BIOLOGICAL CONSERVATION 129 (2006) 271–276

available at www.sciencedirect.com

SCIENCE DIRECT®

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

Mushroom picking does not impair future harvests – results of a long-term study in Switzerland

Simon Egli[a,*], *Martina Peter*[a], *Christoph Buser*[b], *Werner Stahel*[b], *François Ayer*[a]

[a]*Research Department Landscape, Swiss Federal Research Institute WSL, Zuercherstrasse 111, CH-8903 Birmensdorf, Switzerland*
[b]*Department of Mathematics, Swiss Federal Institute of Technology, CH-8092 Zurich, Switzerland*

A R T I C L E I N F O

Article history:
Received 10 August 2005
Received in revised form
27 October 2005
Accepted 31 October 2005
Available online 5 December 2005

Keywords:
Mushroom picking
Trampling
Fungi
Species richness
Conservation

A B S T R A C T

Forest fungi not only have important functions within the forest ecosystem, but picking their fruit bodies is also a popular past time, as well as a source of income in many developing and developed countries. The expansion of commercial harvesting in many parts of the world has led to widespread concern about overharvesting and possible damage to fungal resources. In 1975, we started a field research project to investigate the effects of mushroom picking on fruit body occurrence. The three treatments applied were the harvesting techniques picking and cutting, and the concomitant trampling of the forest floor. The results reveal that, contrary to expectations, long-term and systematic harvesting reduces neither the future yields of fruit bodies nor the species richness of wild forest fungi, irrespective of whether the harvesting technique was picking or cutting. Forest floor trampling does, however, reduce fruit body numbers, but our data show no evidence that trampling damaged the soil mycelia in the studied time period.

1. Introduction

Forest fungi perform important functions within the forest ecosystem. Saprobic species decompose organic matter and ectomycorrhizal species enhance nutrient acquisition, improve stress tolerance and the pathogen resistance of their host trees (Smith and Read, 1997). Picking wild forest mushrooms is a popular pastime and recreational activity. In certain regions of the world, mushroom harvests are also commercially important, especially for rural communities in developing countries, and in some developed countries as well (Boa, 2004). In Eastern Europe the export of forest fungi has emerged as an important income source (Peric and Pinguli, 2001). In the Pacific Northwest of the United States chanterelles have spawned a large commercial harvesting industry over the last two decades (Pilz et al., 2003). The value of total production of chanterelles on the world market is estimated at about US $ 1.67 billion (Watling, 1997). The "soil expectation value" for forest fungi (e.g. US dollars/ha/year) is on certain forest sites as high as that for timber (Alexander et al., 2002).

According to a recently published FAO study, 2166 edible species are known worldwide and 470 species have useful medicinal properties (Boa, 2004). Harvesting pressure has increased in many parts of the world (Boa, 2004), and fungal species diversity is claimed to have decreased over the past decades (Arnolds, 1991; Wang and Hall, 2004). This has led to widespread concern about overharvesting and possible damage to fungal resources. Several countries or regions have introduced legal restrictions on the harvesting of edible fungi in natural habitats because they fear that the removal of fruit bodies from the forest, often before spore dispersal, might impair their reproduction. Spores are important for the survival, migration, and distribution of genetic variability and for

* *Corresponding author:* Tel.: +41 1 7392271; fax: +41 1 7392215.
E-mail address: simon.egli@wsl.ch (S. Egli).

0006-3207/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2005.10.042

bringing together compatible mating types for sexual reproduction (Dix and Webster, 1995).

Since the 1970s, 19 of the 26 cantons in Switzerland have introduced weight limits or closed seasons. This has caused some controversy, since there is no scientific evidence regarding the effectiveness of such restrictions. We therefore started a research project in 1975 to investigate the impact of harvesting mushrooms on subsequent fruiting. The study was carried out in the fungus reserve Chanéaz, located in a typical mixed forest on the Swiss Central Plateau. In a preliminary analysis, no significant effects of harvesting were detected on 15 species that met the minimum requirements for a statistical analysis (Egli et al., 1990). Consequently, we decided to extend the study to obtain results for more species over a longer period. A second study was started in a subalpine pure Norway spruce forest (Moosboden) to obtain additional data from another prevalent Swiss forest type and popular area for mushroom harvesting. Whereas at Chanéaz we studied the effects of harvesting and harvesting techniques (picking/cutting), the Moosboden study focused on the effects of the concomitant trampling of the forest floor. This focus was chosen because an earlier experiment had shown a strong negative effect of trampling on the fruit body production of a colony of the Yellow Foot Chanterelle, *Cantharellus lutescens* Fr. (Egli and Ayer, 1997).

