similarly, forested land in rural settings worldwide has been developed or utilised disproportionately, with a general decrease in area, because of the imbalanced increasing demands from the growing population (FAO, 2010). In the past 30 years, the international community has begun to pay attention to deforestation, forest degradation and the associated loss of forest biodiversity (Rayner et al., 2010). As a result, the rate of forest loss has slowed in the last decade, especially through establishment of new tree plantations and restoration of natural forests, mainly in Asia and Europe (FAO, 2010). However, forest biodiversity loss still remains rapid and uneven, because the intensive deforestation and forest degradation of recent decades have mostly occurred in biodiversity-rich natural forests in developing countries, e.g. in tropical forests, while the tree plantations established have mostly been even-aged forest monocultures (CBD, 2010; Schulze et al., 2004).

3.2 Biotope mapping for identifying and visualising biodiversity attributes at different scales

Due to the current trend in developments concerning human-disturbed urban and rural landscapes, new ways to approach biodiversity issues are required. Since the Convention on Biological Diversity's Rio Earth Summit in 1992, there has been more focus on ecological and biodiversity values for urban and rural landscapes (e.g. Cilliers et al., 2004). In order to maintain a characteristic flora and fauna and the functionality of ecosystems, spatial planning must consider how proposed land use changes will influence the biotope structure of a certain area (Löfvenhaft et al., 2002). Basic data on the ecological characteristics of individual biotopes and their interconnections are fundamental in answering this question. One of the leading projects to date focusing on landscape ecological issues in terms of basic data collection is the biotope mapping scheme. It was first established in Germany and then spread and developed in other countries as well, such as the UK, Sweden, Turkey, Brazil, Korea, etc. (Mansuroglu et al., 2006; Hong et al., 2005; Freeman & Buck, 2003; Löfvenhaft et al., 2002; Sukopp & Weiler, 1988).

The word 'biotope' in these applications is synonymous with the word 'habitat' and refers to any demarcated area which is endowed with specific environmental conditions and is suitable for particular flora and fauna (Hong et al., 2005). Biotope mapping in turn is the process of identification and specification of existing biotopes and landscape units (Freeman & Buck, 2003; Löfvenhaft et al., 2002; Sukopp & Weiler, 1988). The maps obtained through the method can act as an evidence-based foundation to assist in decision making concerning urban and rural spatial planning on ecological and biodiversity issues (Yilmaz et al., 2010).

Mapping can be employed for all biotopes in a certain area or part of an area, such as urban biotope mapping, forest biotope mapping, wetland biotope mapping, etc. Two mapping methods are usually used: (1) Selective biotope mapping, where only the biotopes worthy of protection are mapped; and (2) comprehensive biotope mapping, where all biotopes are mapped (Sukopp & Weiler, 1988). Field surveys, categorisation of biotopes and evaluation were once the main steps in the mapping process, in which the conditions in the environment, e.g. land use, flora, fauna, soil etc., are evaluated and graded by various ecological values on the map. However, the field surveys have now been largely replaced by the more advanced technique of GIS-based interpretation of remote sensing data, which is a more time- and cost-efficient method for assessing, characterising and updating biotope maps than the conventional field survey (Yilmaz et al., 2010).

Biotope mapping initially targeted the protection of rare species and valuable habitats in specific contexts, but the focus has gradually shifted to a wider range of applications concerning e.g. landscape planning, delineation of protection zones, design of corridors or biotope linkage networks, environmental impact assessment and environmental management for urban and rural ecosystems (Hong et al., 2005; Weiers et al., 2004). However, the mapping method applied to ensure planning quality on biodiversity and to consider landscape changes still needs to be improved.

Poor and non-homogeneous compilations of biodiversity-orientated information on the structure, type, size and quality of biotopes through the existing mapping process have been identified as a major constraint for the implementation of biodiversity conservation strategies (Weiers et al., 2004). In response to different applications of biotope mapping, a well-structured classification of biotopes has been developed to provide a fundamental basis for most biotope classifications used in practice, but it mainly focuses on land use and habitat type (Werner, 1999).

Temporal and spatial vegetation structure has not been comprehensively taken into account in this classification, especially concerning forest biotopes and their interactions with their environmental context, which has been shown to be closely related to biodiversity. For example, Berglund and Jonsson (2001) found that tree canopy coverage is positively correlated with species richness of polypore and crustose lichens in old-growth spruce forest in northern Sweden. Jukes et al. (2001) found that the composition of the ground beetle community changes with vertical stratification in coniferous plantations in the UK, while vertical stratification is negatively correlated with ground beetle species richness. Gil-Tena et al. (2009) concluded that forest bird species richness increases with stand age in Mediterranean forest ecosystems in Catalonia. Other studies have demonstrated that forests with long continuity display higher species richness of vascular plants and lichens, and also have different species composition of lichens and bryophytes than forests without continuity (e.g. Fritz et al., 2008). The success of biodiversity conservation in urban and rural areas could be greatly improved if temporal and spatial vegetation structure information were to be integrated into the biotope mapping scheme.

3.3 Target biodiversity and its indicators

When focusing on biodiversity conservation, it should be borne in mind that although methods, e.g. biotope mapping, may have been devised for measuring biodiversity in urban and rural settings, these are useless unless the specific goals of spatial planning concerning biodiversity are known. Therefore, desired aspect(s) of biodiversity should be specified in the first phase of the planning process. However, a full assessment of the target biodiversity could in most cases be difficult and costly, especially on large scales. Therefore surrogate measures (i.e. indicators) are increasingly being used to monitor temporal and spatial changes in biodiversity (Boutin et al., 2009).

In this thesis, a key step in the study of biodiversity indicators in forest ecosystems was to explore the correlation between an indicator of forest biodiversity and its indicandum (i.e. the aspect of biodiversity indicated). In a later step, studies were conducted to explore whether including the temporal and spatial vegetation structural parameters in the modified biotope mapping model improved its function. This work concentrated on forest ecosystems, but could also be a stepping stone for research studying biodiversity indicators in other ecosystems, e.g. grassland, wetland etc.

The target biodiversity, i.e. the indicandum for the indicators studied, chosen in this thesis for urban settings when testing the biotope mapping model was vascular plants, birds and mammals. This is because birds and mammals are widely monitored taxa worldwide and prone to respond to environmental change (Sullivan et al., 2011; Henry et al. 2008). In addition, they have great public resonance and thus are good at raising awareness of biodiversity issues (Eglington et al., 2012). When considering rural settings, plant diversity in general, including vascular plants, bryophytes and lichens, was chosen as the target biodiversity in tests of the biotope mapping model. This is because studies of ecosystems such as rural agricultural and mountain landscapes have shown that plant species diversity is the foundation upholding other types of biodiversity (e.g. Bräuniger et al., 2010; Sauberer et al., 2004; Simonson et al., 2001).

4 Research design and methodology

4.1 Research framework

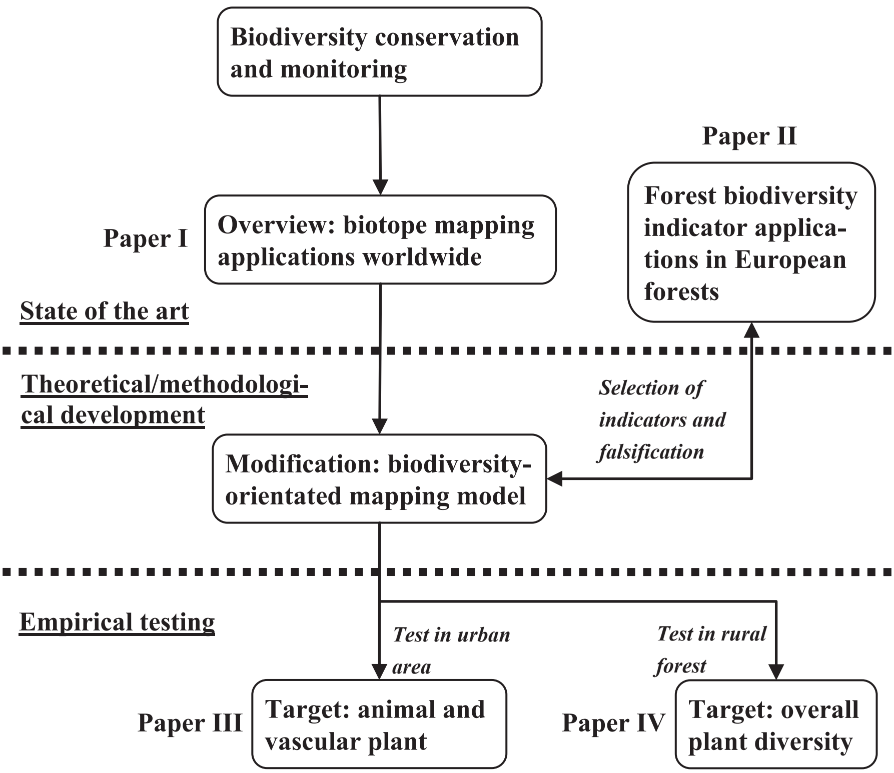


Figure 1. Research framework of the thesis according to papers I-IV

4.2 Methodology

The overall research design used in this thesis (see Figure 1) has similarities with the positivistic school, where a ‘hypothesis’ is proposed, in this case theoretical development of the biotope mapping model (especially highlighting forest biotopes). This is then examined for falsification in different tests, here in relation to biodiversity indicators (Paper II), in a test in urban green spaces (Paper III) and in a test in rural forest biotopes (Paper IV). In the latter two studies, the tests followed the principle of induction, i.e. statistical testing of empirical data to identify patterns that validate/falsify the modified biotope mapping model. The assessment of strength of evidence for forest biodiversity indicators also followed inductive principles, where strength of evidence for each indicator was summarised from individual studies throughout Europe.

The inductive principle is a process in which research starts with observations and data collection and theories are formulated towards the end of the research, based on observations (Goddard & Melville, 2004). Inductive research involves the search for patterns in observation and the development of explanations (theories) for those patterns through series of hypotheses (Bernard, 2013). The inductive principles were applied in the literature review and case studies in this thesis. A literature review is a type of scholarly research reporting substantive findings and methodological contributions to a particular topic based on secondary sources (Baglione, 2012). A case study usually employs a combination of different methods, designed to describe and understand the complexity of particular cases. Many researchers regard case studies as offering a particularly useful approach in fields of research that are practice-orientated and deal with “real world contexts”, such as landscape architecture, architecture and planning (Johansson, 2005; Francis, 2001). In this thesis, the ‘hypothesis’, i.e. the modified biotope mapping model for biodiversity information collection, was created through the literature review process and its validity was tested through the case study process.

4.3 Method used in each study

In the first phase of the thesis work (Paper I), a methodological study was carried out on biotope mapping and development of a biotope classification system focusing on biodiversity. Based on an extensive literature review, this study examined questions concerning the main changes of the perspectives on biotope mapping and the importance of the biotope mapping approach in producing functional information to be used when promoting biodiversity. Based on the ‘observations’ made, a modified biotope classification system involving the concept of vegetation structure (with the main focus on forest biotopes) was suggested as an important step for guiding the following studies.

