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Dedicated to Professor Maria Ławrynowicz on the occasion of the 45th anniversary of her scientific activity

Species diversity and composition of fungal communities in a Scots pine forest affected by the great cormorant colony

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A Scots pine forest, affected by the great cormorant colony, was studied by plot-based fungal survey method during the years 2010-2012 in Lithuania. Diversity and composition of fungal communities were investigated at five zones that had been influenced by different stages of breeding colony establishment: starting-point and almost abandoned cormorant colony part (zones A and B), active part (zones C and D), and the edge of the colony (zone E). The control zone G in undamaged by cormorants pine stand was assessed too. A total of 257 fungal species of ascomycetes including anamorphic fungi, basidiomycetes and zygomycetes were recorded. Seven species were registered for the first time in Lithuania. Species richness in the examined zones varied, lowest being in zones B (51 species), C (46) and D (73) and almost twice as high in the zones A and E (129 and 120, respectively). The comparison of fungal species compositions of different zones showed that their similarity was rather low (S_S: 0.22–0.59). The most obvious changes in the trophic structure of fungal communities in the territory occupied by the bird colony were a strong decrease of mycorrhizal species, the presence of coprophilous fungi on forest litter, and the appearance of host-specialized fungi on alien and non-forest plants that have established in the disturbed forest.

Key words: *Phalacrocorax carbo*, *Pinus sylvestris*, fungi, checklist, Lithuania

INTRODUCTION

Colonies of piscivorous birds may become a source of excessive nutrient enrichment by transferring organic matter from aquatic to terrestrial ecosystems thus leading to extraordinary high levels of nutrients in soils and other substrates (Garcia et al.

2002; Osono et al. 2006a; Breuning-Madsen et al. 2010; Kolb et al. 2010) and subsequent changes in whole ecosystem. A cumulative effect of ornithogenic disturbances in forests is tree death due to ammonia poisoning and formation of glades densely overgrown by tall herbaceous plants as well as invasion of elders (*Sambucus* spp.) which rapidly form dense shrub communities replacing dead forest in the post-colony areas (Żółkoś, Markowski 2006; Laiviņš, Čekstere 2008; Garcia et al. 2011). Bird guano increases soil fertility and primary productivity of plants, however, due to ammonia poisoning in the most active parts of the colony plant biomass is lower, than in the areas abandoned by birds (Kolb et al. 2010).

Fungi, together with other ecosystem components react to these disturbances. Though there is a number of studies dealing with reaction of fungi to the increase of nutrient levels (e. g. Ohenoja 1988; Kårén, Nylund 1997; Wallenda, Kottke 1998; Peter et al. 2001, Tarvainen et al. 2003; Edwards et al. 2004), effect of ornithogenic disturbances is, however, much less studied. Ninomiya et al. (1993), Schoenlein-Crusius et al. (1996) and Osono et al. (2002, 2006b) studied soil and forest floor litter micromycetes in bird colonies, but their investigations were based on isolated fungal cultures, not on fungal fructification, and therefore most of mycobiota groups remained unstudied.

Continental subspecies of the great cormorant (*Phalacrocorax carbo sinensis*), not known to be breeding in Lithuania since early 20th century, re-established themselves in the early nineties and their population has increased manifold during the next decades, following the same pattern as elsewhere in Europe (Žydelis et al. 2002). The largest and oldest colony is located in an old-growth forest, part of a protected area in Kuršių Nerija (Curonian Spit) National Park neighbouring with a popular resort Juodkrantė. Rapidly expanding colony receives strong public attention mainly due to its impact on forest. In 2010, a project aiming to investigate changes in the biotic and abiotic components of forest ecosystem induced by a cormorant colony was started. One of the reaserch objects was fungi belonging to various taxonomic and ecological groups. This paper presents data on species richness, distribution and trophic groups of fungi recorded in the colony and its surroundings under varying impact from the bird activity.

STUDY AREA

The study was carried out in the northern part of the Curonian Spit peninsula (Lithuania). The climate in the Curonian Spit is an intermediate between marine and continental with a mean annual precipitation of 725 mm and mean annual air temperatures ranging from 16.6 to 16.8° C in June and August to –2.8 to –2.6° C in January and February (Galvonaitė et al. 2007). Seventy percents of the Spit land is covered by forests with prevailing conifers (80%). Small fragments of old growth *Pinus sylvestris* forest can be found on parabolic dunes and only at Juodkrantė settlement. The soils of the old parabolic dunes consist of eluvial and illuvial parts, they have characteristics of typical podzols (Morkūnaitė et al. 2011).

The present colony of great cormorants established in Juodkrantė old growth forest in 1989 and expanded into so far the largest breeding colony in Lithuania.

