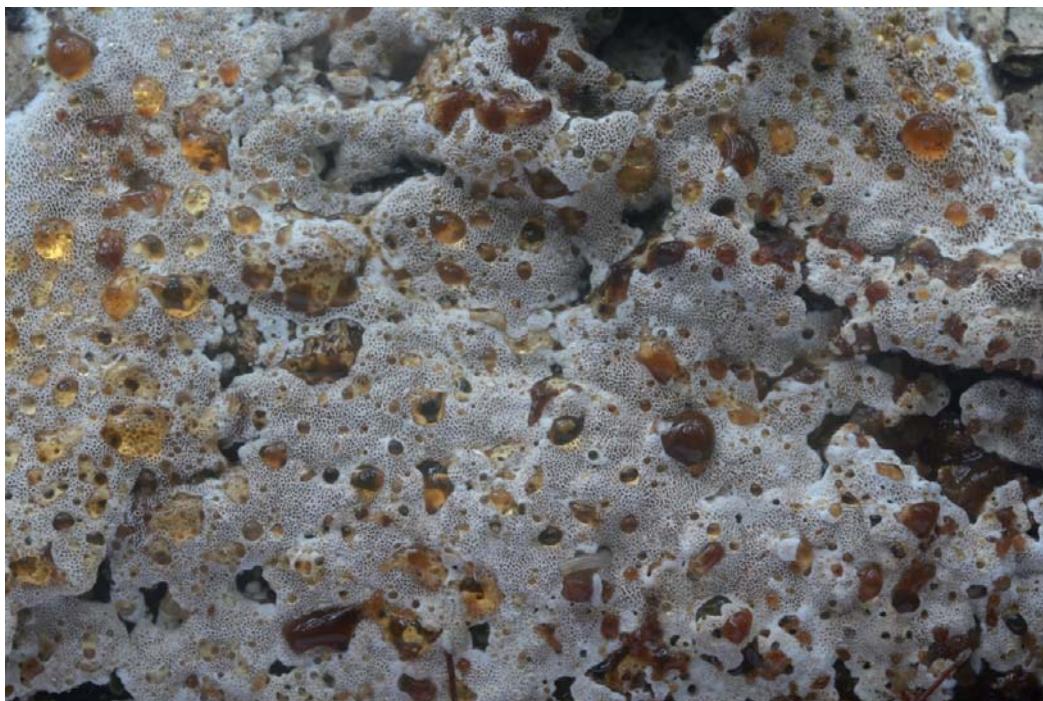


Panu Halme

Developing Tools for Biodiversity Surveys

Studies with Wood-Inhabiting Fungi



JYVÄSKYLÄN YLIOPISTO

JYVÄSKYLÄ STUDIES IN BIOLOGICAL AND ENVIRONMENTAL SCIENCE 212

Panu Halme

Developing Tools for Biodiversity Surveys
Studies with Wood-Inhabiting Fungi

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Developing Tools for Biodiversity Surveys

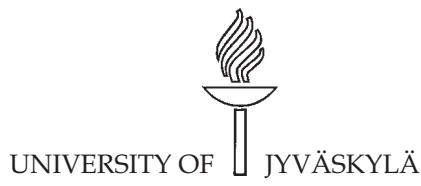
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Cover picture: *Protomerulius caryae* (rustikka in Finnish) is a rare polypore inhabiting large decaying Birch trunks. Korpilahti, Ulakko, 12.9.2007. Photo by Panu Halme.

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ABSTRACT

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Yhteenvetö: Työkaluja monimuotoisuustutkimuksiin – tutkimuskohteina puulla elävät sienet

Diss.

A high number of biodiversity surveys and monitoring projects are implemented to study the current state of species occurrence and abundance. These studies are time consuming and require a broad knowledge base to conduct. In this thesis I tried to assess and improve the quality of biodiversity studies considering one ecologically important species group, wood-inhabiting fungi. I approached this task in two ways. First, I studied if there are indicator species groups that reliably predict the occurrences of endangered taxa and might reduce the costs of exhaustive surveys. I found that polypores with perennial fruitbodies can be used as a surrogate of the species richness of annual and red-listed polypores. However, determining whether something is a good indicator is not simple. Therefore, I developed a method which can be used in quantifying the indicator power of potential indicator species for a target species. The method proved to be useful when I tested it with polypore data. Second, I studied the methodology of the biodiversity studies focusing on the wood-inhabiting fungi. I found that the survey season had a strong effect on the detected number of species, but this effect was very different for different species groups. The number of detected species in a single survey was relatively low even in the peak fruiting season. For most of the species groups, the surveys should be repeated to minimize the error in the collected data. I also studied the effect of setting different size limits on the studied dead wood. Setting the lower limit of the studied dead wood pieces to the traditional levels, like in five centimetres resulted in not detecting most of the species occurrences. To conclude, my thesis provides new information which can be used to improve the quality of biodiversity studies of wood-inhabiting fungi.

Keywords: Biodiversity surveys; boreal forests; monitoring; species inventories; very fine woody debris; wood-inhabiting fungi.

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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original papers, which will be referred to in the text by their Roman numerals I-IV.

- I Halme, P., Kotiaho, J.S., Ylisirniö, A.-L., Hottola, J., Junninen, K., Kouki, J., Lindgren, M., Mönkkönen, M., Penttilä, R., Renvall, P., Siitonen, J. & Similä, M. 2009. Perennial polypores as indicators of annual and red-listed polypores. *Ecological Indicators* 9: 256-266.
- II Halme, P., Mönkkönen, M., Kotiaho, J.S., Ylisirniö, A.-L. & Markkanen, A. 2009. Quantifying the indicator power of an indicator species. *Conservation Biology* 23: 1008-1016.
- III Halme, P. & Kotiaho, J.S. 2010. Optimal timing and number of surveys in studies of wood-inhabiting fungi. Submitted manuscript.
- IV Juutilainen, K., Halme, P., Kotiranta, H. & Mönkkönen, M. 2010. Size matters in studies of dead wood and wood-decaying fungi. Submitted manuscript.

The table shows the contributions to the original papers. Smaller contributions are stated as the authorship or in the acknowledgements of the original papers. PH = Panu Halme, JH = Jenni Hottola, KJn = Kaisa Junninen, KJt = Katja Juutilainen, JSK = Janne S. Kotiaho, HK = Heikki Kotiranta, PK = Panu Kunttu, ML = Mariko Lindgren, AM = Anni Markkanen, MM = Mikko Mönkkönen, RP = Reijo Penttilä, JS = Juha Siitonen, ALY = Anna-Liisa Ylisirniö

| | I | II | III | IV |
|---------------|--------------------------------------|---------------------|---------|-----------------|
| Original idea | ALY, JSK | PH, MM, JSK | PH, PK | PH, KJt |
| Data | See appendix A in paper I | PH, AM | PH | KJt, HK, PH |
| Analyses | PH, JSK | PH | PH, JSK | PH, MM, KJt |
| Writing | PH, ALY, JSK, JS, RP, JH, KJn, ML | PH, JSK, MM, ALY | PH, JSK | PH, KJt, MM, HK |

1 EXPLORING THE MOTIVATION

Before starting to work with any task, the motivation should be clear and precise. With blurred motivation performing any task feels exhausting and the actions may even be targeted towards a wrong direction.

The motivation for a thesis like this is perhaps not the most obvious one. In general this thesis can be described as biodiversity research. The study organisms are wood-inhabiting fungi, and the approach is methodological and comparative. The motivation should therefore include the reason to study biodiversity, the reason to study fungi and the reason to conduct a study with methodological approach instead of simply studying the biology of the studied organisms. For my own and the possible reader's convenience, I start this thesis with an exploration to the obscure world of my motivation.

I begin with the most abstract one, the reason to study biodiversity. Human induced changes in global and local biodiversity have been increasing during the last century. As a result, the rate of species extinctions, both regionally and globally, has increased to a high, though debated level (Stork 2010). The arguments for avoiding extinctions are multiple and include ethical reasoning. In the end, everyone must find their own arguments but, for me and probably for many others, the following philosophical or ethical reasoning holds true:

'How strange the day seems when I think of these reports, looking out my window and erasing with my mind's eye one out of every four species. As I look into the thick, green texture of summer here in upstate New York, instead of the four kinds of leaves I see, there might be only three found on this planet at century's end. Which one goes? All of them are pleasing to the eye and fascinating to look at more closely. And they make all the more interest overlapping each other on this lush, summer day. If ever I have children, I want my children to see them, and we can study them together and make comparisons.'