The modified mapping model was related to forest biodiversity indicators in a study based on a qualitative meta-analysis method (Paper II), in order to validate the structural parameters integrated in the mapping model in a biodiversity perspective. The aim was to obtain a broad picture of interrelationships between forest biodiversity indicators and their indicandum (i.e. aspect/s of biodiversity indicated). The study examined whether vegetation structural parameters could be good indicators of at least some aspects of biodiversity. However, the function of the modified biotope mapping model in collecting biodiversity information on birds, mammals and plants was not thoroughly studied, so two further studies were conducted.

In separate cases studies, the modified mapping model was tested for its utility in targeting different species groups in urban settings (for birds, mammals and vascular plants) (Paper III) and rural settings (for bryophytes, lichens and vascular plants) (Paper IV). Both these case studies involved statistical analysis of empirical data (data from a direct field survey in Paper III and from a large landscape database in Paper IV) with the aim of identifying patterns that might validate the modified biotope mapping model. Paper III examined whether the modified mapping model could be used for collecting detailed information about biodiversity, e.g. the abundance and distribution of animals and the diversity of vascular plants. Paper IV compared forest stand structure types in relation to their plant species diversity and composition, and examined whether these structural types could provide fundamental information for the processes of biodiversity-orientated landscape management and planning.

All methods used are summarised below in relation to the results obtained. Full details of the methods used in each study can be found in the respective paper.

5 Summary of results in Papers I-IV

In this chapter, the key findings of Paper I-IV are summarised and discussed. For a more in-depth description of all results see Papers I-IV, which are appended to this thesis.

5.1 Development of biotope mapping method with a proposal for biodiversity data collection (Paper I)

Based on a review of literature from throughout the world and a case-based analysis, in Paper I the development and application of biotope mapping in nature conservation to date was described and new perspectives on biotope mapping in relation to biodiversity values were addressed. The objectives of the study were twofold: (1) To present the state of the art concerning the application of biotope mapping in nature conservation; and (2) to use the findings to develop a modified biotope mapping model integrating the concept of vegetation structure when collecting biodiversity-orientated information.

5.1.1 Historical development of the biotope mapping method and its application

Since the 1980s, biotope mapping has been increasingly used as a tool in spatial planning and nature conservation in different states in Germany. By the year 2000, more than 2000 German cities and towns had implemented biotope mapping for ecological planning on different scales (Schulte & Sukopp, 2000). Owing to the function of biotope mapping in supplying biological and ecological information for research areas, many countries e.g. the UK, Sweden, Turkey, Japan, Korea, New Zealand, Brazil etc. have also used this method for providing basic ecological information in their planning (Mansuroglu et al., 2006; Lee et al., 2005; Freeman & Buck, 2003; Löfvenhaft et al., 2002; Müller & Fujiwara, 1998; Weber & Bedê, 1998; Greater London Council, 1985).

However, the applications of the method and its capability for coping with biodiversity conservation in spatial planning have changed over time.

5.1.2 Biotope mapping approaches and perspectives

Two major approaches have been used for biotope mapping: selective mapping (only 'valuable' biotopes are mapped) and comprehensive mapping (all biotopes in a given area are investigated). The perspectives of biotope mapping have changed from the protection of valuable biotopes for rare and endangered species to a more modern nature conservation strategy that also considers ordinary biotopes in efforts to maintain and increase biodiversity as a component of human daily life (Cornelis & Hermy, 2004; Breuste, 1999; Gibson, 1998). In order to accomplish these goals, comprehensive surveys of all land parcels are necessary, especially of common and small-scale biotopes close to people's living places that still have potential biodiversity values.

Biotope mapping nowadays has been adopted by an increasing number of countries in order to develop a view on sustainable urban development, in which biodiversity is an important component (Lee et al., 2005). For example, according to the Swedish Planning and Building Act (Amended January 1996), the maintenance of biodiversity in urban areas is one of the Swedish environmental quality objectives (Regeringens Proposition (Government Bill), 1997/1998, p. 145). Stockholm City Planning Administration has developed a biotope mapping model for the spatial planning of biodiversity issues in Stockholm. The model designates core areas, connectivity zones, buffer zones and green development areas according to identification of different values of target biotopes in green and built-up areas. The relevant strategies adapted to priorities in spatial planning of biodiversity are presented (Löfvenhaft et al., 2002).

Spatially complete biotope mapping has also been pioneered in New Zealand by Freeman and Buck (2003), who aimed to produce a map that would accommodate the diverse characteristics of highly modified habitats in Dunedin and would incorporate all types of space ranging from indigenous habitats (e.g. forest), to exotic habitats (e.g. lawns and residential gardens). The biotope map, which displayed key habitat types and their relative qualities, was used as a basis for developing an overall open space strategy for the city. A German study showed that biotope mapping has been used in very diverse ways (Werner, 2002), primarily for: (1) Habitat protection; (2) green space planning; (3) landscape planning and (4) measures for species protection (Figure 2). Biodiversity conservation is one of the main purposes of all these applications.

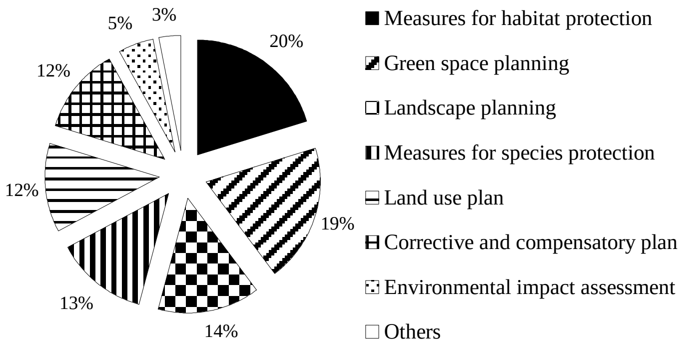


Figure 2. Use of results from urban biotope maps (modified from Peter Werner, 2002)

5.1.3 Drawbacks of the current biotope mapping model for biodiversity information collection

Paper I revealed that the core information in mapped biotopes depends not only on the mapping approaches and perspectives used, but also on the classification of biotopes. The latter fundamentally determines the type and depth of information collected for biotopes, for example green space can be categorised into forest, grassland etc., and forest can be further categorised into e.g. beech forest, oak forest etc. Most biotope classifications are primarily divided into land use types and habitat types (Bastian, 2000). For example, Gyllin (2004) constructed a biotope classification based on a certain number of land use categories, such as "industrial sites", "residential areas", "public green spaces (amenity areas)", "forest", etc. These main categories were further subdivided into a maximum of five levels, giving higher resolution and more detail. For example, "forest" was subdivided on the lowest level characterised by dominant species, such as "oak forest", "elm forest", "poplar forest", "beech forest", etc. However, vegetation structural aspects have been given little consideration in biotope classifications to date.

5.1.4 Modification of the biotope mapping model for biodiversity information collection

Vegetation structure in relation to biodiversity values has been explored by many studies, as mentioned in Chapter 3. The literature shows that vegetation structure has a close relationship with biodiversity, from flora to fauna communities (Pinna et al., 2009; Fritz et al., 2008; Sandström et al., 2006; Ichinose, 2003; Berglund & Jonsson, 2001; Wirén, 1995). Therefore, a biotope classification method integrated with vegetation structural variables for urban and rural biodiversity assessment was devised (Table 1). The structural variables include: (1) age, i.e. annual (biennial) and perennial for sparsely wooded areas, or young, middle-aged and old for wooded areas; (2) horizontal structure, i.e. the projection of vegetation pattern and plant configuration on the ground in terms of the canopy cover of trees and shrubs; and (3) vertical structure, i.e. the vertical stratification in terms of height of different plant groups, including one-layered (tree canopy layer), two-layered (any combination of shrub layer, middle layer and tree canopy layer) and multi-layered (more than two layers).

The classification system proposed in Paper I identifies land cover type of an area in terms of vegetation structure variables, regardless of land use or habitat type of the area. The system starts from the division between grey space (dominated by built-up area), green space (dominated by vegetated area) and blue space (dominated by water area). The grey space category is designed to identify the presence of abiotic surfaces and associated vegetation patterns. The green space category is composed of vegetation patterns and structures. There are five subclasses in this category, which identify the hydrology of the soil conditions, the horizontal structure, age, plant type (deciduous/broad-leaved or evergreen/coniferous) and the vertical structure (Table 1). Little structure is involved in the blue space category.

The modified biotope mapping model is able to: (1) Facilitate a comprehensive survey in urban and rural settings for collecting detailed structural information which may reflect the status of different species groups; (2) reflect the values of small-scale biotopes which are usually overlooked in practice, e.g. private gardens, a solitary old grove with broad crown trees etc.; and (3) be applied to different site situations and scales, e.g. by adjusting the vegetated coverage and age profile. However, this modified mapping model first had to be applied in practice to test its validity.

Table 1. *Proposed hierarchical order of biotope categories: Level 1-Level 6*

Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
***Grey space*:** Areas mainly covered by abiotic matter, such as construction, extraction sites, beaches *etc*.	% abiotic	Mainly trees/shrubs	Young trees Middle-aged trees Old trees	Deciduous (D) Evergreen (E) Mixed D&E	–
		Mainly herbaceous vegetation	Annual (biennial) Perennial	Short-cut grass/tall grass Vegetable/flower gardens	–
		Minimal/no vegetation	–	–	Buildings/pavement Exposed earth/rock/sand
***Green space*:** Vegetated land or water in or adjoining an urban area, which may contain small-lot abiotic surfaces.	Xerantic to mesic soil Mesic to wet soil	Open green area (<10% canopy cover of trees/shrubs) Partly open green area (10-30% canopy cover of trees/shrubs)	Annual (biennial) Perennial	–	Short-cut grass/tall grass Mosses/lichens Emergent plants
		Partly closed green area (30-80% canopy cover of trees/shrubs) Closed green area (>80% canopy cover of trees/shrubs)	Young trees Middle-aged trees Old trees	Deciduous Evergreen Mixed D&E	One-layered Two-layered Multi-layered
***Blue space*:** Open water with no emergent vegetation.	River/stream/pond/lake/ wetland open water	Submerged plants Floating leaved plants	–	–	–

5.2 Application of biodiversity indicators: Forest ecosystems as an example (Paper II)

In relation to the modified mapping model developed in Paper I, an intensive literature review of forest biodiversity indicators was carried out in Paper II. The aims were to determine the application status of forest biodiversity indicators in European forests and to test the validity of the modified mapping model, i.e. whether the vegetation structural elements integrated into the model are capable of reflecting certain aspects of biodiversity. Specific objectives were to: (1) Explore correlations between indicators and their indicandum; and (2) assess the strength of evidence for each indicator studied.

5.2.1 Definition of biodiversity indicators

Because biodiversity is a broad concept, it is clear that everything concerning biodiversity cannot be measured directly. Instead, a few variables must be selected to represent key components of biodiversity (Ferris & Humphrey, 1999), just as the temporal and spatial vegetation structural parameters do in the modified biotope mapping model. These representative elements are called biodiversity indicators. In Paper II, biodiversity indicators were further divided into: (1) Species/compositional indicators, i.e. the presence of species and the diversity of variety of species in a collection are able to reflect those of other species/taxa in the community; and (2) structural indicators, i.e. the presence of structural elements/physiognomy of forest and fluctuations in these are able to reflect certain species/taxa in the community.