Now (together with a small, stable colony of grey herons (*Ardea cinerea*)) the great cormorants occupy an area of forest more than 700 m long and 370 m wide, and their colony currently counts over 3300 occupied nests (M. Dagys, pers. com.). At present the colony is located throughout an upper part of the dune ridge (altitude up to 34 m), down to dune slope terraces and a dune hollow (alt. 0–2 m). Upper part of the colony originally was ca. 110 year-old and slope terraces – ca. 230 year-old pine forest of *Empetro nigri-Pinetum* association, growing on nutrient-poor sandy soil, while dune hollow was formerly occupied by 230 year- old pine and spruce forest developed on temporarily wet mesotrophic soils (Jončys, Paulaitis 1987). Now on the dune slope *P. sylvestris* trees are dead or dying, in the dune hollow *P. sylvestris* trees are dead and mostly fallen.

Eighteen permanent sampling plots (100 m^2 each) for current investigation were established in six zones (3 plots in each zone) that were chosen considering forest type, age and slope exposition, and basing upon different activity of the bird colony:

A – the oldest part of the colony in the dune hollow: formerly a pine and spruce forest on mesotrophic temporarily wet soil, coniferous trees are now dead, few young *Picea abies*, *Quercus robur*, *Betula pubescens* are still alive but partly dried out, a large part of the area is overgrown with tall herbs as well as *Sambucus* spp. shrubs, standing and laying barkless pine deadwood is abundant but in places overshadowed with herbs and bushes. Cormorant nests are absent or very few, but birds fly over the area to feed in the Curonian Lagoon.

B – the oldest part of the colony on the dune terraces: no living trees, standing dead *P. sylvestris* trees are mostly barkless, large amounts of dead wood – laying and standing, litter composed of fine twigs, larger and smaller pine bark pieces, fish scales and bones. Vegetation consists mainly of nitrophilic herbaceous communities with *Sambucus* spp. shrubs. Moss layer is absent, patches of bare soil abound. Cormorant nests are absent or very few, but numerous birds roost and fly over the area (Fig. 1B).

C – the most active part of the colony in the former oligotrophic pine forest with the highest concentration of nests; pine trees are dead or dying but still with bark; shrub layer consists of *Sorbus aucuparia* and *Sambucus* spp., sparse remaining *Juniperus communis* shrubs are dying; herb layer makes up to 10 % with predominantly nitrophilic species; moss layer is absent, patches of bare soil present (Fig. 1C).

D – an inner edge of the colony with the most recent and still rather few nests in an oligotrophic pine forest on the upper part of dune, trees alive, but their vitality is reduced – crowns are thinner; shrub layer is thickened with *Sorbus aucuparia*, young *Sambucus* spp , *Juniperus communis* appear weakened; herb layer is depauperized due to extinction of some oligotrophic herbs, meso- and eutrophic species become abundant, patches of bare soil appear; moss layer is thinned.

E – edge of the colony with very few, the most recent nests (as recent as 2011), relatively undamaged by cormorants oligotrophic pine forest (association *Empetro nigri–Pinetum*) on the upper part of dune with solitary mesotrophic and eutrophic plants.

G – zone outside of colony, nests absent, closest nests are distanced approximately at 60 m. The stand is oligotrophic pine forest (association *Empetro nigri–Pinetum*) on the upper part of dune, undamaged by cormorants. G-zone was interpreted as a control zone in our study.

Fig. 1. Images of the studied zones B and C: abundant coarse dead wood in the zone B; absence of moss and herbaceous plant cover and appearance of *Sambucus* spp. in the zone C.

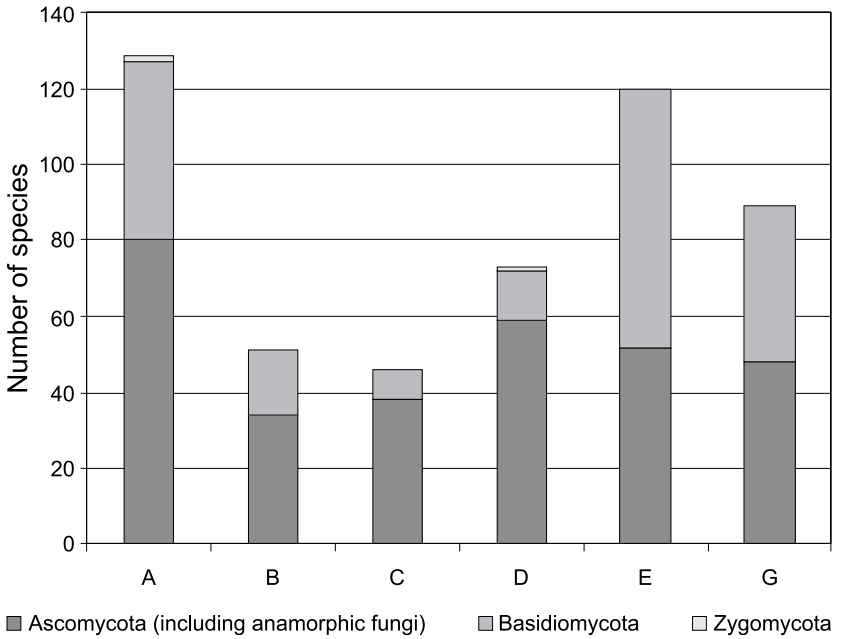

Fig. 2. The overall number of species from the sampled zones A-E and G.