(Bendik-Keymer 2010)

In my ethical reasoning, variation in nature can be compared to our cultural heritage: this generation is not entitled to burn the paintings of the ancient artists, even though we might have some financial benefits from doing that. Similarly, we are not entitled to destroy the natural variation and thus prevent the next generations from living in a biodiverse world. In addition to the ethical reasoning, there are multiple economical and biological reasons to rescue biodiversity. If we recognize the ethical reasons and regard them sufficient, the economical or biological reasons are, actually, not necessary, even though recognizing them may help us in solving potential conflicts between conservation and other actions.

Whatever the most important reason for any person is, the humankind has set up an increasing number of projects to elicit the current state of biodiversity and to monitor the changes of it (Lengyel et al. 2008). Even though knowledge in itself does not halt the loss of biodiversity, it helps to focus the biodiversity rescue actions towards the most important areas, species groups and habitats:

'The prime aim and justification of conservation research is to benefit biological diversity, whether through identifying patterns and mechanisms, quantifying changes, recognizing problems, or testing solutions. Many of the successes in conservation can be attributed to the successful translation of conservation science to conservation practice.'

(Sutherland et al. 2009)

Therefore it is justified to say that conducting reliable high-quality biodiversity studies is one way that can curb the ongoing extinction bloom. Increased knowledge brings awareness to the critically disturbed areas and ultimately helps direct financial aid.

Second, let's try to find the motivation to conduct a methodological study. To design, conduct and report a biodiversity study properly and efficiently is not an easy task. The process may fail in any stage, starting from poor design, erroneously defined targets or misused methodology and ending in flawed results and inaccurate conclusions (e.g. Yoccoz et al. 2001, Failing & Gregory 2003, Legg & Nagy 2006). Methodological research makes it possible to give well founded guidelines for doing something with better methods to get better results. In biodiversity research, this may mean field work has more optimal targets and implementation. By having better tools, biodiversity researchers may better use every euro, dollar, yen or rupee that they have. This cost-efficiency of the data collection is crucial considering its sensibility:

'Assuming resources are limited, more effort put into improving any data will leave fewer resources for applying on-ground conservation. How much effort we spend on assembling data depends on how much it will improve conservation decisions and how quickly options are being lost.'

(Possingham et al. 2007)

This argument can be interpreted in many ways. To me it means that if you are going to use resources for biodiversity data collection, you have to ensure that you do the work with optimal methods to get the results you searched for.

Finally, the motivation to study wood-inhabiting fungi. Fungi are a mighty kingdom. They contribute an unknown, but massive number of species to the global biodiversity (Schmit & Mueller 2007). Above being a diverse group, fungi are functionally important ecosystem engineers. By mycorrhizal symbiosis and decaying activities they form the basis of the growth for the plants. Moreover, they also function as food or shelter for a massive number of animals (Boddy et al. 2008, Schigel 2009). Still, their biology and conservation has been largely neglected (Dahlberg et al. 2010). Compared to their species richness and importance in ecosystem functions, the conservation of fungi is studied very little compared to many other taxa, especially birds, mammals and plants (Fazey et al. 2005, Heilmann-Clausen & Vesterholt 2008, Lonsdale et al. 2008). Related to the earlier ethical reasoning, we are also not entitled to destroy fungal diversity even though most representatives of this generation do not regard fungi as important for aesthetic or ecological reasons. The next generation may, and thus we must maintain their diversity.

To conclude, this thesis is my effort in improving the quality of biodiversity studies. My aim is to provide tools for the researchers and managers who study the state and changes in biodiversity, especially considering wood-inhabiting fungi. Thus, the motivation relies on the assumptions that the society in general believes that biodiversity is worth rescuing, that conducting biodiversity studies is one method in rescuing it, that the methods of biodiversity studies could be improved, and that wood-inhabiting fungi are an important part of the biodiversity.

2 INTRODUCTION

2.1 Designing a biodiversity study

'Designing a study is as much an art as a science. Theoretical and simulation results provide useful guidance about the expected outcome of a study given certain assumptions, analytic techniques and designs. But these results must be tempered with common sense, expert knowledge of the system under study and, occasionally, lateral thinking.'

(Mackenzie & Royle 2005)

Designing a study rigorously is important regardless of the studied issue. However, it is extremely important in studies where data collection is laborious and difficult to repeat. Biodiversity studies are often such. Collecting data for diverse species groups usually requires intensive surveys, while the seasonally varying number of occurrences or their detectability may forbid fast repeats of the failed data collection acts. Thus proper design is extremely important in biodiversity studies.

In general, all biodiversity studies should be able to answer three fundamental questions before allocating effort to the study: why biodiversity is studied, which aspects of the biodiversity are studied, and how the study is going to be conducted (Yoccoz et al. 2001). Answering the 'why?' question requires defining both scientific and management-related objectives. Specifying the scientific objectives mean clear hypotheses instead of a posteriori data mining. Most biodiversity studies and monitoring projects have a management objective of either 1) identifying the system state or trend or 2) providing information on the system response to management actions. Identifying the state may mean notably different methods than providing sufficient information on the population trends (Rhodes et al. 2006).

Answering the 'what?' question requires thorough examination of both the scientific and management objectives and deciding on the variables to be monitored. It usually includes the justified and well argued choice of the

monitored species group, the level of biodiversity that is monitored (genes to ecosystems) and the possible background variables that are studied.

Answering the 'how?' question has attracted most of the interest. There are several extensive guides about the sampling of biological diversity (e.g. Thompson 2004). In general, the potential problems related to this question are due to two error sources: detection error or spatial variation and survey error (MacKenzie et al. 2006, Mattfeldt et al. 2009). The detection error means failure to detect all the individuals or species that are actually present in a studied area. The survey error means the error deriving from spatial variation and is due to the inability to survey large areas entirely. The survey error may for example mean depositing all the sample plots between the sites of actual occurrences and therefore estimating the number of occurrences to zero even though the species actually was present on the studied area. The selected methods should be such that both of these error sources would be minimized.

Many biodiversity surveys and monitoring projects still suffer from poorly selected methods and poorly defined targets of the projects (Legg & Nagy 2006). For example, in a biodiversity monitoring project the objective may be to detect a possible downward trend in the population but the selected methods may be such that detecting such a trend is extremely unlikely (Rhodes et al. 2006, Field et al. 2007, Mattfeldt et al. 2009).

Biodiversity is simply too much to handle in the reality of limited resources. The task of studying the state and changes of the total biodiversity even on a local scale is doomed to fail, if it is taken literally (Kaiser 1997). Biodiversity includes multiple levels ranging from the genetic diversity of a population or a species, through the species diversity at a given site until the turnover rate of the species from a biotope to another and from continents to other. Thus, studies must be tackled in small, digestible pieces. This may mean anything from drawing broad lines like the macroecologists do: 'there seems to be more species in the tropics' (Blackburn et al. 2003), to studying genomic variation of a single or a few populations of a single species (Swatdipong et al. 2009). While the former approach dampens most of the local variation and is only able to provide approximations of biodiversity, the latter approach is so laborious and slow that many of the species may be extinct before we have time to study them.

An intermediate approach is the one this thesis is focused on: studying communities and populations of some subsets of the global biodiversity within a given area. Usually the subsets are taxonomically or functionally delineated species groups, such as birds, vascular plants, beetles, or in my case, wood-inhabiting fungi. Even with the limitations of the studied area and taxa, biodiversity studies are laborious. Thus, numerous approaches have been developed to optimize the effort used in a biodiversity survey. For example, one may estimate the completeness of the conducted surveys regarding the number of species truly living on the studied area (Nakamura & Soberón 2009). It has also been proposed that before and during data collection the risks of methodological errors should be estimated and accounted for to optimize the effort (Field et al. 2004, 2005).

2.2 Imperfect detectability of the studied species

The human ability to detect something that is actually present at a site is called *detectability* (Mackenzie et al. 2002, Mackenzie et al. 2004, MacKenzie et al. 2006, Lamb et al. 2009). One of the most important methodological issues of biodiversity studies is the art of predicting or confirming the presence or absence of a species on a site or a matrix of sites. This task is hindered by the fact that in most cases some proportion of the individuals and species are not detected in all the sites where they truly are present.