2. Materials and methods

2.1. Study sites

The study was carried out in two fungus reserves in southwestern Switzerland.

The first, "Chanéaz" (74 ha), established in 1975 in a dominant forest type of the Swiss Central Plateau at 600 m a.s.l., is a mixed old-growth forest with deciduous and coniferous tree species of different ages (mainly *Fagus silvatica* L., *Quercus robur* L., *Picea abies* (L.) Karst., *Abies alba* Mill., *Pinus silvestris* L., *Pinus strobus* L., and *Larix decidua* Mill.).

The second, "Moosboden" (3 ha), established in 1990 at 1250 m a.s.l., is a pure, uniform Norway spruce forest (*Picea abies* (L.) Karst), reforested 110 years ago.

2.2. Experimental design

Chanéaz. Five 300 m^2 blocks were divided into three plots of 10 m × 10 m with the treatments "harvesting by picking", "harvesting by cutting", and "control".

Moosboden. Fourteen 13 × 13 m blocks were divided into four 6.5 × 6.5 m plots with the randomly distributed treatments "picking with trampling", "picking without trampling", "no picking with trampling", "no picking without trampling". The treatment "with trampling" corresponds to normal walking associated with mushroom harvesting, mimicking that of a mushroom picker. The "without trampling" plots were provided with catwalks to avoid soil contact while picking or counting the fruit bodies. The installations were made in April 1990, before starting the experiment.

All observation plots were surrounded by fences to avoid disturbance by mushroom pickers.

2.3. Sampling

All fruit bodies of the epigeous macromycetes of soil-inhabiting species were identified and counted at weekly intervals from May to December (weeks 21–52). Thirty-nine species that form large quantities of very small fruit bodies (e.g. *Mycena* sp., *Strobilurus* sp., *Marasmius* sp.) were excluded to avoid counting difficulties. Moreover, 12 taxonomically critical species were also excluded to avoid possible irregularities due to unclear identification. When first recorded, the fruit bodies were marked with methylene blue on the cap to avoid double counting. In the picking and cutting treatments, only edible fungi were harvested.

Chanéaz. The survey was started in 1977, and continued until 2003. Between 1980 and 1983, only the edible fungi were recorded. These four incomplete years were excluded from the analyses. A total of 436 species were included and 97,700 fruit bodies counted (edible: 103 species/53,863 fruit bodies; non-edible: 333 species/43,837 fruit bodies).

Moosboden. The survey was started in 1990 and ended in 2000. A total of 250 species were included and 50,222 fruit bodies counted (edible: 51 species/10,173 fruit bodies; non-edible: 199 species/40,049 fruit bodies).

A total of 582 species were recorded at the two sites, with 146 species common to both sites. Collections of all the species recorded are deposited in the mycoherbarium of the Swiss Federal Research Institute WSL.

2.4. Analyses

We tested how the treatments did affect species richness and the total number of fruit bodies produced at the levels of species, families and edible and non-edible species. The numbers of fruit bodies produced per year were log transformed to reduce the influence of plots with large numbers of fruit bodies. To avoid problems with zero observations, we added the value 1 to each year sum before calculating the log. The same transformation was used for the number of species after examining the residuals.

We applied two statistical models: 1. To assess the impact of the different treatments by ANOVA, we calculated means over all years since the production of fruit bodies varied greatly from year to year. 2. To evaluate whether the progression over time of a parameter differed with treatment, we applied a repeated measures ANOVA and tested the interaction of treatment and time using Greenhouse–Geisser's correction. In both models and datasets we included the blocks as a blockfactor. In Chanéaz there was one treatment factor with three steps (control, picking, cutting) and we calculated two contrasts (control vs. mean of picking and cutting; picking vs. cutting). In Moosboden we tested two treatment factors (harvesting, trampling) and their interaction. Since the interactions were not significant (p-values clearly above 0.05, only in one case close to this limit), the main effect model was applied. Model assumptions were checked using a graphic residual analysis. We used a quantile–quantile plot to verify normality (normal plot), the Tukey–Anscombe plot to test for homoscedasticity and lack of fit, and a leverage plot for finding dangerous leverage points. In general the assumptions held, even if there were some outliers. Exclusions of outliers did not change the results noticeably. The analyses were performed with the statistical software R (R Development Core Team, 2004) and the SPSS software (version 12, see http://www.spss.com).