5.2.2 Materials and methods

A literature search was conducted in the two major scientific databases Scopus and Web of Science with a combination of key words: forest* AND biodiversity AND indicator* (* indicating wild card, i.e. any ending possible). When dealing with eligible studies, a mind mapping method was applied to analyse evidence of correlations between indicator and indicandum. Mind mapping is a technique in which analytical processes are visually represented by connecting concepts and ideas related to a central issue or problem (Buzan, 1995). The maps produced provide insights into the manner in which people organise knowledge by capturing concepts deemed relevant to a particular problem (Kern et al., 2006). In the present case, each indicator group was placed as a single concept in the centre of the mind map and branches were drawn to represent related sub-concepts, i.e. individual indicators. These sub-concepts were further linked with their respective indicandum by different patterns of arrow lines illustrating strength of evidence and scale/s at which the indicators were tested. Therefore, the mind maps allowed evidence of correlations to be viewed visually and holistically (see Figure 5a and 5b).

5.2.3 Main results

Among the 133 papers included in the review, 10 groups of forest biodiversity indicators and 83 individual indicators correlated with 51 indicandums were identified on various scales. Of the 133 papers, 39 (29.3%) were reviews and conceptual studies (i.e. not based on direct data collection) and 94 (70.7%) were papers reporting results from empirical studies based on data collection in 21 different European countries. As shown in Figure 3, 18 of the empirical were conducted in Sweden, involving nine indicator groups with 36 individual indicators. A further 10 empirical studies, which involved all 10 indicator groups and 29 individual indicators, were conducted in Italy, while nine studies were conducted in Finland, eight in Spain, seven in France and six in Germany. In the remaining countries, less than five studies met the inclusion criteria and only seven studies were based on data collected across European countries.

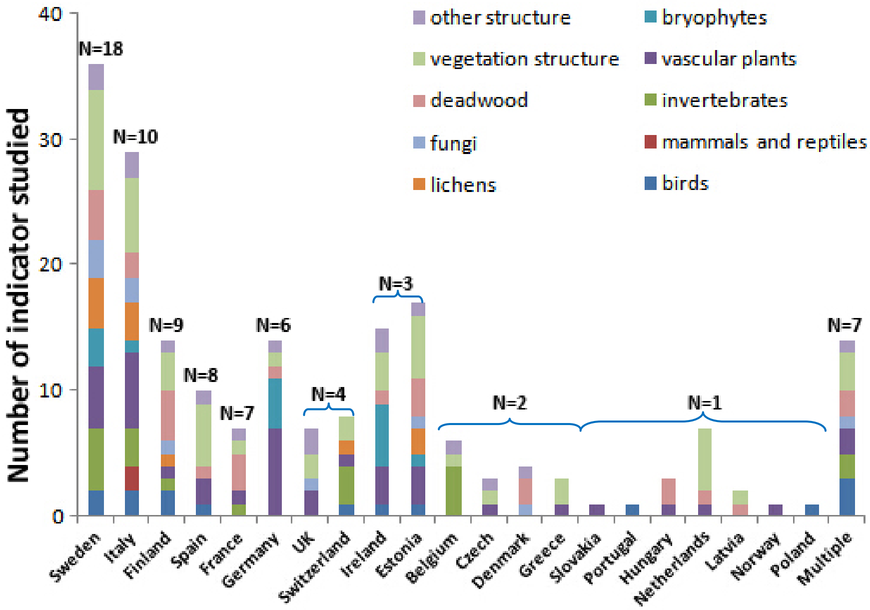


Figure 3. Categorization of studies of forest biodiversity indicators according to the summarized indicator groups and countries in which the study was conducted. "N" refers to the number of articles from each country or multiple countries.

As shown in Figure 4, structural indicators, i.e. deadwood (n=58), vegetation structural indicators (n=45) and other structural indicators (n=54), were the most studied indicator groups. Among species/composition indicators, vascular plants (n=40) and birds (n=31) were most commonly studied. The beetle indicator was mainly studied among invertebrate indicators, with 14 out of 22 studies. Mammals and reptiles (n=12), fungi (n=15) and bryophytes (n=16) were the least studied indicator groups (Figure 4).

Surprisingly perhaps, 59 (44.4%) of the 133 studies did not test for statistical correlations between indicator and indicandum. Of these 59 studies, 39 did not even present a clear indicandum. More than half of all studies about birds, vascular plants and deadwood indicators included no scientific testing. The proportion was even lower for mammals and reptiles, where only one study out of 12 tested the validity of the indicators (Figure 4).

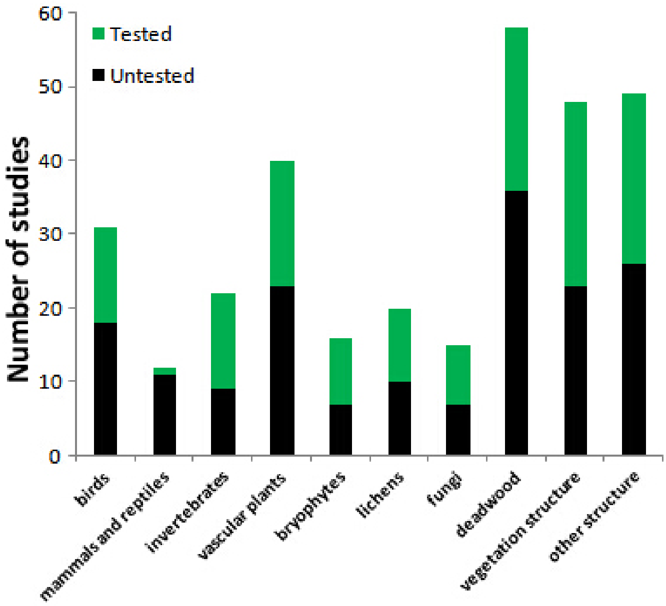


Figure 4. Percentage of total numbers between statistically tested and untested studies in terms of biodiversity indicator groups

As for correlations between indicator and indicandum, a total of 405 correlations were identified, of which most were assessed as having no indicator value (n=197, at various scales) or weak evidence (n=211, all at stand scales), while 16 correlations were assessed as having moderate evidence (Figure 5a and 5b, Figure 6). Only six correlations (five in terms of species richness/diversity and one in terms of species composition) were assessed as having strong evidence, all in tests conducted at stand level (Table 2, Figure 6).

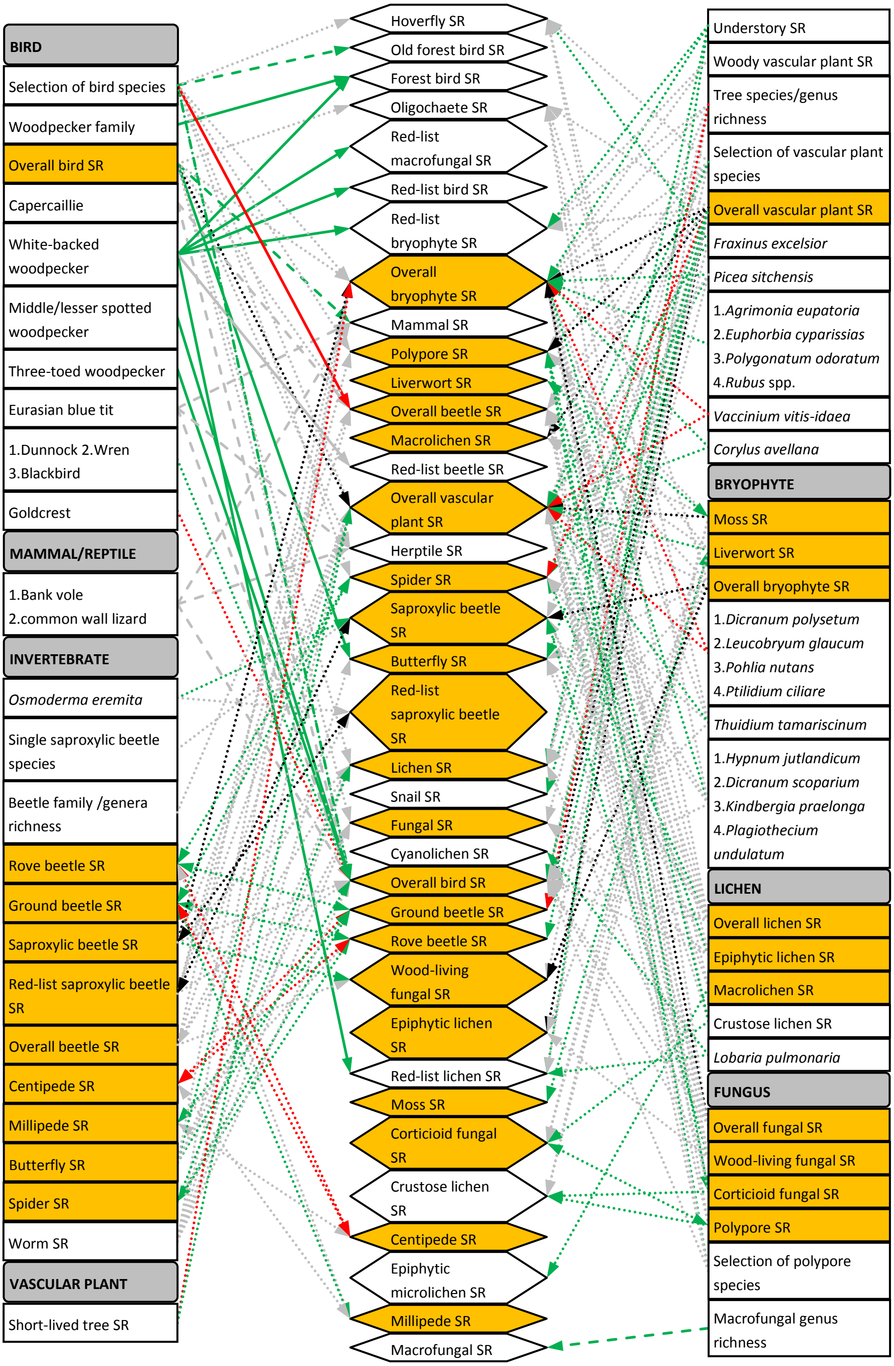


Figure 5a. Correlation between species/composition indicators and their indicandums

The complexity of the correlations between indicator and indicandum are shown in Figure 5a and 5b, where rectangles denote the indicator and hexagons the indicandum, orange highlights stand for both indicator and indicandum. Green arrows represent positive correlations between indicator and indicandum; red arrows represent negative correlations; grey arrows represent no correlation found between indicator and indicandum, and black arrows represent contradictory correlations found in different studies. The diagrams also show the scales at which the indicators were tested, with dotted, dashed and solid lines representing tests on stand, forest and landscape scale, respectively.