MATERIAL AND METHODS

Field sampling was undertaken from September 2010 until October 2012. Due to the rapid colony expansion in 2011, the additional control plots (zone G) were established and studied since spring of 2012. The study plots were inspected thoroughly three times a year: one visit in spring (May) and two visits in autumn (September–October). Specimens of fungal species that were difficult to identify *in situ* were collected for microscopic examination in the laboratory and identified following routine mycological methods (Mueller et al. 2004). Latin names are given according to Index Fungorum (2013). Voucher specimens of the study are deposited in the Herbaria of the Nature Research Centre, Institute of Botany (Vilnius) (BILAS) and Vilnius University (WI).

Sørensen coefficient (S_s) was employed to evaluate the fungal species composition similarity between pairs of the sampled zones. It equals $2W/(A+B)$, where W is the shared abundance and A and B are the sum of abundances in individual sample units. PC-ORD ver. 6 statistical software (McCune, Mefford 1999) calculated a Sørensen distance (S_d) matrix and values of this matrix was converted to a similarity matrix by substracting from one (similarity$=1-S_s$).

RESULTS

Species richness and distribution. Altogether 257 species of fungi were recorded, of which 240 were identified to species and 17 to genus level (Tab. 1). Ascomycetes (including anamorphic fungi) made up 138 species (54% of all recorded), Basidiomycetes – 117 (45%), and Zygomycetes – 2 (1%). Seven species were registred for the first time in Lithuania, namely *Allophylaria fumosella*, *Dicranidion gracilis, Jaapia ochroleuca*, *Junewangia globulosa, Scolecobasidium verruculosum, Triadelphia heterospora*, and *T. uniseptata.*

Table 1
Checklist of fungi collected in a Scots pine forest affected by the great cormorant colony
(+ – taxa recorded)

Abbreviations. Trophic groups: B – biotrophs, M – mycorrhizal fungi, S – saprobes, Sc – coprophilous saprobes. Substrate types: b – bark, c – cones, h – herbs, l – leaves, lt – forest litter, n – needles, s – soil, t – twigs (small branches less than 0.5 cm in diameter), w – wood (trunks, snags, stumps, branches, excluding twigs).

Taxa	Trophic groups/ substrate types	Sampling zones					
		A	B	C	D	E	G
Ascomycota including **anamorphic fungi**							
Acremonium sp.	S/lt(h,n)	+	.	+	+	.	.
Acrogenospora sphaerocephala	S/w	+	.	.	.	.	.
Allophylaria fumosella	S/lt(c,n)	.	.	.	.	+	+
Alternaria alternata	S/lt(h)	+	.	+	+	.	.
Alternaria sp.	S/lt(t)	.	+	+	.	.	.
Anungitea continua	S/lt(n)	.	.	.	+	+	+
Arthrobotrys oligospora	S/lt(b,l,t)	+	+	+	+	+	+
Ascobolus foliicola	Sc/lt(c,n,t),w	.	+	+	+	+	.
Ascocoryne cylichnium	S/w	.	+	.	.	.	.
Ascocoryne sarcoides	S/lt(c),w	+	+	.	+	+	+
Aspergillus sp.	S/lt(t)	.	+	.	.	+	.
Bactrodesmium biformatum	S/lt(t)	+	.	+	.	.	.
Bactrodesmium pithoideum	S/lt(b,t)	+	.	.	.	.	.
Bactrodesmium traversianum	S/lt(t)	+	.	.	.	.	.
Blastophorum pini	S/lt(t)	.	.	.	.	+	+
Botrytis cinerea	S/lt(h)	+	.	.	.	.	.
Brachysporium britannicum	S/lt(t)	+	.	+	.	.	.
Brachysporium nigrum	S/lt(t)	+	.	.	.	.	.
Brachysporium obovatum	S/lt(t)	+	.	.	.	+	.
Brachysporium polyseptatum	S/lt(t)	+	.	.	.	.	.
Cacumisporium capitulatum	S/lt(t)	+	.	.	.	.	.
Calcarisporium arbuscula	S/lt(n)	.	.	.	.	.	+
Calycina conorum	S/lt(c)	+	.	.	.	.	.
Camposporium cambrense	S/lt(t)	+	.	+	+	+	.
Camposporium pellucidum	S/lt(n)	.	.	.	.	.	+
Cenangium ferruginosum	B,S/lt(t)	.	.	.	.	.	+
Chaetosphaeria callimorpha	S/w	+	.	.	.	.	.
Chaetosphaeria ovoidea	S/w	+	.	.	+	.	.
Chalara longipes	S/lt(t)	.	.	.	.	+	.
Chalara microchona	S/lt(b,t)	.	.	.	+	.	.
Chalara sp.	S/lt(t)	+	.	.	.	.	+
Cheiromycella microscopica	S/lt(t),w	+	+	.	.	+	+
Chloridium cylindrosporum	S/lt(t)	+	.	.	.	.	.
Chloridium clavaeforme	S/lt(t)	.	.	.	.	.	+
Chloridium virescens var. *virescens*	S/lt(t)	+	.	+	+	+	+
Circinotrichum britannicum	S/lt(n)	.	.	.	.	.	+