3. Results

The present data show that harvesting does not adversely affect the production of fruit bodies (Table 1 and Figs. 1, 2(a)). Edible fungi, which were selectively harvested, did not decrease relative to unharvested non-edible ones with respect to either the abundance of fruit bodies or species richness. No different trends were detected, even over a period of 29 years, in the harvested and non-harvested sites, irrespective of whether the harvesting technique was picking or cutting (Fig. 1). These findings applied for all the fungal species as well as for single species and families.

The concomitant trampling of the forest floor, however, significantly reduced the number of fruit bodies produced (Table 1 and Fig. 2(b)). Based on the statistical analysis it is likely that trampling reduces fruit body production to about 70% of that on untrampled areas. The mean number of fruiting species per year was also significantly lower in trampled plots than in non-trampled ones. Surprisingly, however, the total number of species that fruited over the decade of sampling was about the same in the trampled as in the non-trampled plots (195 and 189, respectively).

4. Discussion

Fruit body and fruiting species numbers were unaffected in our study areas when they were systematically harvested over a period of 29 years. Irregular field observations in other areas also suggest that the impact of harvesting may well be negligible (Jahn and Jahn, 1986; Jansen and

Table 1 – ANOVA table of the effects of harvesting on fruit body production

Treatment		Mean over time			Treatment × time [a]
Subject	Group	Exp(coef)[b]	Conf. int.[c]	*p*-Value[d]	*p*-Value
Chanéaz (1977–2003)					
Non-harvesting/harvesting			(Reference: non-harvesting)		(All treatments)
No. of fruit bodies	All species	1.03	0.71–1.48	0.878	0.437
	Edible [e]	1.11	0.78–1.58	0.513	0.261
	Non-edible	0.90	0.65–1.26	0.501	0.679
Species richness	All species	0.97	0.81–1.17	0.746	0.373
	Edible	0.99	0.86–1.15	0.887	0.138
	Non-edible	0.99	0.82–1.19	0.876	0.847
Picking/cutting			(Reference: picking)		
No. of fruit bodies	All species	0.81	0.53–1.23	0.279	
	Edible	0.82	0.54–1.22	0.268	
	Non-edible	0.87	0.59–1.28	0.427	
Species richness	All species	0.94	0.76–1.16	0.503	
	Edible	0.99	0.84–1.17	0.936	
	Non-edible	0.89	0.72–1.11	0.267	
Moosboden (1990–2000)					
Non-harvesting/harvesting			(Reference: non-harvesting)		
No. of fruit bodies	All species	1.13	0.85–1.51	0.380	0.343
	Edible	1.16	0.81–1.67	0.413	0.660
	Non-edible	1.09	0.79–1.52	0.589	0.702
Species richness	All species	1.01	0.91–1.13	0.818	0.395
	Edible	0.97	0.84–1.17	0.657	0.829
	Non-edible	1.03	0.94–1.14	0.514	0.910
Non-trampling/trampling			(Reference: non-trampling)		
No. of fruit bodies	All species	0.72	0.54–0.96	0.028*	0.419
	Edible	0.64	0.45–0.92	0.019*	0.064
	Non-edible	0.78	0.56–1.08	0.135	0.392
Species richness	All species	0.86	0.77–0.96	0.006**	0.377
	Edible	0.87	0.75–1.00	0.050*	0.119
	Non-edible	0.86	0.78–0.95	0.004**	0.478

a Treatment × time interactions of repeated measures compare the progression over time of the respective parameter among the different treatments. At Chanéaz, all three treatments (control, picking, cutting) were compared.
b Exp (coef) = exponent of the regression coefficient. This value is a measure of the treatment effect. It can be directly interpreted as a factor value showing the expected changes in the numbers of fruit bodies or species.
c Conf. int. = confidence interval 2.5%/97.5% of the exp (coef).
d Asterisk indicates *p*-value < 0.05, double asterisk indicates *p*-value < 0.01.
e Only edible species were harvested in harvested plots.