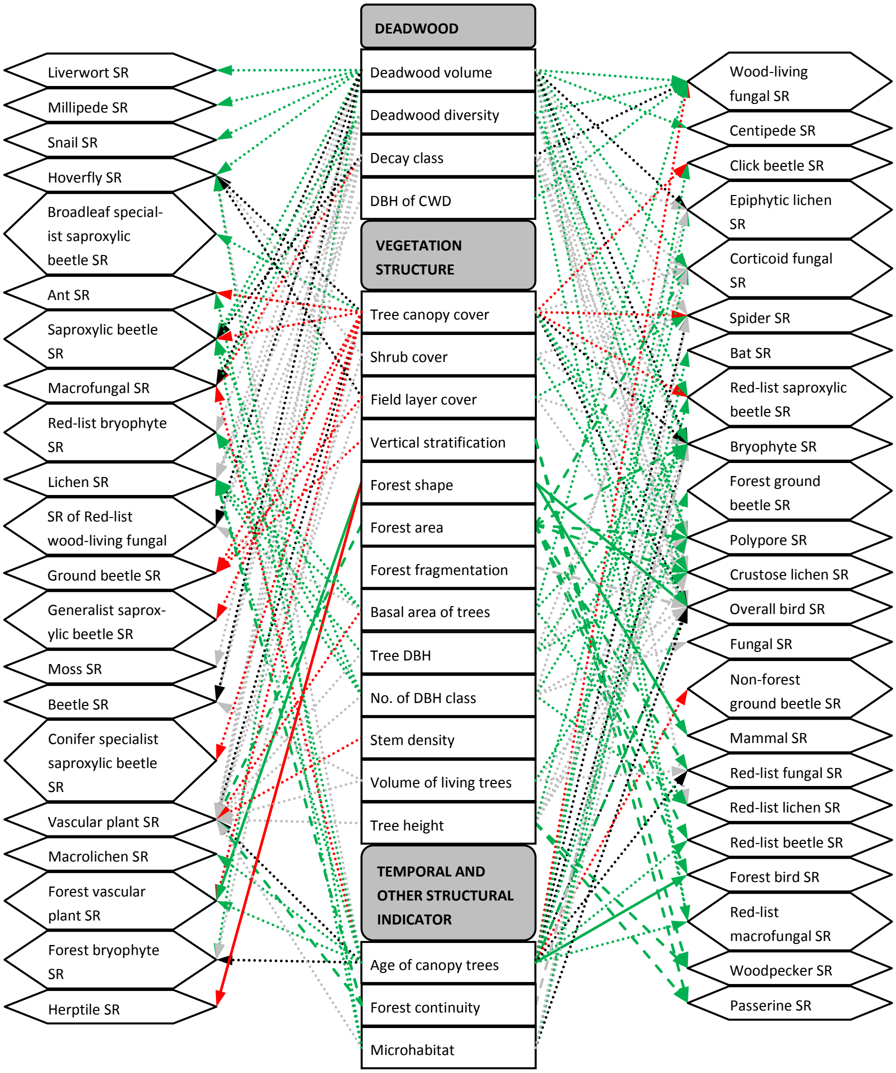


Figure 5b. Correlation between structural indicators and their indicandums

Of the six correlations for which there was strong evidence, five (four in terms of species richness and one in terms of species composition) demonstrated a positive correlation. These were between: (1) Deadwood volume and wood-living fungal species richness (four studies conducted in northern and southern Europe); (2) deadwood volume and saproxylic beetle species richness (one study each in Italy, Finland and Germany, three studies in France and two studies conducted across countries); (3) deadwood diversity and saproxylic beetle species richness (two studies in France and another two studies in Finland and Sweden); (4) age of canopy trees and epiphytic lichen species richness (two study each from Italy and Sweden); and (5) age of canopy trees and epiphytic lichen species turnover (two study each from Italy and Sweden) (Table 2, Figure 6). There was strong evidence of a negative correlation between tree canopy cover and spider species richness (three studies, all in Ireland) (Table 2, Figure 6).

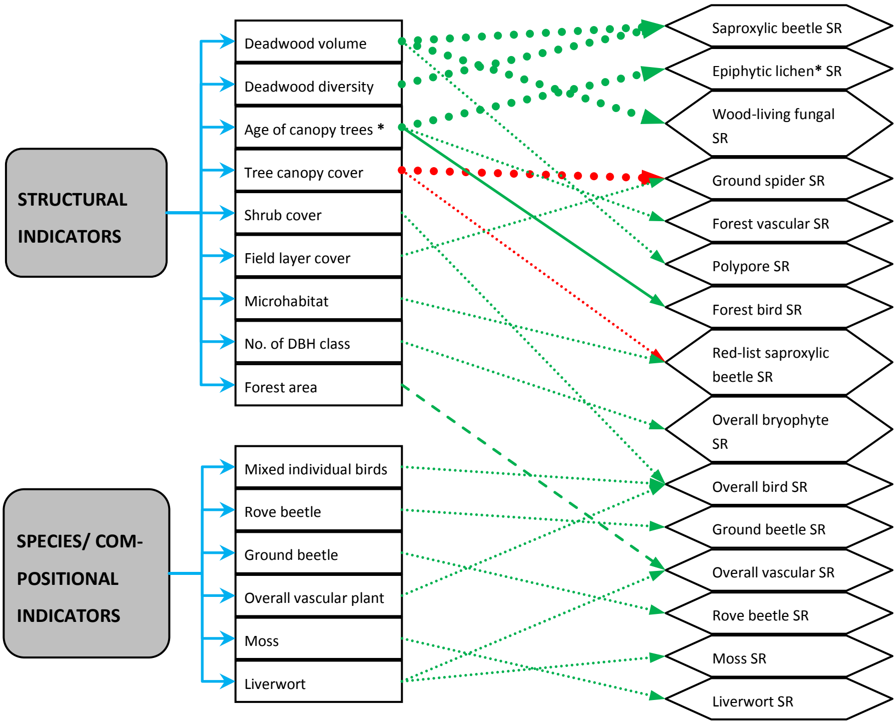


Figure 6. Correlation with strong evidence (bold arrow lines, n=5) and moderate evidence (fine arrow lines, n=16) between indicators and their indicandums. Rectangle denotes indicator, and hexagon denotes indicandum. Green arrow represents positive correlation, and red arrow represents negative correlation. Dotted-lines represent on a stand level, dashed-lines represent on a forest level, and solid-lines represent on a landscape level. Asterisk (*) means that species composition of indicandum changes with the configuration of structural indicator.

The results confirmed that the modified biotope mapping model with the selected vegetation structural parameters integrated, i.e. horizontal structure, vertical structure and age of trees, was able to reflect a spectrum of biodiversity, although no strong evidence was found that vertical structure indicated a specific aspect of biodiversity. However, this was mostly because of the low number of replicate studies testing vertical vegetation structure. The results also indicated that birds and plants were the most tested indicandum of biodiversity at different scales, although none of the individual indicators listed was found to have strong evidence of indicating the diversity of birds and plants. To examine whether the modified mapping model can contribute to capturing the status of bird and plant species, further tests were thus carried out in the case studies.

Table 2. *Most tested correlations concerning species richness/abundance/composition between indicator (x-axis) and indicandum (y-axis). “S”, “M”, “W” and “N” denote Strong, Moderate, Weak evidence and No indicator value, respectively. Superscript letters “S”, “F” and “L” denote Stand, Forest level and Landscape scale, respectively. Asterisk * indicates that species composition of indicandum changes with species composition of species indicators or with configuration of structural indicators. Underlining, i.e. “$\underline{\ \ }$” and “$\underset{\sim}{\ \ }$”, indicates that the correlation was tested by ≥3 studies and by 2 studies, respectively.*

	Overall bird	Red-list bird	Forest bird	Old forest bird	Woodpecker	Passerine	Mammal	Herptile	Bat	Overall beetle	Red-list beetle	Saproxylic beetle	Red-list saproxylic beetle	Conifer specialist saproxylic beetle	Broadleaf specialist saproxylic beetle	Generalist saproxylic beetle	Rove beetle	Click beetle	Ground beetle	Forest ground beetle	Non-forest ground beetle	Ant	Ground-dwelling spider	Butterfly	Snail	Centipede
Overall vascular plant	$\underset{\sim}{M}^{S}$									N^{S}		N^{S}					W^{S} W^{*S}		$\underset{\sim}{W}^{S}$ W^{*S}				W^{S} W^{*S}	W^{S} W^{*S}	W^{S} W^{*S}	
Deadwood volume	$\underline{N}^{S}$									$\underline{W}^{S}$ W^{*S}		$\underline{\mathbf{S}}^{S}$											$\underset{\sim}{N}^{S}$		W^{S} W^{*S}	W^{S} W^{*S}
Deadwood diversity	$\underset{\sim}{N}^{S}$									$\underset{\sim}{N}^{S}$		$\underline{\mathbf{S}}^{S}$														
Decay class	$\underline{N}^{S}$									$\underset{\sim}{N}^{S}$		$\underline{W}^{S}$														
Tree canopy cover	$\underset{\sim}{W}^{S}$											W^{S}	$\underset{\sim}{M}^{S}$	W^{S}	W^{S}	W^{S}		W^{S}	W^{S} W^{*S}			W^{S}	$\underline{\mathbf{S}}^{S}$			
Age of canopy trees	$\underline{W}^{S}$		$\underset{\sim}{M}^{L}$								W^{S}							W^{S}		W^{S}	W^{S}	W^{S}	$\underline{W}^{S}$			

Table 2 continued.

	Hoverfly	Millipede	Oligochaete	Overall vascular plant	Forest vascular plant	Overall lichen	Red-list lichen	Epiphytic lichen	Crustose lichen	Cyanolichen	Macrolichen	Epiphytic microlichen	Overall fungus	Red-list fungus	Polypore	Corticioid fungus	Macrofungus	Red-list macrofungus	Wood-living fungus	Red-list wood-living fungus	Overall bryophyte	Red-list bryophyte	Forest bryophyte	Moss	Liverwort	**Sum of indicandum**
Overall vascular plant			N^S			N^S W^{*S}		$\underset{\sim}{W}^S$	N^S		$\underset{\sim}{W}^S$		$\underset{\sim}{N}^S$		$\underset{\sim}{W}^S$ W^{*S}				N^S		$\underline{W}^S$ W^{*S}			W^S	W^S	**19**
Deadwood volume	W^S	W^S W^{*S}		$\underline{N}^S$		N^S	N^S	$\underset{\sim}{W}^S$	N^S						$\underset{\sim}{M}^S$	W^S	$\underline{W}^S$	W^S	$\underline{\mathbf{S}}^S$	$\underset{\sim}{W}^S$	$\underline{W}^S$	N^S	W^S	N^S	W^S	**24**
Deadwood diversity				$\underset{\sim}{N}^S$		N^S									W^S		W^S		W^S		W^S					**9**
Decay class				$\underline{N}^S$		$\underset{\sim}{N}^S$		N^S	N^S						N^S	N^S	W^S	W^S	$\underline{W}^S$	N^S	$\underline{N}^S$					**14**
Tree canopy cover	$\underset{\sim}{W}^S$			$\underline{W}^S$	W^S				W^S						W^S	N^S					$\underline{W}^S$		N^S			**18**
Age of canopy trees	N^S			$\underline{W}^S$	$\underset{\sim}{M}^S$			$\underline{\mathbf{S}}^S$ $\underline{\mathbf{S}}^{*S}$			W^S	W^S		$\underset{\sim}{W}^S$			W^S	W^S	W^S		$\underline{W}^S$ W^{*S}		$\underset{\sim}{W}^S$			**20**

5.3 Test of the modified biotope mapping model for urban biodiversity assessment: Birds, mammals and vascular plants (Paper III)

In order to evaluate the functionality of the modified biotope mapping model proposed in Paper I in practical biodiversity assessment, a case study was conducted in Helsingborg city, southern Sweden (Paper III). The indicandum of biodiversity used in Paper III was birds, mammals (rabbits) and vascular plants, and the hypothesis was that biotope mapping could be more useful for collecting detailed information about biodiversity values, e.g. distributions of birds and rabbits, species diversity of vascular plants etc., when structural parameters are added to the mapping model.