Cirrenalia sp.	S/lt(t)	+	.	.	.	.	.
Cladosporium herbarum	S/lt(h)	+	+	+	+	+	+
Cladosporium sp.	S/lt(t)	+	.	.	.	.	+
Clonostachys compactiuscula	S/lt(t)	.	.	.	+	.	+
Coniochaeta malacotricha	S/w	+	.	+	+	.	+
Conioscypha varia	S/lt(t)	+	.	.	.	.	.
Cyclaneusma minus	B,S/lt(n)	.	.	+	+	+	+
Dactylaria candidula	S/lt(t)	.	.	.	+	.	.
Dactylella sp.	S/lt(h,n,t)	+	.	.	.	+	+
Dendryphion comosum	S/lt(b,h,t)	+	.	+	+	+	.
Dendryphiopsis atra	S/lt(h)	+	.	.	.	.	.
Diaporthe eres	S/w	+	.	.	.	.	.
Dicranidion gracilis	S/w	+	.	.	.	.	.
Diplocladiella scalaroides	S/lt(t)	+	+	.	.	.	.
Diplococcum spicatum	S/lt(t),w	+	.	+	.	.	.
Doratomyces asperulus	S/lt(b,t)	.	+	+	+	.	.
Endophragmiella eboracensis	S/lt(t)	+	.	.	+	+	.
Endophragmiella pinicola	S/lt(t)	+	+	+	+	+	+
Epicoccum nigrum	S/lt(n)	.	.	+	+	+	+
Erysiphe alphitoides	B/l	+	.	.	.	.	.
Erysiphe vanbruntiana	B/l	+	+	+	+	+	.
Fusarium sp.	S/lt(t)	.	+	+	.	.	.
Gonytrichum caesium var. *caesium*	S/lt(t)	+	.	+	+	.	.
Graphium putredinis	S/lt(t)	+	.	.	+	.	.
Hamatocanthoscypha laricionis	S/lt(c),w	+	.	.	+	.	.
Harzia sp.	S/lt(h),s	+	.	.	.	+	.
Heyderia pusilla	S/lt(n)	.	.	.	.	+	.
Heteroconium chaetospira	S/lt(t)	.	.	.	.	+	.
Hyalorbilia inflatula	S/w	+	.	.	.	.	.
Hyaloscypha aureliella	S/w	+	.	.	.	+	+
Hymenoscyphus fructigenus	S/lt(c)	.	.	.	+	+	.
Hysterium acuminatum	S/lt(t)	.	.	.	.	.	+
Hormiactella fusca	S/lt(t)	.	.	.	.	+	+
Iodophanus carneus	Sc/lt(c)	.	+	.	.	.	.
Junewangia globulosa	S/w	+	.	.	.	.	.
Keissleriella pinicola	S/w	+	+	.	+	.	.
Lachnellula pseudofarinacea	B,S/lt(t)	.	.	.	.	+	+
Lachnellula subtilissima	B,S/lt(t)	.	.	.	.	+	.
Lentithecium arundinaceum	S/lt(h)	.	.	+	+	+	.
Linodochium hyalinum	S/lt(n)	.	.	.	.	+	+
Lophodermium conigenum	B,S/lt(n)	.	.	.	.	+	.
Lophodermium pinastri	B,S/lt(n)	.	.	.	+	+	+
Mariannaea elegans var. *elegans*	S/lt(t)	.	+	.	+	+	.
Menispora ciliata	S/lt(t)	.	.	.	.	+	.
Mycothyridium vestitum	S/w	.	.	.	+	.	.
Mytilinidion mytilinellum	S/w	.	.	.	+	.	.
Mollisia cinerea	S/w	+	.	.	.	+	+
Monodictys putredinis	S/lt(t)	+	.	.	.	+	+
Monodyctis levis	S/lt(t)	+	+	.	.	.	.
Monotosporiella setosa	S/lt(t)	.	.	.	.	+	+
Nectria cinnabarina	B,S/lt(t),w	+	+	+	+	+	.
Nitschkia cupularis	S/lt(t)	.	.	.	+	.	.
Oncopodiella hyperparasitica	S/w	.	.	.	+	.	.
Oncopodiella trigonella	S/lt(b,t)	+	+	+	+	.	.
Orbilia delicatula	S/w	+	+	.	.	+	+
Papulaspora cf. *sepidonioides*	S/lt(b,t)	+	.	+	+	.	.
Paratrichophaea albescens	S/lt(c),w	+	.	+	+	.	.
Penicillium sp.	S/lt(h)	.	.	.	+	.	.
Periconia sp.	S/lt(h)	+	.	.	.	.	.
Pezicula eucrita	B,S/lt(c)	.	.	.	+	.	.
Phaeoisaria clematidis	S/lt(b,t)	+	.	+	+	.	.
Phaeostalagmus cyclosporus	S/lt(b)	.	+	+	.	.	+