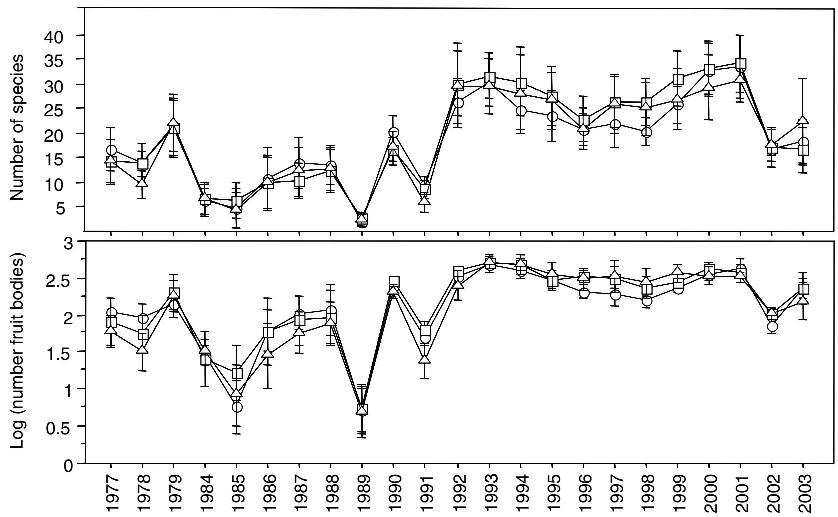

Fig. 1 – Fungal species richness and transformed number of fungal fruit bodies produced in Chanéaz from 1977 to 2003. Fruit bodies of all macromycetes were counted weekly in control plots (circles) and in plots where fruit bodies were harvested by picking (squares) or by cutting (triangles). The values at the top are means of the numbers of fungal species observed per year and those at the bottom are means of log10 transformed annual sums of fruit bodies (n = 5; bars show s.e.m.). Data from 1980 to 1983 are missing.

van Dobben, 1987; Arnolds, 1991). Moreover a 13-year study by the Oregon Mycological Society in the Mount Hood region (Oregon, USA) revealed no statistical evidence that picking suppresses the fruiting of the Golden Chanterelle, *Cantharellus formosus* Corner 1966 (Norvell, 1995; Pilz et al., 2003).

Harvesting the fruit bodies entails removing the spores. Theoretically, we would expect removing all fruit bodies and thus the possibility of sexual renewal by spores to lead to a degeneration of these fungi over time. Fungal species vary in how important spores are for their reproduction (Fioré-Donno and Martin, 2001). Some species repeatedly recruit new colonies from spores, whereas others propagate predominantly by vegetative spread. *Laccaria amethystina* Cke., for example, produces colonies and fruit bodies from spores each year (Fioré-Donno and Martin, 2001), but we did not detect a negative impact of harvesting on this species in either study site. It is possible that adequate numbers of spores entered from the neighbouring areas, or that the fruit bodies in the plots released enough spores during the weekly harvesting intervals. Nevertheless, the present experimental design realistically simulates strong harvesting pressure.

On the second study site we showed that trampling of the forest floor associated with mushroom harvesting reduces the number of fruit bodies and fruiting species observed per year, but not the number of species that fruited over the decade of sampling. This means that, in spite of trampling, the mycelia of all the species we sampled seem to persist in the soil, but simply fruited less often and in smaller numbers. We therefore hypothesize that the pre-fruit body primordia formed at the soil surface might be mechanically destroyed by walking on the forest floor, but that the mycelium is not permanently damaged. This is supported by the results of an earlier trampling experiment in a plot with a colony of the Yellow Foot Chanterelle, *Cantharellus lutescens* Fr. (Egli and Ayer, 1997), where a researcher imitated a mushroom picker and harvested fruit bodies twice a week for 12 years. As a consequence the fungus ceased forming fruit bodies, whereas it regularly fruited in the control plots, which were provided with catwalks to avoid soil contact while harvesting. The treatments were changed twice, once after 6 and once after 11 years. In both cases the fruit bodies appeared again the following year in quantities similar to those before the treatments.