5.3.1 Study area and mapping process

Although no strong evidence was found, the results in Paper II showed that forest continuity is related to plant species richness/diversity (i.e. vascular plants and lichens), which can be considered vegetation temporal structures. Helsingborg city has relatively detailed historical materials concerning dynamic changes in the city landscape, so in Paper III, which used this urban setting as the background for the test, the biotope classification of green space was further refined by integrating the attribute of forest continuity (Table 3). The refined biotope classification, which included four structural parameters, i.e. age of dominant trees, horizontal structure, vertical structure and forest continuity, was then applied to a green structure system in Helsingborg city (Figure 7). Based on the site situation, age was divided into three groups, i.e. less than 30 years, 30-80 years and more than 80 years. Horizontal structure features in terms of canopy cover ratio were identified using aerial photos and vertical structure features in terms of the vertical stratification of trees and shrubs were identified in field surveys. Forest continuity was identified using Ancient Woodland Indicator (AWI) species with historical maps and records. The presence of AWI species in woodland inventories can be taken as evidence of a long continuity of woodland cover (Rose, 1976).

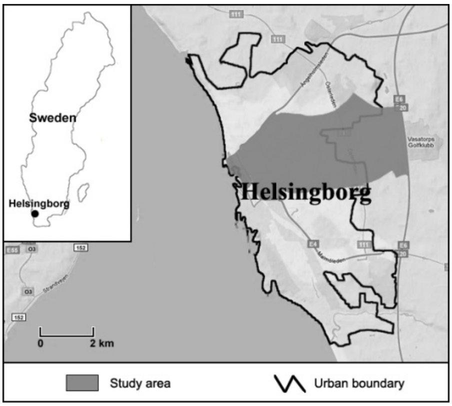


Figure 7. Location of study area for Paper III

Table 3. *Refined biotope classification involving four structural variables shown for green spaces*

Level 1	**Level 2 (horizontal)**	**Level 3 (age and continuity)**	**Level 4**	**Level 5 (vertical)**
Green spaces	Open green area <10% trees/shrubs	With lawn area With grazed land area With meadow area With succession area	Dry/Fresh/Wet	Poor/Rich
	Partly open green area 10-30% trees/shrubs	With lawn area With grazed land area With meadow area With succession area	Dry/Fresh/Wet	Mainly shrubs Mainly trees Mixed
	Partly closed green area 30-80% trees/shrubs	Less than 30 years (with or without AWI species) 30-80 years (with or without AWI species) More than 80 years (with or without AWI species)	Deciduous (D) Mixed D&C Conifer (C) Swamp	One-layered Two-layered Multi-layered
	Forest >80% trees/shrubs >10 000 m^2 (more than 50 m across)	Less than 30 years (with or without AWI species) 30-80 years (with or without AWI species) More than 80 years (with or without AWI species) Clear cut (with or without AWI species)	Deciduous (D) Mixed D&C Conifer (C) Swamp	One-layered Two-layered Multi-layered
	Grove, clump of trees, thicket, tree belt or avenue (less than 50 m across)	Less than 30 years (with or without AWI species) 30-80 years (with or without AWI species) More than 80 years (with or without AWI species)	Deciduous (D) Mixed D&C Conifer (C) Swamp	One-layered Two-layered Multi-layered

Through interpretation of panchromatic aerial photographs and field survey data on the biotope classification, a set of biotope maps integrating vegetation structural attributes was plotted based on GIS (Figure 8 and Figure 9).

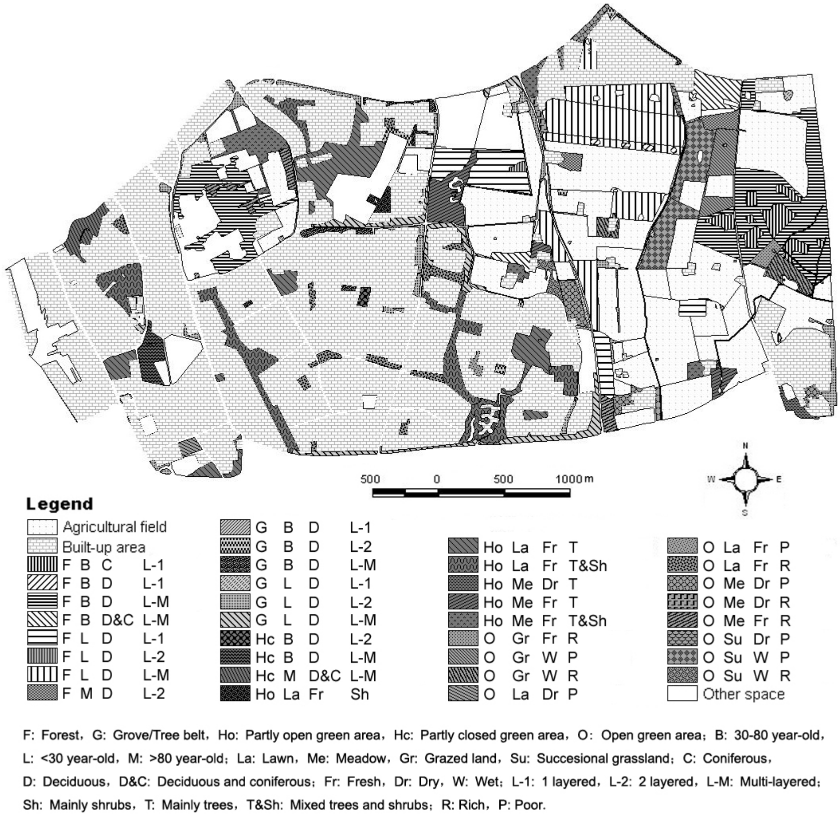


Figure 8. Finest level of biotope map in Helsingborg. The smallest mapping unit is 1000 m^2.

The maps revealed that different types of biotope were represented by different legend patterns and that the interpretation of each pattern could be coarse (see *e.g.* ‘partly closed green area’ in Figure 9) or fine (see *e.g.* ‘HcBD L-2’ in Figure 8, *i.e.* two-layered middle-aged deciduous partly closed green area) according to the level of the biotope classification (Table 3). This means that green space information of differing depth in terms of structural vegetation pattern can be visually displayed in a series of biotope maps.

Figure 9. Biotope map in Helsingborg based on horizontal structure (Level 2)

5.3.2 Methods for testing the validity of the modified biotope mapping model

Questions arising were whether these biotope maps reflect biodiversity information and which aspect of biodiversity they depict. Therefore, an evaluation was carried out in order to test the effect of the mapping method, which examined two aspects in particular: (1) Comparison of species diversity of vascular plants between long-continuity and short-continuity forests; and (2) spatial distribution of animals in the green space in relation to horizontal, vertical and age structure.

The evaluation concerning woodland continuity was conducted by making inventories of vascular plants within nine sample plots (four long-continuity and five short-continuity sites) of similar size, age and structure. The sample plots were selected according to their identification as long-continuity or short-continuity woodland sites based on AWI species (Table 4) and historical documents. Number of vascular plant species (NVPS), Shannon's Diversity Index (SHDI) and Simpson's Diversity Index (SIDI) were used to calculate the species richness of each plot. An independent samples T-test was used to compare the species richness between long-continuity and short-continuity sites.

Table 4. *Ancient woodland indicator (AWI) species list selected from three sources (Peterken, 2000; Rose, 1999; Brunet, 1994)*

AWI species name			
Actaea spicata	*Cardamine bulbifera*	*Milium effusum*	*Stachys sylvatica*
Adoxa moschatellina	*Circaea lutetiana*	*Oxalis acetosella*	*Stellaria holostea*
Allium ursinum	*Galium odoratum*	*Paris quadrifolia*	*Stellaria nemorum*
Anemone nemorosa	*Hedera helix*	*Polygonatum multiflorum*	*Valeriana dioica*
Campanula latifolia	*Maianthemum bifolium*	*Pulmonaria obscura*	*Viola reichenbachiana*
Campanula trachelium	*Melica uniflora*	*Pulmonaria officinalis*	

As for the spatial distribution of animals, various structural factors which could affect the target animals, *i.e.* small birds, medium-sized birds, large birds and rabbits, were analysed. The observations focused on the distribution of animals in the green areas in relation to spatial vegetation structure, mainly horizontal. In open and partly open green areas, the distances between animals and the nearest trees or shrubs were measured. The numbers of animal species observed within forests and partly closed green areas were also recorded.

5.3.3 Main results

The NVPS ranged between 38 and 51 at long-continuity sites and between 15 and 28 at short-continuity sites. There were highly significantly differences in NVPS (p=0.001), SHDI (p=0.006) and SIDI (p=0.014) between the long-continuity and short-continuity forests. In all cases, the range of SHDI and SIDI values was higher in long-continuity plots than in short-continuity plots, which reveals that the former have higher species richness/diversity. Besides their importance for indicating forest continuity, these AWI species groups could also be considered forest biodiversity indicators, indicating species diversity of bryophytes and lichens in term of the results from Paper II, although strong evidence was not found. This is evaluated further in the Discussion section.

Concerning the spatial distribution of target animals in relation to spatial vegetation structures, the total number of animals observed was about 7200, consisting of 78% avian species and 22% rabbits. Of these, 57% were found in forests and partly closed green areas. Small birds showed a strong relationship to woodland, with 82% of small birds being observed in forests and partly closed green areas. The proportion of medium-sized birds, large birds and rabbits observed in forests and partly closed green areas was smaller, 58, 49 and 14%, respectively. For all the animals observed within open and partly open green areas, excluding large birds, the majority of the observations were made close to trees and shrubs. Nearly all rabbits observed were less than 12 m from vegetation, especially dense shrubbery, and about 60% were found within 2 m of vegetation. About 70% of the small birds observed were distributed within 4 m of trees or shrubs, and most were within 12 m. Only a few small birds were located within 20-30 m of trees or shrubs. The distribution pattern of medium-sized birds in relation to trees and shrubs was nearly the same as for small birds, but with a few more observed at longer distances. The distribution of large birds was different to that of other larger animal groups. There was a smaller ratio of large birds observed near trees and shrubs, but with more at 4-12 m and a relatively high percentage of observations at distances of more than 12 m (Figure 10). These results show that spatial vegetation structure has a crucial impact on the distribution of target animal species.