There are several factors that may cause imperfect detectability. Some of them are biological, like the seasonality or short-term variation in the visibility or other detection cues of the individuals of target species, or the abundance of the species on the studied site(s). Other factors are methodological, such as the survey method and the consistency of persons who are conducting the survey (Solla et al. 2005, Kery et al. 2006, MacKenzie et al. 2006, Garrard et al. 2008, Kery & Schmidt 2008). If the imperfect detection is ignored, noise in the data may prevent drawing reliable conclusions. For example, detecting population trends becomes increasingly difficult with lower detectability and abundance of surveyed species. Thus, to detect a change in the prevalence of a rare species with low detectability, a large number of sample plots and multiple survey occasions are usually needed (Nielsen et al. 2009). Moreover, imperfect detectability tends to end up in overestimated extinction rates in revisit studies as some of the ‘extinctions’ are actually false negative observations during the revisits (Kery et al. 2006). Generally speaking, detection problems increase the need for multiple study areas and multiple surveys and thus increase the overall cost of biodiversity studies (Field et al. 2005, Mackenzie & Royle 2005).

Due to the fatal consequences of imperfect detection, it is important to be able to quantify detection probabilities of different species, and to optimize the selected methodology to the case-specific detectability and occupancy patterns (Field et al. 2005, Mackenzie & Royle 2005, Rhodes et al. 2006). This may mean revisiting the study sites (Mackenzie & Royle 2005), using more time during one visit in one site (Garrard et al. 2008) or just adjusting the methods such that the error in the collected data can be minimized (Field et al. 2007). Moreover, after adjusting the methods suitable for the system, the detection probability and occupancy of the species can be analyzed and estimated to further decrease unnecessary noise from the collected data set (MacKenzie et al. 2006, Field et al. 2007).

2.3 Biodiversity surrogates

Conducting a survey which reveals the total biodiversity is practically impossible even a very small area (Kaiser 1997). Thus, to be successful the studies must always target on some subgroup of the total diversity. Often, however, conducting a survey on even a relatively small species group may be extremely difficult and expensive. For these occasions, a biodiversity surrogate or indicator approach has been developed (Williams et al. 2006, Rodrigues & Brooks 2007, Strien et al. 2009). These are measurable elements, which provide information about the biodiversity without the need to measure the total diversity. Both terms are used in various ways, but to me a biodiversity surrogate means more of a substitute for the biodiversity itself, whereas indicator may indicate either biodiversity or another variable of interest, such as changes in the level of environmental pollution. One of the most ambitious definitions of a useful indicator is given in Millennium assessment:

'A useful indicator will provide information about changes in important processes, be sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability, detect changes at the appropriate temporal and spatial scale without being overwhelmed by variability, be based on wellunderstood and generally accepted conceptual models of the system to which it is applied, be based on reliable data to assess trends and have a relatively straightforward data collection process, have monitoring systems in place for the underlying data needed to calculate the indicator, and be easily understood by policy-makers'

(Millennium Assessment, Full Report, Ch. 4. p.111).

The above definition and other similar proposals (Gregory et al. 2005) are practically so overwhelming, that it is a difficult task to match an indicator which would fulfill all the requirements. However, a large number of biodiversity surrogates and indicators have been proposed. Some of them are species-based such as the umbrella species, indicator species or keystone species (McGeoch 1998, Lindenmayer et al. 2000, Roberge & Angelstam 2004). Some of the proposed surrogates are structure-based such as environmental diversity (or heterogeneity), stand complexity or connectivity (Lindenmayer et al. 2000, Juutinen & Mönkkönen 2004, Juutinen et al. 2006, Rodrigues & Brooks 2007).

2.4 Indicator species

'Indicator species' is probably one of the most obscure biological concepts. Using it as a search term in electronic databases one may achieve thousands of results reporting about any biological phenomenon. For example, the search term 'indicator species' (in the topic) resulted in 9009 published results in ISI web of Knowledge (searched in 14th March 2010). Accurately define 'indicator species' has been attempted for multiple times. Often the concept 'indicator species' is too broad for applied purposes. David Lindenmayer and his colleagues proposed (Lindenmayer et al. 2000) seven alternative, more focused concepts or definitions for different categories of indicator species. Melodie McGeoch, on the other hand, proposed three types of indicator species (McGeoch 1998). More definitions and potential uses of different kind of indicators have been proposed widely (e.g. Roberge & Angelstam 2004, Hagan & Whitman 2006). The purposes and selected definitions of these different indicator species categories are given in table 1. Their potential in biodiversity studies varies and some of them are actually more usable in e.g. pollution-related environmental management.

One of the most commonly used categories is *biodiversity indicator* species or species group (McGeoch 1998). Many studies have tried to point out taxa for predicting species richness or community composition of another taxon group. In most cases, the approach has proved to be relatively unpromising, and the predictive ability of potential biodiversity indicators has been low. There are, however, some positive examples of useful biodiversity indicators (examples for both, see Jonsson & Jonsell 1999, Similä et al. 2006, Rodrigues & Brooks 2007, Larsen et al. 2009).

Another commonly used indicator species category in biodiversity research is *ecological indicator*. An ecological indicator is mostly a condition indicator carrying information about the state of a biotope or an area (McGeoch 1998). Along with this local information it would potentially provide information about the history of a site, or the quality of the matrix around the site. Usually, however, it is difficult or impossible to separate these different spatial levels of prediction. The indicator polypores for old-growth forests of high conservation value used in Finland (Kotiranta & Niemelä 1996) are a good example of a useful and widely used ecological indicator species group. Often they are claimed to indicate the continuity of old-growth structures of the forests, even though this has been questioned (Norden & Appelqvist 2001).

TABLE 1 The most common indicator-species categories proposed in the literature and their definitions by Lindenmayer et al. (2000) as well as some other relevant publications.

| Definition by Lindenmayer et al. | Definition by others | Category | Notes |
|--|---|-------------------------|---|
| Species whose presence indicates the presence of a set of other species and whose absence indicates the lack of that entire set of species | A group of taxa, or a functional group, the diversity of which reflects some measure of the diversity of other taxa in a habitat or set of habitats (Mcgeoch 1998) | Biodiversity indicator | Indicators of presence of a particular species (presence ind.) must be separated from the biodiversity indicators |
| Species whose addition to or loss from an ecosystem leads to major changes in abundance or occurrence of other species | | Keystone species | |
| Species whose presence indicates human-created abiotic conditions | | Pollution indicator | |
| Dominant species that provides much of the biomass or number of individuals in an area | | Dominant species | I do not fully understand why these are called indicator species in the first place |
| Species that indicates particular environmental conditions such as certain soil or rock types | Responds predictably, in ways that are readily observed and quantified, to environmental disturbance or to a change in environmental state (McGeoch 1998) | Environmental indicator | Indicators of woodland key habitats are examples of this category (see Meriluoto & Soininen 2002). |
| Species thought to be sensitive to and therefore to serve as an early warning indicator of environmental changes | | Bioindicator | |
| Management indicator species, which is a species that reflects the effects of a disturbance regime or the efficacy of efforts to mitigate disturbance effects. | Demonstrates the effect of stress factors on biota, and whose response is representative of the response of at least a subset of other taxa present in the habitat (McGeoch 1998) | Ecological indicator | Indicators of structurally valuable habitats (such as Kotiranta & Niemelä 1996) belong to this category although they may be referred as biodiversity indicators. |
| | A species whose conservation confers protection to a large number of naturally co-occurring species (Roberge & Angelstam 2004) | Umbrella species | |

2.5 Wood-inhabiting fungi

'Fungi constitute a significant proportion of the yet-undiscovered biota that is crucial to the maintenance of ecological processes and human well-being. Without fungi, major problems in nutrient cycling would occur, plants would suffer without the nutrients that fungi secure for them from the soil, many animals would be without food, woody materials would not be broken down, some insects and other animals would not be able to digest plant materials, and even soil structures would differ.'