Phialocephala humicola	S/lt(t)	+	.	.	.	.	.
Phialograpium sp.	S/lt(b)	.	+	.	+	.	.
Pleurophragmium acutum	S/lt(t)	.	+	.	+	.	.
Pleurotheciopsis brambleyi	S/lt(b,t)	+	+	.	+	.	.
Pleurothecium recurvatum	S/lt(t)	+	.	.	.	.	.
Podosphaera aucupariae	B/l	+	.	+	+	+	.
Polyscytalum fecundissimum	S/lt(t)	.	.	.	.	.	+
Polyscytalum pini	S/lt(n)	.	.	.	.	+	+
Pseudospiropes obclavatus	S/lt(t)	+	.	.	+	+	+
Rhinocladiella sp.	S/lt(t)	.	.	.	+	+	.
Saccobolus versicolor	Sc/lt(c)	.	.	.	+	.	.
Scolecobasidium verruculosum	S/w	.	+	+	+	.	.
Scutellinia scutellata	S/w	+	.	.	.	.	.
Selenosporella curvispora	S/lt(t)	.	.	.	.	+	+
Septonema fasciculare	S/w	+	.	.	.	+	+
Sirococcus strobilinus	S/lt(c)	.	.	.	.	.	+
Sympodiella acicola	S/lt(n)	.	.	.	.	+	+
Spadicoides atra	S/lt(t)	+	.	.	.	.	.
Sphaeropsis sapinea	B,S/lt(b,c,n,t)	+	+	+	+	+	+
Sporidesmiella hyalosperma var. *hyalosperma*	S/lt(h,t)	+	+	.	+	.	+
Sporidesmium cf. *pedunculatum*	S/lt(t)	+	.	.	.	.	.
Sporidesmium sp.	S/w	+	.	.	.	.	.
Sporormiella leporina	Sc/lt(h,t),w	.	+	+	+	.	.
Stachybotrys cylindrospora	S/lt(b,t)	.	.	+	.	.	.
Taneolella stricta	S/lt(t)	+	.	.	.	.	.
Tapesia strobilicola	S/lt(c)	+	.	.	.	.	.
Thysanophora penicillioides	S/lt(n)	.	.	.	.	+	+
Torula herbarum	S/lt(h)	+	+	+	+	.	.
Triadelphia heterospora	S/lt(b,t)	+	+	.	+	.	.
Triadelphia uniseptata	S/w	+	.	+	+	.	.
Trichocladium asperum	S/lt(t)	+	+	+	+	.	.
Trichoderma viride	S/lt(t,n),w	+	+	+	+	+	+
Tridentaria sp.	S/lt(t)	+	+	+	+	+	+
Trimmatostroma betulinum	S/lt(t)	+	.	.	.	.	.
Trimmatostroma scutellare	S/lt(t)	+	.	.	.	.	.
Trimmatostroma sp.	S/w	+	.	.	+	.	.
Troposporella monospora	S/lt(n)	.	.	.	.	.	+
Verticicladium trifidum	S/lt(n)	.	.	.	.	+	+
Verticillium albo-atrum	S/lt(h,n)	.	+	+	+	+	+
Xylohypha ferruginosa	S/lt(t)	+	.	.	.	.	+
Basidiomycota							
Amanita citrina	M/s	.	.	.	.	+	+
Amanita fulva	M/s	.	.	.	.	+	.
Amanita porphyria	M/s	.	.	.	.	+	+
Amanita vaginata	M/s	.	.	.	.	+	.
Amphinema byssoides	M/w	.	.	.	.	+	+
Antrodia sinuosa	S/w	.	.	.	.	+	.
Antrodia xantha	S/w	.	.	.	.	+	.
Armillaria mellea	S/w	+	+	.	.	.	.
Athelia decipiens	S/w	.	.	.	.	+	+
Auricularia aurica-judae	B,S/w	+	.	+	.	.	.
Baeospora myosura	S/lt	.	.	.	+	+	.
Botryobasidium candicans	S/w	.	+	.	.	.	.
Botryobasidium obtusisporum	S/w	+	.	.	.	.	.
Botryobasidium subcoronatum	S/w	+	+	.	+	+	+
Botryobasidium vagum	S/w	+	.	.	.	+	.
Ceraceomyces cystidiatus	S/w	.	.	.	.	+	.
Clitocybe clavipes	S/s	.	.	.	.	+	+
Clitocybe metachroa	S/lt	.	+	.	.	.	.
Clitocybe nebularis	S/lt	.	.	.	.	+	.
Collybia butyracea	S/lt	.	.	.	.	+	+
Collybia confluens	S/lt	.	.	.	+	.	.