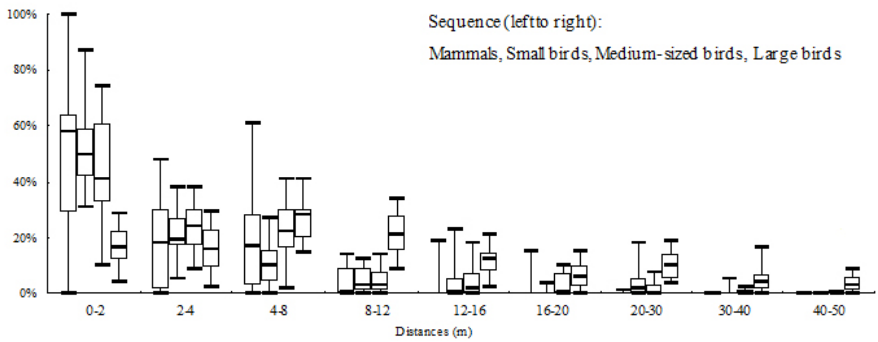


Figure 10. Percentage of mammals, small birds, medium-sized birds and large birds distributed at different distances from trees/shrubs in open and partly open green areas.

Through evaluating the relationship between vegetation structure and biodiversity, Paper III was able to confirm that the modified biotope mapping model involving temporal and spatial vegetation structures can be used as a tool for collecting more detailed biodiversity information on birds, mammals and vascular plants. In practice, the results in Paper III indicate that: (1) Areas with long continuity and aged trees should be given more attention in order to avoid deterioration or loss; (2) urban faunal qualities can be enriched by altering the patterns and structures of urban green areas; and (3) vegetation structures for target animals can be imitated to meet requirements for their conservation and recreational purposes.

The validity of the modified mapping model in a rural setting was examined in Paper IV.

5.4 Temporal and spatial vegetation structures involved in the biotope mapping model as indicators of overall plant species diversity (Paper IV)

When testing the mapping model for its utility in collecting biodiversity information in urban settings, vascular plants, birds and mammals were the indicator groups studied. When testing its validity in a rural setting, the diversity of plants in general (*i.e*. vascular plants, bryophytes and lichen) in forest ecosystems was studied (Paper IV). This was done by combining the structural parameters in the mapping model (*i.e*. canopy coverage, age of canopy trees, tree species composition and canopy stratification) for use as indicators (in the biotope map this means the patterns of forest biotopes at the finest level; see Figure 8) of overall plant diversity in forest ecosystems.

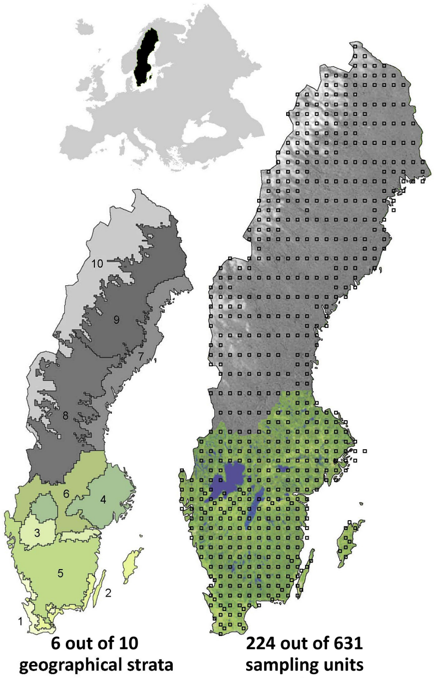
From a cost-benefit and time-efficiency perspective, obtaining information on vegetation structures from existing datasets, *e.g*. data parameters collected as part of National Forest Inventories (NFIs), rather than performing field inventories, is an attractive proposition (Chirici et al., 2012). In Paper IV, extensive field data concerning vegetation structure characteristics were obtained from the NILS programme in Sweden. However, due to a lack of large-scale forest continuity data in NILS and other NFIs datasets, the forest continuity parameter unfortunately had to be excluded from the mapping model.

The overarching aim in Paper IV was to evaluate stand structural types (combinations of structural parameters were considered as forest stand structures) as indicators of plant species diversity at stand level. Specific objectives were to: (1) Analyse the relationship between the four stand structure parameters and plant species diversity; (2) identify the most influential structural parameter(s) for plant species diversity at stand level; and (3) establish a gradient of forest stand structure types in relation to plant species diversity and composition.

5.4.1 Study area and method

The study covered the entire temperate forest zone in southern Sweden, approximately below the Limes Norrlandicus and covering Strata 1-6 (out of 10 strata; Figure 11) including 224 (out of 631) permanent sampling units (Ståhl *et al*., 2011). Grey shades in Figure 11 indicate Strata 7-10, including 407 sampling units, data on which were not used in Paper IV.

Figure 11. Study area and method design in Sweden for Paper IV



In data interpretation for these 224 permanent sampling units, landscape composition and land cover types were determined based on manual interpretation of colour infrared (CIR) aerial photos (scale approx. 1:30,000) of a 1 km x 1 km square located at the centre of each sampling unit (Figure 12). Within the 1 km^2 square, 12 circular sampling plots of 20 m radius and 250 m apart were inventoried in the field. Only data obtained from plots located within semi-open and closed forest throughout Strata 1-6 were included (n=1290) (Figure 12). Each circular NILS sampling plot consists of the following set of concentric circular plots: (a) A 20 m radius plot in which the basic conditions in the plot, *e.g*. canopy tree species, coverage, forest stand variables, are assessed; (b) a 10 m radius plot in which understory and shrub layer species (if present) and their coverage are measured and basic assessments of field layer vegetation are made based on broad taxonomy of plants, *i.e*. herb, fern, dwarf shrub and graminoid; and (c) three 0.28 m radius plots in which field/ground layer species/genera, including mosses and lichens, are documented in detail by measuring their frequency of occurrence (Figure 12). In the dataset used in Paper IV, the field inventories distinguished 286 plant species comprising 35 tree species, 42 shrub species and 209 field layer species. From a taxonomic perspective, these 286 plant species included 237 vascular plant species, 33 bryophyte species and 16 lichen species.

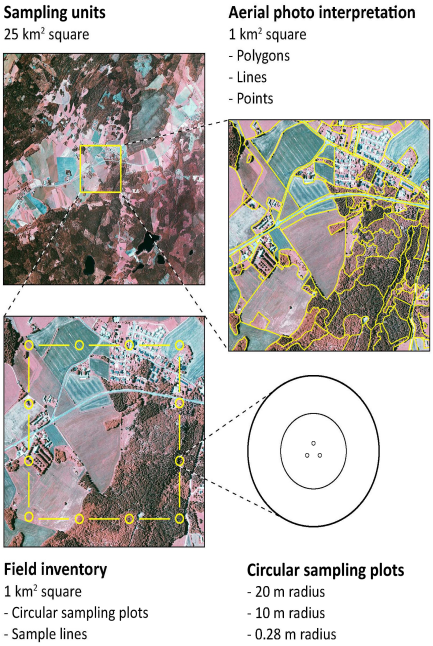


Figure 12. The scheme of sampling structure by NILS programme combining aerial photo interpretation and field inventory.

The classification of forest stand structures was extracted from the biotope mapping model in Papers I and III, only focusing on vegetated areas with semi-open and closed canopy (Table 5). Soil conditions as a complement to the model for stand structures were also taken into account, *i.e.* the NILS sampling plots were classified into different soil classes. More specifically, based on a revised version of the Ellenberg indicator values (Hill *et al*., 1999), data on field layer vascular plant species (n=132) were used to divide sampling plots into a uniform matrix reflecting nine soil classes in terms of soil water conditions (SWC) and soil pH value.

Table 5. *Model used for classification of forest stand structures into 36 different types, e.g. C2D1: a closed canopy forest with mainly 30- to 80-year-old broadleaved trees with one vertical layer.*

Level 1: Canopy coverage	**Level 2: Age of canopy trees**	**Level 3: Tree species composition**	**Level 4: Canopy stratification**
Semi-open canopy (S)	<30 years (1)	Broadleaved (D)	One-layered (1)
Closed canopy (C)	30-80 years (2)	Coniferous (C)	>One-layered (2)
	>80 years (3)	Mixed (M)	

In the statistical analysis, SHDI values were used for calculating the plant species diversity of each forest sampling plot. The Sørensen-Dice index (SDI) was used for comparing similarities in plant species composition between stand structure types.

The impacts of soil class, the four stand structure parameters, their interactions and sub-categories, as well as the impacts of stand structure types on plant species diversity (SHDI value), were tested using a General Linear Mixed Model (GLMM). In addition, the impact of stand structure type on plant species composition was calculated. Species composition change (SDI value), *i.e.* species turnover, was tested between stand structure types within each soil class using pooled species number for each stand structure type.

5.4.2 Main results

The 1290 sampling plots were allocated to 26 different stand structure types (Table 6). The SHDI value for sampling plots located in different soil classes differed significantly ($p<0.001$) in terms of plant species diversity. Plots on mesic soils with high pH (class VI) and plots on wet soils with medium pH (class VIII) had the highest SHDI values, while the few sampling plots located on dry soils (classes I-III) had the lowest SHDI values. As shown in Table 6, it was easy to identify the profile of the 1290 sampling plots where managed coniferous forest stands with young and middle-aged trees occupied the majority of sampling plots, while deciduous forest stands were less well represented in the study.

Table 6. *Number of sampling plots for 26 stand structures in relation to soil classes to which samples were allocated. See Table 5 for explanation of stand structure codes*

Stand structure code	**Number of sampling plots in each soil class**								**Number of sampling plots for each stand structure**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	
C1C1	4	3	6	60	27	5	30	14	**149**
C1C2				2	4	4	2	2	**14**
C1D1		1		6	10	11	11	1	**40**
C1D2					6	3		7	**16**
C1M1	1			6	6	3	7	3	**26**
C1M2				3	3	1	3	3	**13**
C2C1	1	1	1	49	40	4	30	5	**131**
C2C2					7	4	6	3	**20**
C2D1			1	2	9	1	2	5	**20**
C2D2					9	7	11	4	**31**
C2M1				8	7	4	6	4	**29**
C2M2					10	2	11	10	**33**
C3C1					7				**7**
S1C1	6	3	2	78	61	6	27	23	**206**
S1C2				12	7	2	4	3	**28**
S1D1	1			7	9	11	4	15	**47**
S1D2					8	6		2	**16**
S1M1			1	13	21	3	13	5	**56**
S1M2					8	3	6	5	**22**
S2C1	3	1	1	87	28	7	40	10	**177**
S2C2				10	7	7	5	4	**33**
S2D1				7	9	7		8	**31**
S2D2				12	10	13	3	3	**41**
S2M1				19	16	1	10	7	**53**

S2M2				12	11	12	10	1	**46**
S3C1					5				**5**
Number of sampling plots for each soil class	**16**	**9**	**12**	**393**	**345**	**127**	**241**	**147**	

The results showed that the four parameters individually had significant impacts on overall plant species diversity (Table 7). More specifically, in soil classes IV, V, VII and VI + VIII, age of canopy trees had a highly significant impact on SHDI. Canopy stratification had a similarly significant impact to age of canopy trees. Canopy coverage had a highly significant impact on SHDI for soil class IV, a less pronounced impact for class V, but no impact for class VII. Tree species composition had a highly significant impact on SHDI for soil class IV, a less pronounced but still significant impact for classes VII and VI + VIII, and no impact for class V (Table 7). There was almost no interactive effects between the four stand structure parameters within each soil class, with only tree species composition and canopy stratification showing a weak interaction (P=0.043) in soil class VII. This means that the structural parameters affected plant species diversity independently in most cases.

