Fungal Ecology 27 (2017) 193–201

Contents lists available at ScienceDirect

Fungal Ecology

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

The history and future of fungi as biodiversity surrogates in forests

Panu Halme [a, b, *], Jan Holec [c], Jacob Heilmann-Clausen [d]

[a] Jyväskylä University Museum, University of Jyväskylä, Finland
[b] Department of Biological and Environmental Science, University of Jyväskylä, Finland
[c] Mycological Department, National Museum, Cirkusová 1740, Praha 9, Czechia
[d] Centre for Macroecology, Evolution and Climate, Natural History Museum of Denmark, University of Copenhagen, DK-2100 Copenhagen, Denmark

A R T I C L E I N F O

Article history:
Received 29 April 2016
Received in revised form
9 September 2016
Accepted 14 October 2016
Available online 16 February 2017

Corresponding Editor: Claus Bässler

Keywords:
Boreal forests
Flagship species
Indicator species
Primeval forests
Temperate forests
Umbrella species
Wood-inhabiting fungi

A B S T R A C T

Biodiversity surrogates are commonly used in conservation biology. Here we review how fungi have been used as such in forest conservation, emphasizing proposed surrogate roles and practical applications. We show that many fungal surrogates have been suggested based on field experience and loose concepts, rather than on rigorously collected scientific data. Yet, they have played an important role, not only in forest conservation, but also in inspiring research in fungal ecology and forest history. We argue that, even in times of ecosystem oriented conservation planning and molecular tools to analyze fungal communities, fruit bodies of macrofungi have potential as convenient conservation shortcuts and easy tools to communicate complex biodiversity for a broader audience. To improve the reliability of future fungal surrogates we propose a three step protocol for developing evidence based schemes for practical application in forest conservation.

1. Introduction

Nature managers need reliable information on biodiversity to be able to make efficient conservation decisions. However, conducting a full biodiversity survey is practically impossible even for very small areas (Basset et al., 2012), and usually conservation planning needs to be based on information on large, even nationwide or cross-border areas (Lindenmayer and Likens, 2011). Therefore, in the lack of high resolution high coverage data on biodiversity, conservation decisions are usually based on some proxies of the conservation value of relevant areas. In an optimal planning situation, these proxies, preferably containing data on several different species groups (Westgate et al., 2014), are downloaded in spatial conservation planning software and the decision is based on a systematic analysis involving factors like habitat quality, connectivity, complementarity and cost efficiency (Teeffelen et al., 2006; Moilanen et al., 2011). However, often the information needed for such an analysis is fragmentary or lacking, or time constraints are too strict for such a holistic approach. One type of proxy is surrogate species, which according to Caro (2010), "*are used to represent other species or aspects of the environment to attain a conservation objective*".

In reality, surrogate species are used in various ways and for various purposes, and the terminology has historically been highly confusing. Based on Caro (2010), who has made a serious effort to disentangle the most common surrogate types and their usages, the following types can be distinguished:

Biodiversity indicators are proposed to indicate the richness of a larger species group, other species group(s) or even the whole other biota (Fig. 1; Rodrigues and Brooks, 2007; Šálek et al., 2015). Biodiversity indicators have been used to recognize and delineate biodiversity hotspots on the continental to global scale (Orme et al., 2005), and to assist reserve site selection on the national to regional scale (Caro, 2010).

Umbrella species are proposed to serve as conservation umbrellas for a number of other species with shared habitat or management requirements (Roberge and Angelstam, 2004; Branton and Richardson, 2011). Related hereto, the *Focal species* concept is basically a multispecies umbrella species approach, where a set of

* Corresponding author. Jyväskylä University Museum, University of Jyväskylä, Finland.
E-mail address: panu.halme@jyu.fi (P. Halme).