(Hawksworth 2004)

Fungi in general are a megadiverse group, contributing in minimum nearly a million species to the global species pool, probably even more (Schmit & Mueller 2007). A majority of these species are microfungi which are usually not visible to a bare human eye. However, macrofungi, the megafauna of fungi, are diverse as well. The estimated global species richness of macrofungi, the fungal species visible to bare eye, is from about 50 000 to more than 100 000 species (Mueller et al. 2007).

Wood-inhabiting fungi are not a taxonomic group. Instead, they are a group including both micro- and macrofungi from all sides of the fungi kingdom. They simply are fungi that grow on woody material other than litter (needles or leaves). An often used nearly synonym is saprophytic fungi. Saprophytic means a species that is dependent on dead wood, either directly or by utilizing another species that grows on dead wood (Siionen 2001). A similar term with saprophytic is wood-decaying, which should mean more strictly that the species actually utilize the wood itself. Wood-inhabiting in my understanding is a broader concept including also the species living on the trunks of the living trees, such as parasites, as well as the mycorrhizal fungi fruiting on woody material. In this thesis the concept wood-inhabiting fungi means fungal species that normally fruits on pieces of wood regardless of their source of nutrition (wood, other wood-inhabiting organisms or litter).

Many wood-inhabiting fungi are ecologically important as being the main decomposers of the woody material in forests throughout the world. By this role they are the main engineers, which take care of the carbon and nutrient cycles of the forests (Boddy et al. 2008). Beyond that they provide substrate or resource for a massive number of other organisms, especially for insects and other arthropods (Boddy & Jones 2008, Schigel 2009), but also for bacteria (de Boer & van der Val 2008), slime moulds and vertebrates. Globally the threats that push wood-inhabiting fungal species towards extinction are probably mostly related to the rapid decrease of global forest cover (Ewers 2007). However, this argument cannot be verified with global extinction estimates, since only three (!) fungi species were treated in the latest list of globally endangered species (Dahlberg et al. 2010).

In boreal and temperate forests, the most serious risk for wood-inhabiting fungi is not the decrease in forest cover, but instead a decrease in the natural quality of the forests (Lonsdale et al. 2008). Due to modern forestry, the average amount of decaying wood in Fennoscandian forests has decreased from around 100 or even more cubic meters in a natural forest to around 0-40 cubic meters in the managed forests depending on the stand characteristics and the measurement methods (Siitonens et al. 2000, Jönsson & Jonsson 2007, Siitonens et al. 2009, Eräjää et al. 2010). As a result, the lack of decaying wood and the changes in the age structure of the forests are the most important reasons for the national endangerment of wood-inhabiting fungi species in Finland (Rassi et al. 2001). In temperate Europe, the most important threats include the decline in the amount of dead wood, the increased forest fragmentation and the changes in dead wood composition (Heilmann-Clausen & Vesterholt 2008).

Ecological and conservation-related research of wood-inhabiting fungi has been relatively intensive recently in northern Europe. The research topics have included for example the effects of forest fragmentation on polypore species (Penttilä et al. 2006, Hottola 2009), the efficiency of restoration as a conservation tool (Junninen et al. 2008) and the efficiency of small conservation areas in polypore conservation (Sippola et al. 2005, Junninen & Kouki 2006, Hottola & Siitonens 2008). Also the dispersal (Edman et al. 2004a, Edman et al. 2004b) and for example colonisation and spatial patterns have been somewhat studied (Edman & Jonsson 2001, Jönsson et al. 2008, Ylisirniö et al. 2009).

Most of the studies have been conducted with polypores as a study species group, even though in many cases a small number of additional species have also been studied (Hottola & Siitonens 2008, Mönkkönen et al. 2009). In a few studies also corticioids have been included to the study (Penttilä & Kotiranta 1996, Berglund et al. 2005). In temperate areas the tradition seems to be somewhat different and the study species groups has often been larger, including often corticioids and other groups, such as agarics or ascomycetes (Heilmann-Clausen 2001, Heilmann-Clausen et al. 2005, Küffer et al. 2008, Pouska et al. 2010). The Fennoscandian enthusiasm to use solely polypores as a study species group may be at least partly due to the fact that polypores are a well known species group in these countries (Niemelä 2005) and thus easy to use as a model species group in research projects.

An important note on the studies focusing on the wood-inhabiting fungi is that they are almost solely targeted on detecting the fruit bodies, i.e. the reproducing structures of the fungi. It is largely unknown that what proportion of the species is detectable on the substrate as fruit bodies instead of being present solely as hyphal stage (see, however Allmér et al. 2006, Ovaskainen et al. 2010). Detecting the species from hymenial samples with molecular techniques is a growing and promising topic. However molecular techniques are labor intensive and are dependent on reference samples making these techniques less relevant in searches of the rarest species (Heilmann-Clausen & Vesterholt 2008).

3 THE AIMS OF THIS THESIS

Wood-inhabiting fungi are an ecologically important megadiverse species group (Boddy et al. 2008). Yet the ecological or conservation related research focusing on them lacks solid evidence-based knowledge of many methodological issues such as the optimal survey methods in different occasions, how these species should be studied, and what kind of biodiversity surrogates or indicators could be used? The existing guides for the research methods provide mostly general guidelines based on expert opinions (Huhndorf et al. 2004). Also, the few existing indicator systems are based on expert opinions (Kotiranta & Niemelä 1996). Even though expert opinions tend to be at least relatively valid because they are usually given by people specialized on the studied subject, they may be partly distorted due to the opinions and personal preferences of the people giving them. Thus evidence-based methodological research and supplementary recommendations are necessary.

In this thesis I try to provide knowledge for selecting suitable research methods for studies of wood-inhabiting fungi. I do this by two separate approaches: First, I study the possibilities of quantifying different indicator species groups among the wood-inhabiting fungi that could be used to predict the species richness or other conservation aspects of other species groups (I, II). If this kind of biodiversity indicators can be used, the expense of the studies could be reduced and more information could be derived from more easily collected species. My specific study questions considering this topic are

- 1) Polypores with long-living (perennial) fruit bodies are an easily studied species group with low short-term variation in their detectability. Could they be used as an indicator species group, from which the occurrences of some other groups could be predicted?
- 2) How can we quantify the indicator power based on a potential indicator species which indicates the occurrences of a target species?

- 3) White-Backed Woodpecker habitats are currently protected solely based on the knowledge about the woodpecker occurrences. Are there powerful indicator species that could be used to predict the occurrences of red-listed polypores in these habitats so that their future conservation work could be combined with the protection of woodpecker?

Secondly, I study the effect of survey methods on the results of biodiversity studies that focus on the wood-inhabiting fungi (III, IV). My specific study questions considering this topic are

- 4) How does the timing of the surveys affect the number of detected species?
- 5) How does the number of survey repeats affect the survey results?
- 6) How does the selected study species group affect the survey results?
- 7) What are the consequences of the size of the studied dead wood fractions on the results attained from the study?

4 MATERIAL AND METHODS

4.1 The data

4.1.1 Potential of wood-inhabiting fungi as biodiversity indicators (I, II)

I studied this topic using two separate data sets, 'the pooled data' and 'the White-Backed Woodpecker (*Dendrocopos leucotos*) data'. The aim of the collection of the pooled data was to study the potential of perennial polypores as indicators. I compiled the pooled data from different data sets collected by a large group of researchers (the authors in study I) and from published literature. The study area included Finland and adjacent Russian Karelia. The integrated data included datasets from hemiboreal to northern boreal vegetation zones (Ahti et al. 1968). The studied forest stands or larger areas had been affected by varying levels of forest fragmentation and forestry history. Most of the data were collected by the authors of study I and were therefore available with all the recorded environmental information. The rest of the pooled data were collected and published by other researchers, so conducting analysis could be done using only the relevant parts of the data in print.

All data were included only if all of the following conditions were fulfilled: 1) the data were collected of the whole polypore species assemblage growing on the studied dead wood pieces, and species identifications were considered reliable. 2) The data were enough up-to-date regarding the present knowledge of the polypore taxonomy. Therefore, datasets older than 30 years were not included. 3) Each dataset had to include at least the following information: species list, location of sampling site, sampling year, sampling dates with at least the accuracy of one month, and methods of sampling. 4) The data were collected during the autumn (August-November).