Table 7. *Shannon diversity index (SHDI) values for sub-categories of each parameter in soil classes IV, V, VII and VI+VIII*

Soil class	Parameter	Sub-category	SHDI (±S.E.)	Parameter	Sub-category	SHDI (±S.E.)
IV (P_{SA}<0.001)	Canopy coverage	Semi-open (S)	2.55±0.06 a***	Tree species composition	Coniferous (C)	2.32±0.06 **b****
		Closed (C)	2.28±0.08 b***		Broadleaved (D)	2.30±0.12 **b****
	Age of canopy trees	<30 years old (1)	2.30±0.07 b***		Mixed (M)	2.62±0.09 **a****
		30-80 years old (2)	2.53±0.07 a***	Canopy stratification	One-layered (1)	2.23±0.05 **b*****
					>One-layered (2)	2.60±0.11 **a*****
V (P_{SA}=0.033)	Canopy coverage	Semi-open (S)	3.00±0.12 a*	Tree species composition	Coniferous (C)	2.77±0.12 a
		Closed (C)	2.73±0.12 b*		Broadleaved (D)	2.85±0.15 a
	Age of canopy trees	<30 years old (1)	2.51±0.09 b***		Mixed (M)	2.98±0.15 a
		30-80 years old (2)	2.93±0.07 a***	Canopy stratification	One-layered (1)	2.59±0.11 **b*****
		>80 years old (3)	3.15±0.30 a***		>One-layered (2)	3.13±0.14 **a*****
VII (P_{SA}=0.161)	Canopy coverage	Semi-open (S)	2.56±0.08 a	Tree species composition	Coniferous (C)	2.60±0.08 **b***
		Closed (C)	2.66±0.10 a		Broadleaved (D)	2.48±0.20 **ab***
	Age of canopy trees	<30 years old (1)	2.39±0.09 b***		Mixed (M)	2.75±0.10 **a***
		30-80 years old (2)	2.83±0.09 a***	Canopy stratification	One-layered (1)	2.42±0.09 **b****
					>One-layered (2)	2.80±0.12 **a****
VI+VIII (P_{SA}=0.704)	Canopy coverage	Semi-open (S)	3.00±0.09 a**	Tree species composition	Coniferous (C)	2.68±0.12 **b***
		Closed (C)	2.72±0.11 b**		Broadleaved (D)	2.84±0.12 **ab***
	Age of	<30 years old (1)	2.60±0.10 b***		Mixed (M)	3.07±0.14 **a***

	canopy trees	30-80 years old (2)	3.12±0.10 a***	Canopy stratification	One-layered (1)	2.52±0.09 **b*****
					>One-layered (2)	3.20±0.12 **a*****

Note: LS-Mean SHDI values followed by different letters are significantly different. ***P<0.001, **P<0.01, *P<0.05. No asterisk means no significant difference between sub-categories. Random influence of each 1 km ×1 km square was considered.

The results also demonstrated that different stand structure (*i.e.* combining the four parameters together) represented different species richness/diversity (Figure 13), as well as different species composition of overall plants (Figure 14). The comparisons included 10 forest stand structure types in soil classes IV and VII and 12 forest stand structure types in soil classes V and VI + VIII. The selected forest stand structure types were all represented by 10 or more sampling plots, except the stand structure types with old canopy trees, *i.e.* C3C1 and S3C1 (Table 6).

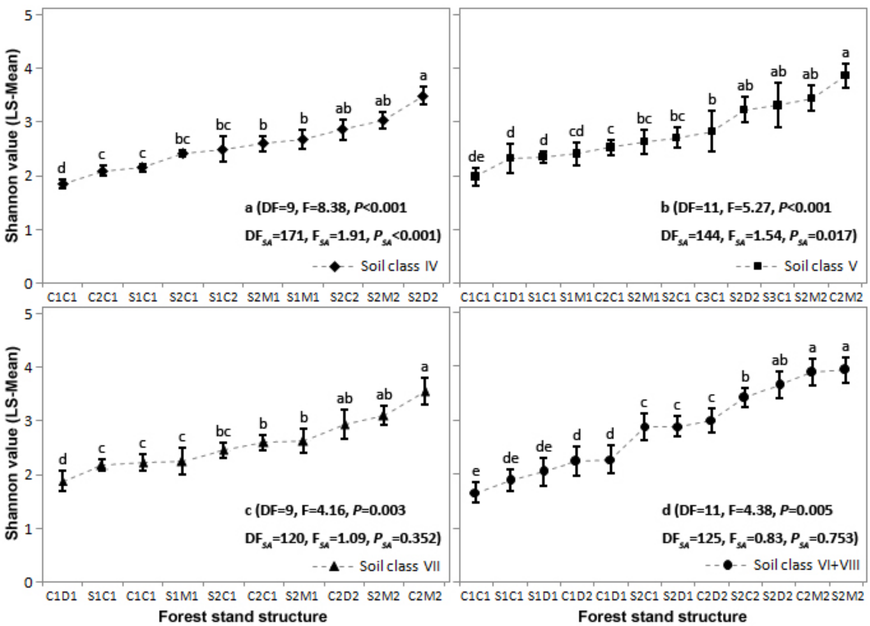


Figure 13. Line chart of Shannon diversity index value (y-axis) for each forest stand structure (x-axis) in soil class IV, V, VII and VI+VIII.

There was a highly significant difference (p<0.005) in plant species diversity between forest stand structure types, which followed a similar pattern for all soil classes (Figure 13). Stand structure types with more than one layer and dominated by mature trees always had high SHDI values, particularly if the stand structure was mixed forest with a semi-open canopy (S2M2, see Table 5 for explanation of stand structure codes). Conversely, one-layered structure types dominated by young trees always had low SHDI values, particularly if the stand was coniferous forest with a closed canopy (C1C1).

As for species turnover along the stand structure gradient of increasing SHDI value, plots in soil class IV had a lower variation in species composition than plots in other soil classes. The mean value for the measure of SDI was 0.72 in soil class IV and 0.61 in classes V, VII and VI + VIII. Among all soil classes, the highest similarity of species composition found was between C1C1 and C1C2 (SDI = 0.81) in class IV, and the highest variation was between C1D1 and S2C1 (SDI = 0.44) in class VI + VIII; between C1D1 and S1C1 (SDI = 0.48) in class VII; and between C1D1 and S1C1 (SDI = 0.49) and between S2D2 and S3C1 (SDI = 0.49) in soil class V (Figure 14). This indicates that tree species composition could be decisive for species composition between forest stands.

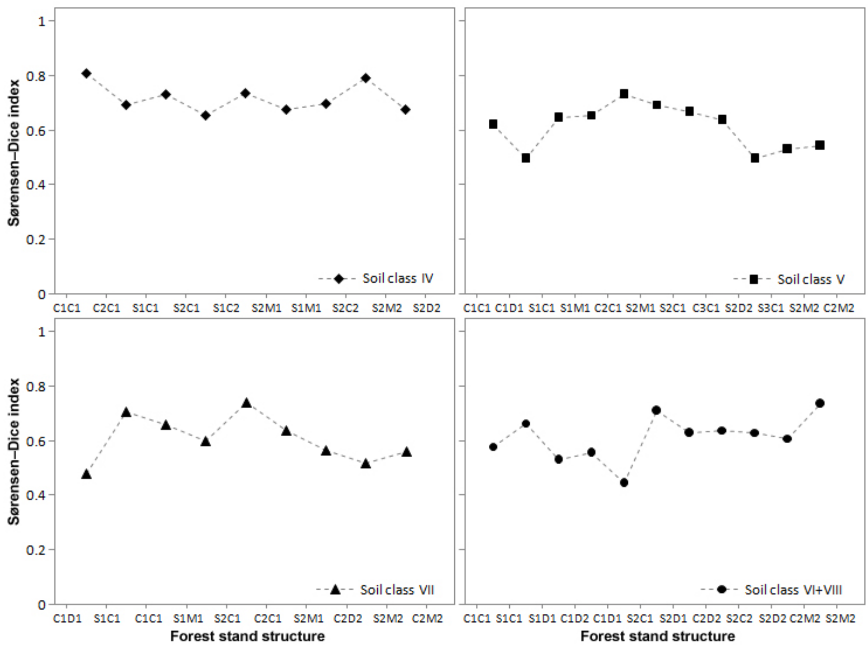


Figure 14. Variations in Sørensen-Dice index value (y-axis) along stand structure gradient of Shannon value increase in soil classes IV, V, VII and VI+VIII.

The findings in Paper IV positively confirm that the modified biotope mapping model can be used as a tool for collecting biodiversity-orientated information on forest stands that can be used in the process of landscape management and planning. Although these tests were mainly conducted in a rural context, the results could probably be applied to urban settings if the goal is to promote plant diversity in cities. This is further discussed in the next chapter.

6 Discussion

In order to conserve forest biodiversity in urban and rural settings, there should be useful tools and specific targets on biodiversity to be preserved. This thesis showed that biotope mapping methods integrated with temporal and spatial vegetation structural parameters (which can also be considered biodiversity indicators) provide a viable and promising path for collecting biodiversity-orientated information on site. This information can be used to devise strategies for accomplishing biodiversity conservation. In this chapter, the results from Papers I-IV papers are discussed in relation to each other and relevant methodological developments and future research are addressed.

6.1 Structural parameters in the mapping model, biodiversity indicators and their indicandum

The vegetation structural parameters, *i.e*. age, horizontal structure and vertical structure, included in the mapping model are consistent with the findings in the biodiversity indicator study (Paper II). There was strong evidence that two of these structural parameters in particular reflect the status of specific taxa, namely (1) Canopy coverage, which negatively indicated spider species richness/diversity; and (2) age of canopy trees, which positively indicated species richness/diversity and determined the species composition of epiphytic lichens (see Figure 6). Vertical structure was used as a biodiversity indicator in some studies and for different indicandums of biodiversity, *e.g*. abundance of black grouse (*Tetrao tetrix*) (Patthey *et al*., 2012), species richness and composition of ground beetles (Jukes *et al*., 2001), and species diversity of passerines and woodpeckers (Kati *et al*., 2009). However, none of these correlations had strong evidence, most likely because there were few replicate studies testing correlations between the same indicator and indicandum. For example, we only found one paper each reporting on the correlation between vertical structure and: black grouse, ground beetles, and passerines and woodpeckers.