Analysis of the interaction between the treatments trampling and harvesting indicates that, if anything, the combination of harvesting/non-trampling seems to be the most appropriate precondition for producing a maximum number of fruit bodies. Although trampling of the forest floor reduces the number of fruit bodies, this seems of minor importance compared to other factors influencing fruit body formation, as suggested by the large annual variability in fruit body production (Figs. 1 and 2). Good or poor mushroom years seem to be determined mainly by climatic conditions (Agerer, 1985; Kasparavicius, 2001; Straatsma et al., 2001). Air pollution, such as nitrogen deposition in forests, appears also to affect fungal species diversity, as demonstrated in an adjacent study plot at Moosboden (Peter et al., 2001). In this study the input of nitrogen proved to have an immediate and negative impact not only on the fruit body production but also on the below-ground structures of ectomycorrhizal fungi.

Although fungi are difficult to study in the soil, we need to understand their in situ ecology better if scientists are to provide conservationists and policy makers with clear criteria for evaluating measures to protect the biological diversity of forest fungi and to maintain sustainable harvests. Our study shows no evidence that harvesting fruit bodies harms the diversity of fungi residing in forest soils. From the

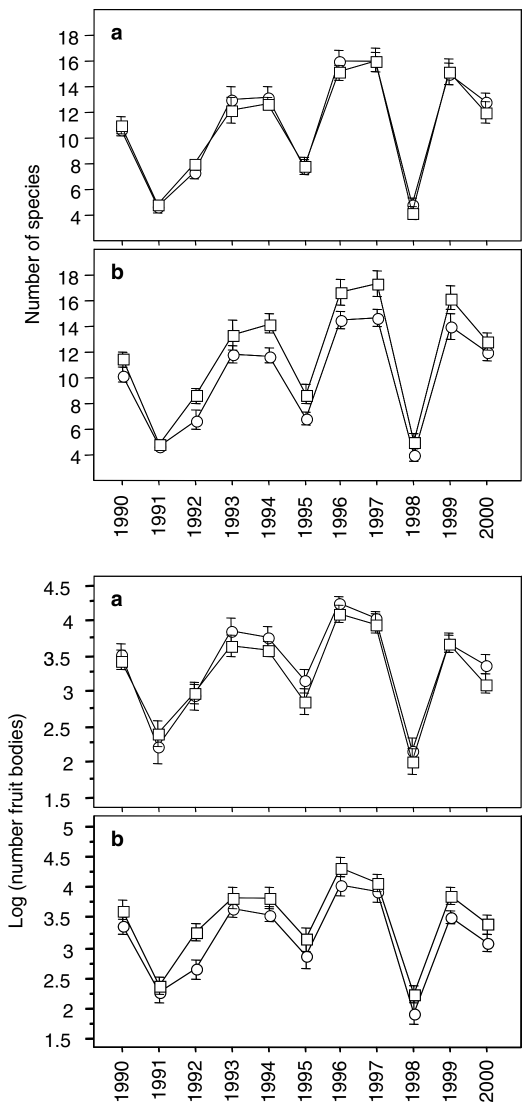

Fig. 2 – Fungal species richness and transformed number of fungal fruit bodies produced in Moosboden from 1990 to 2000. Fruit bodies of all macromycetes were counted weekly (a) in plots with (circles) or without (squares) harvesting of fruit bodies, and (b) in plots with (circles) or without (squares) forest floor trampling. The values in the top figure are means of the numbers of fungal species and those in the bottom one are means of log10 transformed annual sums of fruit bodies (*n* = 14; bars show s.e.m.; within the 14 blocks the two plots with the same treatments were averaged before calculating the mean and standard error).

anthropocentric perspective, however, both fungal species richness and the yield of edible fungi are impaired by the trampling of the forest floor. It is the fruit bodies of the fungi that we see and use. Fewer are formed after trampling of the forest floor, but they reappear when the sites are left to recover.