A majority of the data was collected from sample plots of varying size ranging from 0.03 to many hectares. The inventory methods of these plots varied especially considering the minimum size of the studied dead wood pieces. The rest of the data were collected mostly by opportunistic searches,

which means that the forest stands were inventoried with more or less random walks and all the detected polypore species were recorded.

The motivation for using the White-Backed Woodpecker data here was to test how the indicator power of potential indicator species towards the target species could be quantified. The polypore assemblages in the territories of White-backed woodpecker were inventoried in 2007. The data included 122 forest compartments in 10 woodpecker territories located in southern and central Finland. The inventories were a part of biodiversity monitoring acts of Metsähallitus (former Finnish forest and park service). Detailed information about the studied sites is given in (Markkanen 2008a) and can be attained from the inventory reports available from the Metsähallitus (Halme 2008, Markkanen 2008b). The inventories were conducted with an opportunistic sampling (Stokland & Sippola 2004) rather than based on fixed sample plots. The majority of the dead wood pieces with a diameter of more than five centimetres were always inspected and the whole detected polypore assemblages of the studied forest compartments were recorded.

4.1.2 How, when and how many times should we survey wood-inhabiting fungi? (III, IV)

I studied this topic with two separate data, the intensive survey data and the very fine woody debris data. The intensive survey data was collected to study the effects of the season, number of surveys and study species group to the results of the surveys. The research site (Kuusimäki) was situated in the municipality of Muurame in Central Finland. It is a state-owned about 90 hectares large conservation forest with a history of being slash and burn cultivated in 19th century but abandoned around 1860s and conserved as old-growth forest in 1980s. At present, the forest is of high conservation value, mostly due to the high number of threatened wood-decaying species that inhabit it.

I conducted an intensive sampling scheme in the forest during the years 2005-2008. I included 107 decaying trunks with a minimum diameter of 15 centimeters on the set up (Fig. 1). Every trunk was surveyed monthly during the whole snowless season in Central Finland. The first survey was conducted in mid-May, when the last snow patches have just melted. The last survey was conducted in mid-October, the time after which the first snowfalls usually happen within a few weeks. Thus the number of surveys was six in a year, totaling 24 surveys during four years.



FIGURE 1 One of the studied trunks (Scot's pine, *Pinus sylvestris*) in study III. The home of *Antrodia sinuosa*, *Hyphodontia aspera*, *Gymnopilus penetrans*, *Mycena stipata*, *Postia tephroleuca* and about 15 other detected species.

The target species group included polypores (Polyporaceae s.l.), agarics (Agaricales), about a third of the corticioid species including all the hydnoid and stereoid species and some other genera forming robust fruit bodies (*Phanerochaete*, *Scytonostroma*, *Phlebia* etc.), Gasteromycetes, some large-sized genera of Ascomycetes (such as *Peziza* and *Gyromitra*), all the ramarioid fungi and genus *Calocera* (Dacrymycetes). Thus the surveyed fungi included all the wood-inhabiting fungi that form easily delimited fruit bodies and are possible to be identified with a reasonable effort.

The very fine woody debris data was collected to study the effects of the size of the studied dead wood pieces on the results of the study. The data was collected in 2007 from 16 forests situated around Central Finland. Half of the studied forests were dominated by Scots pine (*Pinus sylvestris*) and half by Norway spruce (*Picea abies*). At each of the study sites, three 10 x 10 m sample plots were established: From the center of the forest stand or forest compartment three lines (10 m, 30 m, 50 m) were drawn at randomized compass courses. The end points of the lines were NW corners for the sample plots. The sides of the plots paralleled the principal compass points. In total, 48

sample plots were established. Considering the whole sample plot, all dead wood with a minimum diameter of two centimetres were counted and searched for the target species occurrences.

Four smaller 2×2 m sub-plots were assigned at corners of the sample plots. On each sub-plot every piece of dead wood (excluding leaves, needles and detached pieces of bark) was counted and searched for the target species occurrences (Fig. 2). The basal diameter of each piece was estimated. For some of the conducted analyses all dead wood was classified into five diameter classes: <0.5 cm, $0.5-1$ cm, $1-5$ cm, $5-10$ cm, and ≥ 10 cm. The target species group included corticioid fungi and polypores.



FIGURE 2 Part of a typical study plot of the very fine woody debris data. Every piece of dead wood visible in the figure (excluding the piece of detached pine bark) was counted and searched for the studied fungi.

4.2 Species identification and nomenclature (I, II, III, IV)

The species identification was conducted similarly in all the collected datasets (I, II, III and IV). All the occurrences were identified based on visible fruit bodies on the species level already in the field whenever possible. If the identification succeeded, herbaria samples were collected only if the species was especially rare or occurring in an extraordinary habitat. When the identification was not possible in the field, a sample was collected for microscopical identification. The samples were dried with an electric drier and later identified with a light microscope. In the pooled polypore data, storage of the collected samples varies and can be tracked from the original articles given

in the appendix A in study I. The majority of the samples collected for the other data sets are deposited in the natural history collection of the Jyväskylä University Museum (JYV). Some of the samples collected in study IV are deposited in the personal collections of Heikki Kotiranta and Katja Juutilainen and a few samples collected in studies II and III are deposited in other Finnish Herbaria (TUR, H).

The identification work was always conducted with the latest identification guides (e.g. Hansen & Knudsen 1997, Hansen & Knudsen 2000, Niemelä 2005, Knudsen & Vesterholt 2008) and the species division and nomenclature followed (Kotiranta et al. 2009) for Aphylloporoid fungi, (Knudsen & Vesterholt 2008) for Agarics and (Hansen & Knudsen 2000) for Ascomycetes. The identifications in study I were performed by a large group of polypore specialists, mostly the authors in the studies of appendix A. In study II mostly Anni Markkanen and I did the identifications, I identified all species in study III and identifications for study IV were performed by Katja Juutilainen, Heikki Kotiranta and I. By necessity, other specialists were consulted with the most difficult samples to maximize the proportion of the correctly identified samples.

4.3 Analyses (I, III, IV)

The pooled polypore data in study I was analyzed using regression analysis and analysis of covariance (ANCOVA).

The intensive survey data in study III was analyzed with repeated measures general linear model as well as with occupancy estimation analysis. In study three, we also calculated the overall detectability estimates for the studied species groups:

$$\text{Eq. 1} \quad D = 1 - (1 - d)^v$$

Where D is the probability that a species is detected at least once in v surveys, and d is the detectability in a single survey. The value attained from this formula reflects the probability to detect the species at least once during v surveys. The value scales from zero to one. Setting D at, for example, 0.95 and solving for a known d yields the number of visits (v) to attain a 95 % probability to locate a species at least once during the study. On the other hand, setting d and v on known levels and solving for D yields an overall detectability estimate.

The very fine woody debris data in study IV was analyzed with detrended correspondence analysis (DCA) as well as with mixed model analysis of variance (Mixed ANOVA) and Pearson correlation test.

The occupancy estimation analyses were conducted with program *Presence* (MacKenzie et al. 2006), DCA with PC-ORD (McCune & Mefford 2006). The rest of the analyzes were conducted with SPSS 14.0 or 16.0 for Windows (SPSS Incorporated).

4.4 The method for quantifying the indicator power (II)

In study II a new computational method was developed to enable quantifying the indicator power (IP) of a species for a single or several target species. For a single target species, IP of an indicator species I for the target species T is:

$$\text{Eq. 2} \quad \text{IP}_I = \sqrt{\{(S / O_I) (1 - [O_T - S] / [N - O_I])\}}$$

Where O_I is the frequency of occurrence of the indicator species I, O_T is the frequency of occurrence of the target species T; S is the frequency of shared occurrences of the species I and T; and N is the total number of sites surveyed.

The method seems simple and it is meant to be such too. However, despite its simplicity it provides multiple types of information, such as the strength on which the presence of the indicator indicates the presence or absence of the target species. The indicator power provides also the strength on which the absence of the indicator indicates the presence or the absence of the target species. Moreover, the method can be used simultaneously for multiple target species by counting parameters about how it performs in indicating their presences.