Coniophora arida	S/w	+	+	.	.	+	+
Cortinarius caperatus	M/s	.	.	.	.	+	+
Cortinarius cinnamomeus	M/s	.	.	+	.	.	.
Cortinarius sp.	M/s	.	.	+	.	.	+
Crucibulum laeve	S/w	+	.	.	.	.	.
Cystoderma amiantinum	M/s	.	.	.	.	+	+
Cystoderma carcharias	M/s	.	.	.	.	+	.
Dacrymyces stillatus	S/w	.	.	.	.	+	+
Flammulina velutipes	S/w	+	.	.	.	.	.
Fomitopsis pinicola	S/w	+	.	.	.	.	+
Galerina marginata	S/w	+	.	.	.	.	.
Galerina oedipus	S/lt	+	.	.	.	.	.
Galerina triscopa	S/w	+	.	.	.	.	.
Galerina unicolor	S/lt	+	.	.	.	.	.
Galerina vittiformis	S/lt	.	.	.	.	+	.
Gymnopilus bellulus	S/w	+	.	.	.	.	.
Gymnopilus penetrans	S/w	+	.	.	.	.	+
Gymnosporangium sp.	B/l	.	.	.	.	+	+
Hyphoderma argillaceum	S/w	+	.	.	.	+	.
Hyphoderma obtusiforme	S/w	.	.	.	.	+	.
Hyphoderma pallidum	S/w	+	.	.	.	+	.
Hyphoderma praetermissum	S/w	+	.	.	.	+	.
Hyphoderma puberum	S/w	+	+	.	.	+	.
Hyphoderma subdefinitium	S/w	.	.	.	.	+	.
Hyphodontia alutacea	S/w	.	.	.	.	+	.
Hyphodontia alutaria	S/w	.	.	.	.	+	.
Hyphodontia aspera	S/w	+	.	.	.	.	.
Hyphodontia breviseta	S/w	.	+	.	.	+	+
Hyphodontia crustosa	S/w	.	.	.	.	+	.
Hyphodontia pallidula	S/w	+	.	.	.	+	.
Hyphodontia sambuci	S/w	+	.	.	.	.	.
Hypochnicium geogenium	S/w	+	.	.	.	.	.
Jaapia ochroleuca	S/w	.	.	.	.	+	.
Kuehneromyces mutabilis	S/w	+	.	.	.	.	.
Laccaria amethystea	M/s	.	.	.	.	+	.
Laccaria laccata	M/s	+	.	.	.	.	.
Lactarius quietus	M/s	+	.	.	.	.	.
Lactarius rufus	M/s	+	.	.	.	+	+
Lepista inversa	S/lt	+	+	.	.	.	.
Lepista irina	S/s	+	.	.	.	.	.
Leucogyrophana mollusca	S/w	.	.	.	.	+	.
Marasmius oreades	S/lt	.	.	.	.	.	+
Meruliopsis taxicola	S/w	.	.	.	.	+	+
Metulodontia nivea	S/w	.	.	.	.	.	+
Mucronella flava	S/w	.	.	.	.	+	.
Mycena epipterygia	S/lt	+	.	.	.	+	.
Mycena filopes	S/lt	+	.	.	.	.	.
Mycena flavescens	S/lt	.	.	.	.	+	.
Mycena flavoalba	S/lt	+	.	+	+	.	.
Mycena galericulata	S/w	.	.	+	+	+	+
Mycena galopus	S/lt	.	.	.	+	+	+
Mycena haematopus	S/w	.	.	.	+	.	.
Mycena leptocephala	S/lt	+	.	.	+	.	.
Mycena maculata	S/w	+	.	.	+	+	.
Mycena rorida	S/w	.	.	.	+	.	.
Mycena sanguinolenta	S/lt	+	.	+	+	+	+
Mycena stipata	S/lt	+	.	+	.	.	.
Mycena vitilis	S/lt	+	.	.	+	.	.
Mycena zephirus	S/lt	+	.	.	.	.	+
Oligoporus rennyii	S/w	.	+	.	.	+	.
Oligoporus sericeomollis	S/w	.	.	.	.	.	+
Paxillus involutus	M/s	.	.	.	.	+	+

Phanerochaete sordida	S/w	.	.	.	.	+	.
Phlebia tremellosa	S/w	+	.	.	.	.	.
Phlebiella pseudotsugae	S/w	.	.	.	.	.	+
Phlebiella sulphurea	S/w	.	.	.	.	+	+
Pholiota flammans	S/w	+	.	.	.	.	.
Piloderma byssinum	M/w	.	.	.	.	+	+
Piloderma croceum	M/w	.	.	.	.	+	.
Pleurotus ostreatus	S/w	.	+	.	.	.	.
Pluteus atromarginatus	S/w	+	+	.	.	.	.
Pluteus cervinus	S/w	+	+	+	.	.	.
Postia caesia	S/w	.	.	.	.	+	.
Pseudohydnum gelatinosum	S/w	.	.	.	.	+	.
Pseudotomentella tristis	M/w	.	.	.	.	.	+
Radulomyces confluens	S/w	+	+	.	.	+	.
Resinicium bicolor	S/w	.	+	.	.	+	+
Russula emetica	M/s	.	.	.	.	+	.
Russula integra	M/s	.	.	.	.	+	.
Russula sanguinea	M/s	.	.	.	.	+	+
Russula sardonia	M/s	.	.	.	.	+	+
Russula vesca	M/s	.	.	.	.	+	+
Russula xerampelina	M/s	.	.	.	.	+	+
Schizopora paradoxa	S/w	+	+	.	.	.	.
Stereum sanquinolentum	S/w	.	.	.	.	+	.
Strobilurus esculentus	S/lt	.	.	.	+	+	+
Stropharia aeruginosa	S/w	+	.	.	.	.	.
Tomentella lilacinogrisea	M/w	.	.	.	.	.	+
Trechispora cohaerens	S/w	.	.	.	.	+	+
Trechispora farinacea	S/w	+	+	.	.	+	+
Trichaptum fuscoviolaceum	S/w	+	.	.	.	.	.
Tricholomopsis rutilans	S/w	.	.	.	.	+	.
Tubulicrinis subulatus	S/w	.	.	.	.	.	+
Tylopilus felleus	M/s	.	.	.	.	+	+
Vesiculomyces citrinus	S/w	.	+	.	.	.	.
Xerocomus badius	M/s	.	.	.	.	+	.
Zygomycota							
Mortierella sp.	S/lt(t)	+	.	.	+	.	.
Rhopalomyces elegans var. *elegans*	S/lt(b)	+	.	.	.	.	.