Our results raise questions about the usefulness of harvesting restrictions. We do not, however, know how many spores are needed to ensure the survival of fungal species. We are also not yet in a position to prove our hypothesis that trampling of the forest floor does not harm the mycelia in the soil. We therefore suggest maintaining closed seasons as a precaution to conserve forest fungi. In addition, we should not underestimate the importance of the psychological effects of constraints, for instance in increasing public recognition of forest fungi as a precious natural resource in our forests worthy of protection.

Acknowledgements

We thank Ch. Fillistorf, H. Bugnon, J.-M. Carrard, R. Dougoud for field assistance, D. Pilz, S. Dingwall, M. Fenaroli, B. Senn-Irlet, I. Brunner and P. Duelli for discussion and critical reading of the manuscript. We are also grateful to two anonymous reviewers for their helpful comments.

REFERENCES

Agerer, R., 1985. Zur Oekologie der Mykorrhizapilze. Bibl. Mycol. 97, Cramer, Vaduz.

Alexander, S.J., Pilz, D., Weber, N., Brown, E., Rockwell, V.A., 2002. Mushrooms, trees, and money: value estimates of commercial mushrooms and timber in the Pacific Northwest. Environ. Manage. 30, 129–141.

Arnolds, E., 1991. Decline of ectomycorrhizal fungi in Europe. Agric. Ecosyst. Environ. 35, 209–244.

Boa, E., 2004. Wild edible fungi. A global overview of their use and importance to people. Non-Wood Forest Products 17. FAO, Rome.

Dix, N.J., Webster, J., 1995. Fungal Ecology. Chapman & Hall, London.

Egli, S., Ayer, F., 1997. Est-il possible d'améliorer la production de champignons comestibles en forêt? L'exemple de la réserve mycologique de La Chanéaz en Suisse. Rev. For. Fr., Numéro special, pp. 235–243.

Egli, S., Ayer, F., Chatelain, F., 1990. Der Einfluss des Pilzsammelns auf die Pilzflora. Mycol. Helv. 3, 417–428.

Fioré-Donno, A.-M., Martin, F., 2001. Populations of ectomycorrhizal *Laccaria amethystina* and *Xerocomus* spp. show contrasting colonization patterns in a mixed forest. New Phytol. 152, 533–542.

Jahn, H., Jahn, M.A., 1986. Konstanz und Fluktuation der Pilzvegetation in Norra Warleda (Uppland). Beobachtungen auf einem schwedischen Bauernhof. Westfälische Pilzbriefe 10/11, 352–378.

Jansen, E., van Dobben, H.F., 1987. Is decline of *Cantharellus cibarius* in the Netherlands due to Air Pollution? Ambio 16, 211–213.

Kasparavicius, J., 2001. Effect of trampling on fructification of *Cantharellus cibarius* and *Boletus edulis* in Scots pine forests. Biologija 3, 21–23.

Norvell, L., 1995. Loving the chanterelle to death? The 10 year chanterelle project. McIlvanea 12, 6–25.

Peric, B., Pinguli, E., 2001. South Eastern Europe mushrooms menaced by global demand. The Bulletin 10/4, 16–17.

Peter, M., Ayer, F., Egli, S., 2001. Nitrogen addition in a Norway spruce stand altered macromycete sporocarp production and below-ground ectomycorrhizal species composition. New Phytol. 149, 311–325.

Pilz, D., Norvell, L., Danell, E., Molina, R., 2003. Ecology and Management of Commercially Harvested Chanterelle Mushrooms. Gen. Tech. Rep. PNW-GTR-576. Portland OR:

Department of Agriculture, Forest Service, Pacific Northwest Research Station, pp. 1–83.
R Development Core Team, 2004. R: A language and environment for statistical computing. In: R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. Available from: http://www.R-project.org.
Smith, S.E., Read, D.J., 1997. Mycorrhizal Symbiosis. Academic Press, London.
Straatsma, G., Ayer, F., Egli, S., 2001. Species richness, abundance, and phenology of fungal fruit bodies over 21 years in a Swiss forest plot. Mycol. Res. 105, 515–523.
Wang, Y., Hall, I.R., 2004. Edible ectomycorrhizal mushrooms: challenges and achievements. Can. J. Bot. 82, 1063–1073.
Watling, R., 1997. The business of fructification. Nature 385, 299–300.