http://dx.doi.org/10.1016/j.funeco.2016.10.005
1754-5048/

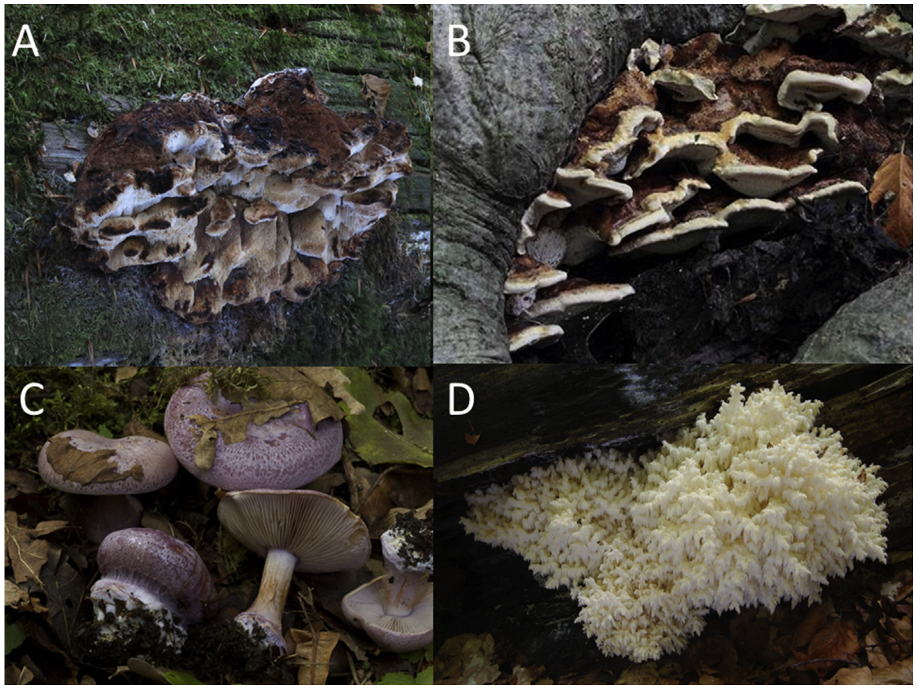

Fig. 1. Examples of suggested fungal surrogates: (A) *Amylocystis lapponica* is a widely used indicator of old-growth forest habitats, and may serve as a suitable umbrella species for conserving threatened biota associated with old-growth spruce forests (see Nordén et al., 2013). (Czech Republic, Boubínský prales virgin forest, photo Jan Holec); (B) *Inonotus cuticularis* is a key agent in forming hollows in living beech trees, and can hence be considered a potential fungal keystone species, responsible for the creation of important habitats for threatened beetles (Müller et al., 2014). (Denmark, Hesede Skov, photo Thomas Kehlet); (C) Based on nested subset patterns *Cortinarius sodagnitus* was identified by Jeppesen and Frøslev (2011) as a good biodiversity indicator for communities of *Cortinarius* subg. *Phlegmacium* species forming ectomycorrhizas with deciduous trees on clayey or calcareous soils (Sweden, Bohuslän, photo Thomas Stjernegaard Jeppesen); (D) *Hericium coralloides* has been promoted as an indicator species several times and has obvious flagship species qualities, due to its attractiveness and large size. However, in this issue Abrego et al., (2016, 2017) show that actually it is not strictly dependent on well-connected old-growth forests (Czech Republic, Boubínský prales virgin forest, photo Jan Holec).

selected species are proposed to have specific life history characteristics that are expected to confer protection to other species that are facing similar threats if addressed properly in conservation planning (Nicholson et al., 2013).

Keystone and engineering species are defined as species with especially important roles in the ecosystem. Their presence is often needed for maintaining important aspects of ecosystem functioning and, as surrogates, their presence in an ecosystem simply indicates that these roles are played (Paine, 1995; Caro and O'Doherty, 1999).

Flagship and iconic species are primarily conservation awareness raising tools and used mostly to target public interest towards endangered habitats or species (Andelman and Fagan, 2000; Caro, 2010).

Ecological disturbance indicators are proposed to indicate a general effect of a certain disturbance in the environment whereas *cross-taxon disturbance indicators* are proposed to indicate the effect of a disturbance specifically on some certain taxa other than the indicator group itself (Caro, 2010). Usually these indicators are used to monitor the effects of negative disturbances such as extensive pollution. Closely related to disturbance indicators, different concepts of ecological indicators have been proposed. For example, Ellenberg indicator values (Ellenberg et al., 1991) are well-known tools to identify ecological conditions especially in plant communities. Ellenberg values have been developed to estimate the position of known communities along gradients of humidity, soil productivity, pH, continentality and other important factors, without taking direct measurements (see for example Dupouey et al., 2002; Seidling and Fischer, 2008; Simmel et al., 2017). These approaches should be separated from biodiversity surrogate approaches because of their different focus and purpose, even if they are highly relevant in monitoring habitat quality, and not least changes in habitat quality over time.

In this paper we focus on non-lichenized fungi as biodiversity surrogates in forest habitats. We first review how fungi have been used as biodiversity surrogates historically. We continue with a critique on proposed surrogate schemes conceptually, and in relation to the current knowledge of good surrogate schemes, and our own experience. Finally, we suggest a proposal for better protocols with a special focus on fungi as surrogate agents. Our proposal is divided in 3 separate steps that should, in our opinion, be followed to reach a justified and reliable surrogate system.

2. The history of fungi as practical surrogates in forest conservation

The use of fungi as biodiversity surrogates in forest conservation was initiated in North Europe in the 1990s (Høiland and Bendiksen, 1991; Vesterholt, 1991; Karström, 1992; Kotiranta and Niemelä, 1996; Parmasto and Parmasto, 1997, Table 1). The proposal of fungal surrogate species was stimulated by increasing awareness of modern forestry as a threat to forest biodiversity, and was fueled by the fact that boreal forests have a low diversity of vascular plants (see Heilmann-Clausen et al., 2015). In contrast, fungi are often more visible, very diverse and play important roles in boreal forest ecosystems as decomposers and mycorrhizal symbionts, and many are associated with old-growth forest characteristics, like the presence of large dead wood and undisturbed forest soils. Typically, the selection of species was based on the long-time experience of leading field mycologists combined with studies of fungal diversity in selected areas or monitoring plots. The surrogate lists were made for evaluation and comparison of various forest stands with the aim