5 RESULTS AND DISCUSSION

5.1 Potential of wood-inhabiting fungi as biodiversity indicators (I, II, III)

The earlier work on the potential of wood-inhabiting fungi as indicator species has mostly focused on the possibility to use them as indicators for the condition of the biotopes that they inhabit. Kotiranta & Niemelä (1996) proposed some polypores and other wood-inhabiting species that could function as indicators of old-growth forests with especially high conservation value. A similar proposition, even though not as extensive, was done by (Bredesen et al. 1997), and one species was proposed to be a suitable indicator of forest continuity by (Sverdrup-Thygeson & Lindenmayer 2003). There have been also some attempts to predict the species richness of some other species groups based on the species richness of polypores, and vice versa (Jonsson & Jonsell 1999, Similä et al. 2006).

I studied the possibilities to use some wood-inhabiting fungi as indicators of species richness or presence of some other species. The first study (I) was focusing on the possibility to use perennial polypores as indicators of annual polypores. The other study (II) was targeting on the possibilities to predict the occurrences of any target species based on the occurrences of some potential indicator species. The method was general, but the example data treated polypores in the White-Backed Woodpecker habitats.

5.1.1 The potential of perennial polypores to be an indicator species group (I, III)

In general, the number of perennial species (Figure 3) was a strong indicator of the number of annual species, explaining 69.7% of the total variation in their number. The explanatory power was almost as good for the number of red-

listed annual species, explaining 67.4% of their total variance. This result could have been derived solely just because the larger the sampled area, the more perennial species and thus the more annual and annual red-listed species. However, the inventoried area was a poorer predictor of the variation in the annual species richness (58.9%) and especially of the variation in the richness of the red-listed annual species (35.8%).



FIGURE 3. Examples of an annual and a perennial polypore. A) *Ceriporia excelsa* (kirjokerikääpä in Finnish) is a species with annual, fleshy and soft fruit body. This particular fruit body lived for less than two months and it was not detectable on the trunk in most of the years (part of the data in study III). Muurame, Kuusimäki 23.9.2008. B) *Haploporus odorus* (raidantuoksukääpä in Finnish) is a species with perennial, long-living fruit body. More over, the species grows typically on standing Goat willow (*Salix caprea*) trunk and is thus visible from a relatively long distance. Pihtipudas, Lamminahonrinne, 14.10.2006.

When studied in more detail, the number of perennial polypores explained the variation in the number of all annual and annual red-listed species relatively well in all the studied vegetation zones, explaining a minimum of 61% of the variation. However, when studied in forests with different management histories the picture was different. The species richness of perennial polypores succeeded in the prediction of the species richness of annual species relatively well in forests with all kind of management histories, but the predictive ability was strikingly weak for the species richness of annual red-listed polypores in the managed forests (25.6%) and to some extent also in seminatural forests (45.5%).

It is difficult to find a biological solution for this lack of predictive ability in the managed forests. Thus, the most promising explanations derive from the data or the study set up. In managed forests, a sample plot includes often only a few polypore species due to the lower amount of coarse wood debris (Penttilä et al. 2004). The fewer they are, the more their identities are random. Thus the

managed plots, having smaller number of occurrences, have a more random sample of perennial, annual and annual red-listed species.

Actually, in study I, the size of the sample plot clearly affected the predictive ability of the number of perennial species. Considering the species richness of red-listed annual polypores, a sample plot with a size of about 0.5 hectares seemed to be adequate for relatively reliable conclusions. It is obvious that the scarcer the decaying trunks and thus the polypore occurrences are, the larger the plot must be to make reliable conclusions about the relationship between different species groups. On the other hand, if there are (almost) no occurrences, conservation value of the site is obviously low. One aspect that was neglected in study I, but could be more thoroughly discussed, is the potential of perennial polypores as a species group in long-term biodiversity monitoring projects. The reasons for biodiversity follow-up programs are the need to follow the effects of conservation efforts, restoration programs or exploitation of species (Kull et al. 2008).

It is critical to select suitable methods and species groups for the monitoring programs for them to be successful (Legg & Nagy 2006). A suitable method and species group should produce results that are repeatable and do not reflect other attributes than the one that is of interest. For example, there may be strong dependence of a species group on short-term changes in weather, which will easily bring unnecessary noise into the monitoring data, and possibly even lead to wrong interpretations based on the data. Thus the use of species groups with low short term variation in the occurrences should be advocated in monitoring programs. Perennial polypores could be a highly potential group in this sense. Their occurrences are not dependent on the season and the yearly fluctuations on the detected number of species are low, as evident based on the results of study III.

There is one feature that may disturb the use of perennial polypores as an indicator species group in monitoring projects. The long-living feature of their fruit bodies and hyphae may induce a time lag between the change and the moment when it is detected based on the number of fruit bodies (or species) of perennial polypores. However, since a majority of perennial polypores seems to be producing fruit bodies that only live for a few years, I do not regard this as a major problem. In general, wood-inhabiting fungi are probably relatively slow to indicate environmental change (Sippola & Renvall 1999). However, they may still be a useful tool by being relatively easy to survey and important considering their ecosystem functions.

5.1.2 Potential polypore indicators for the red-listed polypore species occurring in the White-backed Woodpecker territories (II)

Based on the polypore inventories conducted in the White-Backed Woodpecker territories, two red-listed polypore species, *Gloeoporus pannocinctus* and *Protomerulius caryae*, were relatively common in these habitats. At present their

occurrence in the woodpecker territories is protected by chance. Their protection could be combined with protection of the woodpecker if the occurrences of the polypores were known. Then the polypore occurrences could affect the delineation of the protected areas. The most serious obstacles for combined protection are that both these polypore species are difficult to observe and identify. If, there were indicators that were easy to observe and identify and that would predict the occurrences of these red-listed polypores, it would be possible to train the bird specialists conducting woodpecker inventories to recognize these indicators.

We tested if there were such easily detected and identified polypore species, potential indicators that had a strong indicator power towards the two red-listed species. Six species had a significantly high indicator power for *Gloeoporus pannocinctus* and 7 species for *Protomerulius caryae*. The species with the highest indicator power for each of the target species also had, in most cases, the highest total indicator power, i.e. the indicator power for the both of the target species.

In study II we recommended the use of the species with the highest total indicator power as the indicator species for red-listed polypores occurring in White-backed Woodpecker habitats in central Finland. However, after finishing the paper, the conservation status of the studied target species is probably changing (Kaisa Junninen, Pers. Comm.). Apparently *Gloeoporus pannocinctus* will be classified as LC (least concern) and *Protomerulius caryae* as NT (near threatened) in the forthcoming Finnish red-list which will be published in 2011. Thus it is questionable, if it is politically reasonable to put any effort in their indication even though there would be efficient indicators and biologically their conservation still makes sense. Moreover, their treatment in study II is still useful as an example of the search for suitable indicator species for particular target species.

5.2 How, when, and how many times should we survey wood-inhabiting fungi? (III, IV)

Fungi in general are a difficult species group to survey. The temporal hide and seek that their fruit bodies play with the biologists makes it difficult to locate them even when they are present at a site. Moreover, being flexible in their physiology, the fungi may be able to colonize surprising substrates. If the substrate is small, the fungi may simply perform a reproduction effort with a smaller fruit body. These flexible and unpredictable qualities of the fungi, combined with the overall poor knowledge about their biology, makes their biodiversity studies challenging.

5.2.1 The effects of seasonality (III)

The fruit bodies of wood-inhabiting fungi are seasonal in their occurrences, with the exception of perennial polypores (I, III) and a few other species with perennial fruit bodies. The details like strength and timing of their seasonality are, however, mostly unknown. Little more is known about the seasonal variation in the occurrences of ground-inhabiting fungi (Schmit et al. 1999, Straatsma et al. 2001, Lagana et al. 2002, Salerni et al. 2002, Baptista et al. 2010). There are huge regional and taxonomic gaps also considering the knowledge about their seasonal variation as most studies have focused on Agarics and other Basidiomycetes and been regionally restricted. The ecological mechanisms behind the seasonality are also poorly known, even though at least temperature and humidity, both seasonally varying environmental variables, are known to affect the fruit body production of wood-inhabiting fungi (Moore et al. 2008).

In study III, I found that the seasonal differences in the fruiting of wood-inhabiting fungi were high in the Kuusimäki intensive survey site. More over, the degree of seasonal variation and the emplacement of the fruiting peak varied between the years. However, the fruiting of different species groups varied; for example agarics showed a high peak in their fruiting in September while annual polypores showed a more flat fruiting peak such that the number of detected species was on average similar during the whole autumn (Fig. 4).