Besides usage of biodiversity indicators, establishing the target aspect of biodiversity is vital in the process of biodiversity-orientated planning or design, because it is the ultimate aim to be accomplished. However, a number of biodiversity studies do not present a clear indicandum (target aspect of biodiversity) but merely cite "biodiversity". For instance, Torras and Saura (2008) studied the effects of silvicultural treatments on biodiversity maintenance in Mediterranean forests by choosing six forest biodiversity indicators (snags, mature trees, shrub abundance, shrub species richness, tree species richness and tree species diversity) cited in other studies as representing biodiversity. Those authors described how the silvicultural treatments affected these six indicators, without mentioning which aspect of biodiversity was actually affected. Failing to define an indicandum of biodiversity or mixing indicandum and indicator is a common fault in biodiversity indicator studies. The indicandum of biodiversity is the 'endpoint' or 'fundamental objective', whereas the indicator is the method or strategy used to achieve the 'fundamental objectives' (Failing and Gregory, 2003). Although methods may be devised for measuring biodiversity in an urban green space or rural forest context, these are useless unless the specific goals for biodiversity are known (Gao *et al*., 2014).

In this thesis, the use of structural parameters/indicators was extended for another indicandum of biodiversity, *i.e.* resident birds, mammals and vascular plants (tested in Paper III), and plants in general (tested in Paper IV) (Figure 15).

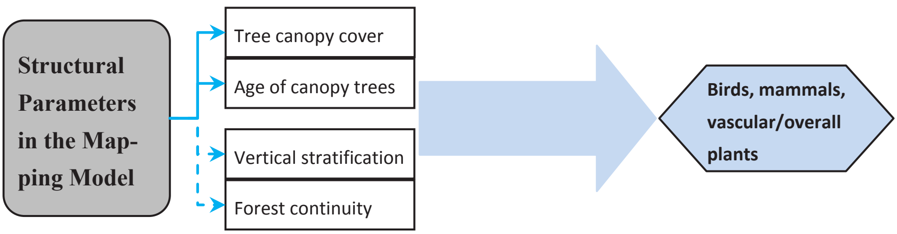


Figure 15. New correlations between the structural parameters and target aspects of biodiversity

6.2 AWI species group as an indicator of forest biodiversity

Forest continuity as a structural parameter in the modified mapping model was tested in the Helsingborg case study. The identification of long-continuity forests was based on AWI species richness and abundance, complemented with historical records. The AWI species used in the study were mainly field layer vascular plants which are capable of growing in shade, seldom occur outside woodlands and are slow colonisers (Peterken, 2000; Rose, 1999) (Table 4). Higher richness and abundance of AWI species found in forests indicated higher possibilities of the forests being long-continuity and consequently having higher species richness/diversity of vascular plants. In the forest biodiversity indicator study (Paper II), a similar finding was made for indicators of species diversity of bryophytes and lichens, although it was supported by weak evidence. Brunialti *et al*. (2010) demonstrated that higher species richness of bryophytes and lichens was mostly related to high vascular plant species diversity of the understory/field layer, and to old-growth forests characterised by old trees.

The AWI species group could thus be considered as a forest biodiversity indicator too, because it could be included in the biodiversity indicator 'understory vascular plants' (Figure 5a). Therefore, the application of the indicator 'understory vascular plants' can be extrapolated to indicating the species richness of vascular plants in general, in addition to indicating the species richness of bryophytes and lichens (Figure 16). However, this result needs to be further tested in other cases.

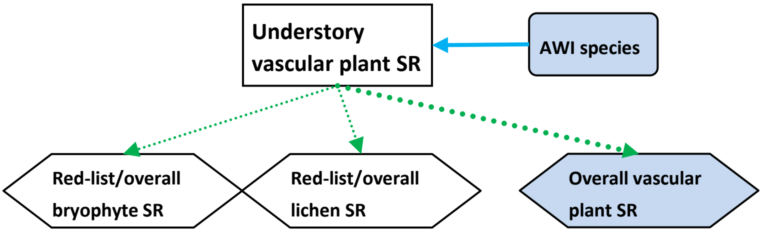


Figure 16. Integrating AWI species group into biodiversity indicator "understory vascular plant". Rectangle denotes indicator, and hexagon denotes indicandum. Green arrow represents positive correlation and dot-line represents on a stand level.

AWI species richness and abundance are also likely to relate to the structural parameters, *i.e*. age of canopy trees and vertical stratification, in the mapping model. Paper III showed that AWI species are found mainly in mature and older forests rather than in young stands, and that the spatial structure of these woodlands is relatively complex. Biotopes with old, well-stratified vegetation will generally support more biodiversity than biotopes with young vegetation concentrated to a single layer, as also shown in Paper IV (Hunter, 1990).

AWI species may, however, also occur spontaneously in stands with young trees, because long woodland continuity could include short periods of relative openness after *e.g*. forest fires, storms, radical felling of trees or clear-cutting of managed forest. This means that long-continuity woodland does not necessarily mean woodland with old trees or total coverage of trees (Kirby & Goldberg, 2002). Openness might change the microclimate and the ground flora could be affected (Brunet *et al*., 2000; Brunet & von Oheimb, 1998). The presence of a large number of AWI species, and of individuals within species, is hence most likely to indicate mature stands with long continuity, rather than young stands with long continuity.

This implies that although some regions lack historical maps and records for their forest biotopes, forests with old, well-stratified vegetation should be given extra attention in development and conservation strategies, because these biotopes could have high potential to be long-continuity sites.

6.3 Application of the modified biotope mapping model in different contexts

The modified mapping model was empirically tested in different contexts, *i.e.* urban settings (urban green space) (Paper III) and rural settings (rural forest biotopes) (Paper IV). In contrast to rural settings, urban green space may suffer greater disturbances from human activities and the pattern of urban green space may also be more fragmented and disconnected. However, the results from both case studies could be transferred to the other context. For instance, in Paper III, large birds in forest biotopes were mostly observed (94%) in well-stratified mature and older stands rather than in one-layered young plantations (6%). According to the forest stand structure types in Paper IV (Table 5), the well-stratified mature and older stands could be types C2M2 or S2D2 *etc*., which were shown to have high species diversity of plants in general and perhaps also the potential for high species diversity/abundance of avian fauna. In contrast, one-layered young plantations could be considered C1C1 or C1D1 *etc*., which were shown to be low in species diversity of plants in general and potentially low in species diversity/abundance of avian fauna in a rural context.

Stand structure type is always regarded as a significant factor influencing species richness and abundance of animals. The correlation between the types and animals relies on cover dependence, because of *e.g.* food preference, predator avoidance, shelter, breeding and roosting location, as well as disturbance from human activities (Robles *et al*., 2012; Robles *et al*., 2007; Newton, 1998; Wirén, 1995). The importance of these factors however varies between species (Rotenberry & Wiens, 1998; Holmes & Robinson, 1988). In a forest biotope, for example, regardless of urban or rural setting, large tree branches in the top layer could provide nesting sites for large birds; a well-developed understory and shrub layer could provide nesting and foraging opportunities for smaller birds; and field layer plants could supply foods and microhabitats for a wide range of animals, *e.g.* butterflies, other invertebrates *etc*.

Paper IV showed that mature stands with a multi-layered structure always had higher plant species diversity, particularly if they were also mixed broadleaved and coniferous and/or had a semi-open canopy (*e.g.* S2M2 and C2M2 in Table 5). In contrast, young, one-layered forest stands always had low plant species diversity, particularly if they were also coniferous and/or had a closed canopy (*e.g.* C1C1 and C1D1). Other forest stand structures (*e.g.* S2D1, S2C1, C1D2, C2M1 etc.) were intermediate in terms of plant species diversity. Combined effects of light availability, microhabitat, successional stage and canopy tree species type presumably determine the gradient of plant species diversity and composition in forest stands (Zhang *et al*., 2014; Chávez & MacDonald, 2012; Barbier *et al*., 2008; Sagar *et al*., 2008; Berger & Puettmann, 2000).

The sampling plots used in the test in Paper IV were primarily managed stands, so management practices could also be applied in urban settings to construct or maintain certain desired structure types representing not only animal biodiversity, but also plant species diversity and composition.

6.4 Application of the modified biotope mapping model for collecting biodiversity information

Biotope quality in urban and rural contexts is essential for preserving and promoting biodiversity and is also related to opportunities for human recreation. However, it is clearly impossible to measure everything when studying biodiversity. Instead, it is necessary to select a few variables, *i.e.* biodiversity indicators, that represent target components of biodiversity considered to be important based on the best knowledge currently available and what is feasible to measure (Ferris & Humphrey, 1999).

One of the key factors in this regard is the vegetation structure of biotopes, which plays a significant role as a biotope indicator reflecting various spectra of biodiversity. The modified biotope mapping model including temporal and spatial vegetation structures, which visually presents biodiversity information in biotope maps, could be important in producing a basic database for the process of biodiversity-orientated landscape management and planning.

This thesis presented instructive findings that can be meaningful to real practice in urban and rural contexts. It was found for example that:

- Faunal qualities can be enriched by changing the design and management of green spaces. More specifically, the vegetation structure of biotopes favoured by target animals can be imitated to meet their requirements and probably also for human recreational purposes.

- Green areas with long continuity and aged trees should be given more attention to avoid deterioration or loss, since they make a significant contribution to biodiversity in urban and rural settings, and also probably to people's appreciation.
- Mature and well-stratified forests with a semi-open canopy of mixed coniferous and broadleaved trees host high plant species diversity, so constructing such forest profiles would be one way of promoting urban and rural plant biodiversity on site level.
- When seeking to promote plant biodiversity on a larger scale, *e.g.* cityscape or rural landscape level, green space should be designed and managed in a way that supports as many forest stand structure types as possible, and should include other types of green space (*e.g.* open, partly open *etc.*) apart from forest, in order to maximise beta diversity and maintain viable populations for species.

6.5 Methodological development and proposed future research

This thesis thoroughly investigated the modified biotope mapping model using the case of forest biotopes in both urban and rural settings. The structural parameters included in the mapping model, *i.e.* age of canopy trees, canopy coverage, vertical stratification, as well as forest continuity and tree species composition, were all tested concerning the validity of mapping model for reflecting certain aspects of biodiversity.

However, the studies in both settings used an observational design with inductive thinking, which involved statistical analysis of species diversity and composition to identify patterns that validated the modified biotope mapping model, rather than a rigorously controlled experimental design. Similarly, the study of forest biodiversity indicators followed the inductive principles and the individual studies in the review mostly used the observational design for inventory and analysis of species richness and community. It is more difficult to draw final conclusions from these compared with controlled experiments, but surprises sometimes emerged that would not be observable in controlled experiments. For example, the study of forest biodiversity indicators showed that none of the structural parameters included in the mapping model had a strong correlation with birds, mammals and plants, so further validations based on these were conducted in subsequent studies.

Forest biotopes were the main focus in this thesis. However, only the abundance and distribution of resident birds and mammals in relation to open and partly open green spaces in urban settings was investigated. Other types of biotope, *e.g*. open grassland, sparsely wooded open green space, *etc.* were not comprehensively studied using the modified biotope mapping model. Thus future studies should focus on these other types of green space, in both urban and rural settings. Future studies should also look for other reliable parameters that are able to reflect certain aspects of biodiversity for other types of green space, because the current parameters included in the mapping model (age of canopy trees, vertical stratification and tree species composition) are more likely to be related to forest biotopes than open green space.

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