Species richness in the studied zones conspicuously varied. The highest numbers of fungal species were recorded in zones A (129 species) and E (120) (Fig. 2), meanwhile species richness in zones B, C and D was about two times lower, 51, 46 and 73 species, respectively.

Distribution of individual fungal species varied strongly within the study area. Majority of fungi occurred in one (119 species, 46%) or two zones (75 species, 29%). Only 6 species (2% of all species) were found in all six zones – *Arthrobotrys oligospora*, *Cladosporium herbarum*, *Endophragmiella pinicola*, *Sphaeropsis sapinea*, *Trichoderma viride* and *Tridentaria* sp. Additionally, *Erysiphe vanbruntiana* and *Nectria cinnabarina* were widespread and notably abundant in all zones within the area currently occupied by cormorant colony (zones A-E). Few more species, e.g. *Trichocladium asperum, Torula herbarum* and *Oncopodiella trigonella*, were widespread only in strongly affected forest parts (zones A-D).

The fungal species compositions also differed between the zones. In general, the comparison of species compositions of different zones showed that their similarity was rather low (S_S: 0.22-0.59) (Tab. 2). The highest similarity was between zones E and G (0.59), the lowest – between zone G and zones A, B, C, D (S_S: 0.22-0.27). Zones A, B, C, D showed average similarity between each other (S_S: 0.33-0.41), except for zones C and D which were rather similar in fungal species compositions (0.57).

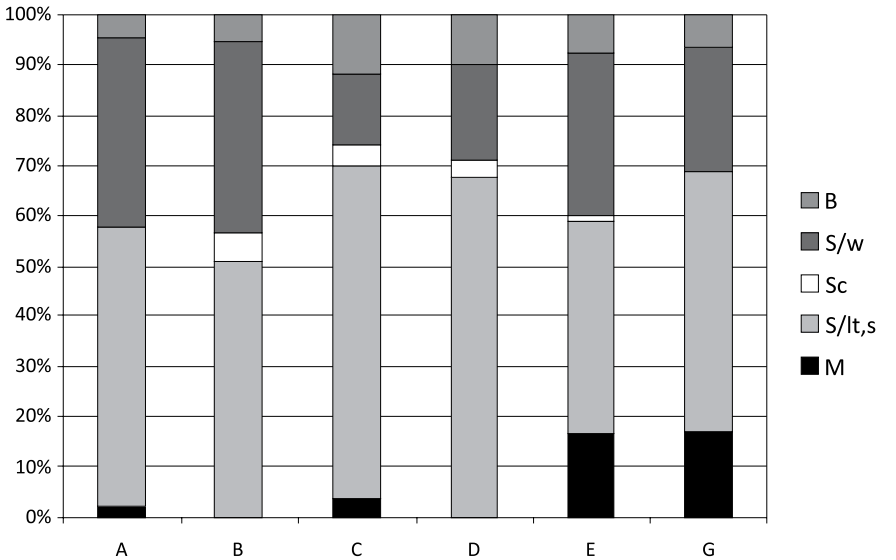

Fig. 3. The percent proportion of fungal trophic groups from the sampled zones A-E and G. Abbreviations of trophic groups as in Table 1.

Trophic structure of fungal communities. Fruiting fungi from main trophic groups were present in the study area, however, the trophic structure of fungal communities more or less differed between zones as well (Fig. 3). Only a minor difference in the percent proportions of trophic groups was detected between scarcely affected forest zone E and control zone G. Meanwhile, obvious disparity of trophic structure existed between the latter two zones and all the rest of study zones. In the zones B and D, mycorrhizal species were not found, and their percentage was very low in the zones A (2%; 3 species: *Laccaria laccata, Lactarius rufus* and *L. quietus*) and C (4%; 2 species from the genus *Cortinarius*) when compared with zones E (17%; 21 species) and G (17%; 16 species). On the other hand, the percentage of wood-inhabiting fungi was very high in the zones A and B (both 38%; 50 and 20 species, respectively), but was rather modest in the zones C (14%; 7 species) and D (19%; 15 species). Four coprophilous species from the genera *Ascobolus*, *Iodophanus*, *Saccobolus* and *Sordaria* were notably present on forest litter (not directly on excrements) in the zones B, C and D, and showed appearance in the zone E.