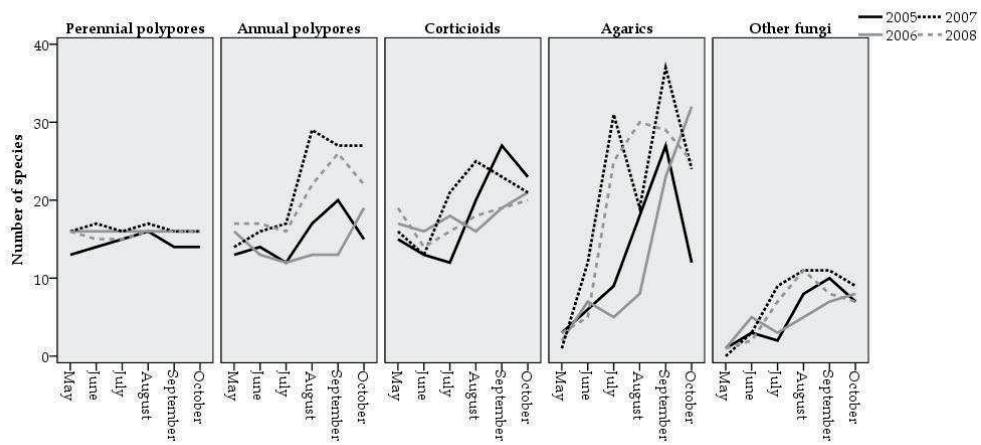


FIGURE 4 Seasonal variation of the number of detected species in different taxon groups by survey month and year.

Considering the whole fungal community surveyed, the four-year average showed that, in the study area, September is the optimal season for detecting

maximum number of species in a single survey. However, every survey month in the intensive survey data included unique species, i.e. species detected only during one survey month (although possibly in multiple years) during the four season period. Thus, conducting surveys in the peak season does not enable detecting the whole fruiting species pool.

5.2.2 The effects of repeated surveys (III)

Most of the published studies focusing on wood-inhabiting fungi have included only a single survey. Some exceptions, however, exist (e.g. Heilmann-Clausen 2001, Berglund et al. 2005, Heilmann-Clausen & Christensen 2005, Pouska et al. 2010). The most potential reason for the dominance of studies based on a single survey seems to be that the study species group has been polypores in most of studies, and they are estimated to be rather easily detected already based on a single survey (Berglund et al. 2005). However, the easy detectability of polypores as a group has recently been challenged (Löhmus 2009). Another reason for studies with no repeated surveys might be the pressure to establish studies with high number of replicates. Conventional wisdom may support studies with high number of replicates, even though the quality of the collected data would be better enhanced by conducting multiple surveys in fewer sites, if the studied species are detected imperfectly (Mackenzie & Royle 2005). Especially if the aim is to estimate the prevalence of some particular species, the surveys should always be replicated to maximize the cost efficiency of the data collection in a case of imperfect detectability (Mackenzie & Royle 2005).

Based on the results of study III it seems that for wood-inhabiting fungi, conducting multiple surveys in one study site should be the baseline, while conducting a single survey should be an exception. The only species group that has such a high detectability that a single survey may be enough, is the perennial polypores. For most of the species groups, an average species is detected with such a low probability, that two to four repeats would be the optimal number of surveys for minimizing the error in the data set in a cost-efficient manner if the aim is on community aspects or on the estimation of the prevalence of some particular species (Mackenzie & Royle 2005). The only case where one survey may be cost-efficient for species with low detectability is a situation where the species identities do not count like when the focus is to compare the number of species in different habitat types.

The selected season for the repeated surveys was also important considering the number of detected species. The seasonal effect favoring surveys in September was so strong that when conducting two surveys, to detect a maximum number both of them should be conducted in September. The number of detected species increased somewhat when one or two years were left between the repeats. This was probably mostly due to the fact that some species are not fruiting in some years. The succession of the studied trunks may also have some effect, but this should be relatively low because the

number of species on individual trunks was not studied. Thus, even though the succession during the four years would have caused a species to disappear from some particular trunk, it may have occurred on some other trunk and therefore be accounted for in the number of detected species.

5.2.3 The effect of dead wood size

The minimum size of the studied dead wood is an essential methodological decision done in about every properly designed study considering wood-inhabiting species or the dead wood itself. Usually the minimum is set on some size that has more sense in a view of metric system rather than the ecology of the studied species. It is, to me at least, rather unlikely that the ecologically most meaningful size limits of different types of dead wood are at the even numbers that are commonly used (e.g. 1, 5, 10, 15 and 40 cm) (Kruys & Jonsson 1999, Kruys & Jonsson 1999, Heilmann-Clausen & Christensen 2004, Norden et al. 2004, Junninen et al. 2006, Hottola & Siitonen 2008, Castro & Wise 2009, Mönkkönen et al. 2009, Yamashita et al. 2009). Thus, being a decision done for practical reasons, the effects of skipping the smaller dead wood should be at the minimum known when conducting the study.

Some research has been conducted to find out the importance of the smallest dead wood items. Norden et al. (2004) found that small-sized dead wood pieces (from 1 to 10 centimeters) are especially important for ascomycetes, but to some extent also for basidiomycetes in temperate forests. Kruys and Jonsson (1999) on the other hand, found that for species richness, the small-sized dead wood seems to be especially important when the total volume of dead wood is low.

The only study so far focusing on the importance of really small dead wood pieces, the so called very fine woody debris, on the wood-inhabiting fungi has been the one conducted by Küffer et al (2008) in the forests of Switzerland and Ukraine. They studied the very smallest dead wood pieces and revealed that there are ecologically important diameters of the dead wood creating differences between the communities inhabiting them. These limiting values were at about 0.7 and 1.4 cm. Thus the most striking differences in the community of the wood-inhabiting fungi seem to be below the size limits of most of the studies.

In study IV the importance of the smallest dead wood pieces on the detected community was striking, especially considering the number of occurrences. Setting the lower limit of the surveyed dead wood at one centimeter induced the loss of almost half of the occurrences of wood-inhabiting fungi. Raising the limit to five centimeter increased the proportion of lost occurrences to 66%. Thus, the majority of the wood-inhabiting fungi community occupies small-sized dead wood. Considering for example some conservation-related issues, it may sometimes be reasonable to survey only the larger dead wood pieces. However, at least in the studies trying to understand

the whole community, surveying also the smallest dead wood pieces is relevant. It may totally change our views of the population sizes, metapopulation dynamics and other similar things considering the ecology of wood-inhabiting fungi. From an applied point of view it should be noted that a very recent and growing forest management method, the energy-wood harvesting seems to have a heavy effect on the volume of fine woody debris (Eräjää et al. 2010). Therefore the knowledge about the ecological importance of small dead wood pieces for the fungal community should be better known for the estimation of forest management effects.

6 APPLIED PERSPECTIVES

In this thesis I have provided different examples of the approaches which could improve the quality of biodiversity research focusing on the wood-inhabiting fungi.

First, I studied the possible use of one potential indicator species group. I argue that in some occasions, especially in the poorly known areas of the globe, it would be useful to conduct surveys considering only or mostly the perennial polypores even though their predictive power towards the annual red-listed species was not always strong. Their use would enable conducting reliable surveys based on a single visit and regardless of the season. In poorly known areas, gathering preliminary knowledge with low costs might be extremely important. Moreover, also in the areas with good knowledge of the polypore communities, using perennial polypores as a species group in monitoring would be rational. The use of them or another similar species group with low short-variation in the occurrences would reduce the risk of conducting wrong conclusions resulting from weather or other locally and temporally varying conditions. I also recommend conducting mathematical calculations about the indicator power of the proposed indicator species before their implementation. Quantifying the indicator power gives more credibility to the proposed indicators, even though I must admit that a suitable data for this does not always exist. Therefore, I still recommend that when indicators are dire the experts may propose indicators based on their own experience if the data for confirming the indicator power does not exist.

Second, I studied the effects of the selected survey methods on the quality of the collected data I found that the current methods used in the studies of wood-inhabiting fungi are not always optimal. More focus should be put on the proper, open-minded and lateral consideration of the methods before the study is conducted. If the study aims, for example, to understand the community of the wood-inhabiting fungi, more than one visit to the study sites should be done, the season of the visits should be properly selected and at least some of the smallest dead wood pieces should also be checked. Polypores are as a whole are not a considerably easier study group than some other groups of wood-

inhabiting fungi. Thus, I strongly recommend that the study species group in the studies would be considered more based on ecological basis instead of simply studying polypores because of historical motives.

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During the years 2002-2004 something awesome happened in my mind. I joined some undergraduate courses organized by Seppo Huhtinen, and fell in love with the fungi. Thank you Seppo for letting me and the fungi meet. A big hug and kiss to the whole community of Finnish mycologists, especially Heini and Teppo Rämä, Tuula Niskanen, Hanna Tuovila, Lasse Kosonen, Ilkka Kyttövuori, Mauri Lahti, Kare Liimatainen, Timo Kosonen, Mika Toivonen, Tea von Bonsdorff-Salminen, Panu Kunttu, Jukka Vauras, Stefan Jakobsson, Jarkko Korhonen, Emilia Pippola, Jussi Ruotsalainen, Dmitry Schigel and Unski Söderholm. We have had some really wonderful times learning, speaking and living fungi. Thank you all for teaching and learning together!

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along the way. We have tried to swim upstream in a rapid, and against all odds, succeeded!

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YHTEENVETO (RÉSUMÉ IN FINNISH)

Työkaluja monimuotoisuustutkimuksiin – tutkimuskohteina puulla elävät sienet

Ihmisen toiminta uhkaa planeettamme luonnon monimuotoisuutta monin tavoin. Lajeja kuolee sukupuuttoon kiihtyvä vauhtia, jopa niin paljon, että ilmiötä kutsutaan jo maapallon historian kuudenneksi sukupuuttoaalaksi, siis vastavaksi ilmiöksi kuin esimerkiksi dinosaurusten katoaminen planeetaltamme. Lajiston katoamista vastaan voidaan taistella monin tavoin. Lajien ja alueiden suojelun pohjaksi tehdään paljon tutkimusta, joka pureutuu lajen uhanalaistumisen syihin, pyrkii havaitsemaan lajen ja niiden populaatioiden runsausmuutoksia ja niin edelleen. Nämä tutkimukset pyrkivät antamaan poliitikoille ja muille toimijoille tietoa ja ohjeita siitä, millaista luontoa tulisi erityisesti suojella, missä ja kuinka paljon.

Monimuotoisuustutkimusten tekeminen oikein ei kuitenkaan ole helppoa. Tutkimus voi epäonnistua kaikissa vaiheissaan, ja pahimmassa tapauksessa siihen uhratut resurssit voivat mennä täysin hukkaan, jos tutkimus esimerkiksi ei pysty vastaamaan niihin kysymyksiin joita varten se on tehty. Näin ollen on syytä varmistua siitä, että monimuotoisuustutkimukset toteutetaan optimaalisilla menetelmillä, jotka ovat kustannustehokkaita ja mahdollistavat hyvien ja luotettavien vastausten saamisen.

Sienet ovat valtavan monimuotoinen ja runsas lajiryhmä. Maailmanlaajuisesti sienilajeja arvioidaan olevan vähintään lähes miljoona. Sienet ovat toiminnallisesti hyvin tärkeitä ekosysteemi-insinöörejä, jotka huolehtivat esimerkiksi kasviaineksen lahottamisesta, tehostavat puiden ja muiden kasvien kasvua ja ovat samalla itse resurssina valtavalle joukolle muita eliöläajeja. Puulla elävät sienet ovat esimerkiksi tärkein lahottajaryhmä kaikissa maailman metsissä. Ilman niiden toimintaa kuollut puuaines jäisi metsiin lahoamatta ja metsien ravinteekerto häiriintyi. Puulla elävien sienten joukossa on myös valtava joukko uhanalaisia lajeja. Esimerkiksi Suomessa tavatuista puulla elävistä sienilajeista useita kymmeniä on arvioitu uhanalaiseksi.

Tutkin väitöskirjassani puulla elävien sienten monimuotoisuustutkimusten menetelmiä. Tarkoituksenani oli kehittää menetelmiä, joiden avulla puulla eläviä sieniä voitaisiin tutkia kustannustehokkaasti ja optimaalisesti niin, että saatavien tulosten luotettavuus olisi maksimoitu. Pyrin tähän kahden erilaisen lähestymistavan avulla: ensinnäkin tutkimalla voisiko lahottajasienten joukossa olla sellaisia indikaattori- eli ilmentäjälajiryhmiä, joiden lajiston selvittäminen olisi helppoa, ja joiden perusteella voitaisiin ennustaa joidenkin vaikeammin tutkittavien ryhmien läsnäoloa. Toisaalta tutkin myös sitä, miten valitut tutkimusmenetelmät

kuten selvityksen ajankohta, selvityksen toistojen määrä, tutkittava lajiryhmä tai tutkitun lahopuun koko vaikuttavat havaittavaan lajijoukkoon.

Mahdollisena ilmentäjälajiryhmänä tutkin erityisesti pitkäikäisiä, useita vuosia eläviä itiöemiä muodostavia käännejajeja. Koska niiden itiöemät ovat aina näkyvillä, niiden selvittäminen ja havainnointi on helppoa, eikä tutkimustulos riipu esimerkiksi säätilasta tai vuodenajasta. Näin ollen olisi mielekästä tutkia vain niitä, jos niiden lajirunsauden perusteella voitaisiin ennustaa myös vaikeammin tutkittavien lajien runsauksia. Tulokset osoittivatkin, että monivuotisten käänpien lajimäärä ennustaa melko hyvin muiden käänpien lajirunsautta luonnontilaisissa tai lähes luonnontilaisissa metsissä. Ennuste ei kuitenkaan ollut yhtä hyvä ihmisen käsittelemissä metsissä, joissa monivuotisten käänpien määrä enusti uhanalaislajien määrää vain heikosti.

Kehitin myös laskennallisen menetelmän, jonka avulla yksittäisen potentiaalisen ilmentäjäljin osoittama ennuste toisen lajin läsnäolosta voidaan laskea ja määritellä suhteessa muihin lajeihin. Testasin menetelmää käänpääaineistolla, joka oli kerätty valkoselkätikköjen reviireiltä. Havaitsin, että on olemassa lajeja, joiden läsnäolo ilmentää voimakkaasti joidenkin valkoselkätikkametsissä esiintyvien uhanalaisten käänpien esiintymistä. Opettamalla nämä lajit metsissä liikkuville lintuasiantuntijoille saataisiin samoilla maastokäynneillä tietoa myös käävistä. Tällä tavoin valkoselkätikan suojeleutoimiin voitaisiin yhdistää myös lahottajasienten suojeleua, ja tehtävät suojelepäätökset olisivat laajemmin perusteltavisa.

Tutkimukseni erilaisten lahottajasieniryhmien tutkimusmenetelmistä osoittivat, että suurin osa Pohjoismaisista lahottajasienitutkimuksista tehdään käytäen ainakin osin epäoptimaalisia tutkimusmenetelmiä. Lahottajasienten esiintyminen vaihtelee vuosien sisällä ja vuosien välillä niin paljon, että useimmissa tutkimuksissa pitäisi tehdä toistettuja inventointeja, jotta tutkimustulosten luottavuus paranisi.

Havaitsin myös, että pienikokoisella lahopuulla elää runsas lahottajasieniyhteisö, joka eroaa suurikokoisen puun lajistosta. Pienikokoisella puulla olevien sieniesiintymien määrä oli hyvin suuri, ja uskon, että tämän resurssin merkitystä ei ole aiemmin ymmärretty. Tulevissa tutkimuksissa pitäisikin useammin tutkia myös hyvin pienet lahopuukappaleet, jotta lahottajasieniyhteisöistä saataisiin kattavampi kuva.

Yhteenvetona voidin todeta, että lahottajasienitutkimusten menetelmiin tulee kiinnittää entistä enemmän huomiota. Käsityksemme lahottajasieniyhteisöistä ja esimerkiksi lajien suojeleutilanteesta voivat tulevaisuudessa muuttua huomattavasti, kun saadaan kerättyä riittävästi tietoa eri alueilta ja erilaisilla, tarkoituksenmukaisilla tutkimusmenetelmillä.

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