In total, 15 species of biotrophic fungi were recorded, and the percentage of biotrophs per zone varied from 5% to 12%. *Erysiphe vanbruntiana*, *Nectria cinnabarina*, *Podosphaera aucupariae*, and *Sphaerospis sapinea* were common on woody plants, damaged by bird activity. Facultative biotroph *N. cinnabarina* strongly infected *Sorbus aucuparia*, *Salix* spp., *Sambucus* spp., *Pinus sylvestris* and *Juniperus communis* in the zones A-D. Needles, bark of twigs and cones of *P. sylvestris* in the colony were inhabited by *Sphaeropsis sapinea*, especially in the zones C and D. Rather common pine needle-inhabiting endophytes were *Cyclaneusma minus* and *Lophodermium* spp.

Saprobic fungi prevailed in all studied zones, however, their presence percentage was more conspicuous at the starting-point and active parts of the colony

Table 2
Matrix showing similarity of fungal species compositions between pairs of sampled zones A-E and G: values of Sørensen (S_s) similarity coefficient

Zones	A	B	C	D	E	G
A	1					
B	0.33	1				
C	0.35	0.41	1			
D	0.41	0.40	0.57	1		
E	0.31	0.27	0.23	0.33	1	
G	0.27	0.24	0.22	0.27	0.59	1

(zones A-D; 84-94%) compared to the only recently occupied and unoccupied by cormorants forest parts (zones E and G; both 76%). Nearly half of all recorded fungal species were forest litter decomposers (116 species). These saprobic fungi inhabiting fallen leaves, needles, cones, small twigs, bark pieces and dead herbs made up highest number of species in the zone A (69 species), but was lowest in the zone B (25 species). The most frequent (appeared in at least five zones) litter saprobes were *Arthrobotrys oligospora, Chloridium virescens* var. *virescens, Cladosporium herbarum, Endophragmiella pinicola, Mycena sanguinolenta*, *Trichoderma viride, Tridentaria* sp. and *Verticillium albo-atrum*. Notably, *Oncopodiella trigonella, Papulaspora* cf. *sepidonioides, Phaeoisaria clematidis, Pleurotheciopsis brambleyi, Torula herbarum*, *Trichocladium asperum* and *Triadelphia heterospora* were common exclusively in the zones strongly affected by cormorants (A-D). Only 3 species out of total 92 species inhabiting wood of trunks, snags, stumps and large branches were recorded in at least five zones: *Ascocoryne sarcoides, Botryobasidium subcoronatum*, and *Trichoderma viride*. Several wood-inhabiting species, such as *Keissleriella pinicola, Pluteus cervinus*, *Triadelphia uniseptata*, and *Scolecobasidium verruculosum* were common only in the zones strongly affected by cormorants.

DISCUSSION

Our observations show that mycobiota in a Scots pine forest affected by the great cormorant colony undergo gradual decline reaching extreme impoverishment in the most active part of the colony. With diminishing influence of birds in the older parts of the colony, the numbers of fungal species start to grow following changes of vegetation and substrates. However, substrates in the abandoned parts of the colony are colonized mostly by different species than these of unaffected forest. Fungal species compositions in recently (year 2011) nested forest (zone E, outer edge of the colony) and in undamaged forest (zone G, control) are still rather similar and largely maintain widespread and specific species of pine forests of both the Curonian Spit (Kutorga et al. 2012) and the Baltic region. Meantime, the species richness is strongly declining at the inner edge of the active colony part (zone D) and was conspicuously (>2 times) decreased at the most active part (zone C). Same effect was observed at the zone B. Species compositions of these zones also show obvious differences from the little- or not affected forest parts.

The highest number of fungal species (129) was recorded in the zone A. Apparent reason for that is abundance of herbaceous plants, shrubs and dead wood in this zone in combination with more favourable humidity and light regime, type of initial (pre-colony) vegetation and decreased present activity of birds (absence of nests). Therefore in this zone high diversity of litter saprobes and wood-inhabiting ascomycetes were found, among them *Scutellinia scutellata*, a moist wood and soil preferring fungus (Schumacher 1990), recorded exclusively in the zone A. This zone also harboured rich corticioid and polyporoid wood-inhabiting mycobiota, agaricoid wood saprobes, such as *Pluteus*, *Mycena*, *Galerina* were common there as well.

Trophic structure of fungal communities especially strongly reacted to the cormorant colony-induced disturbances. Mycorrhizal species were dramatically reduced by the bird activity, albeit not eliminated totally; a few species from the genera *Laccaria*, *Lactarius* and *Cortinarius* fruited inside the colony. The change in vitality of partner trees and in edaphic conditions are the key factors inducing a change in diversity of mycorrhizal fungi. For example, the absence of fruiting mycorrhizal fungi in the zone B apparently was due to the absence of living trees. In the zone A, all pines were dead, but several surviving oak trees enabled a scarce fruiting of few mycorrhizal species, such as an oak-specific *Lactarius quietus*. Extremely poor and sporadic fruiting of mycorrhizal fungi in active part of the cormorant colony (zone C) was mainly determined by excessive nutrients from bird droppings and to some extent by the reduced vitality of trees. It is a documented fact that forest fertilization reduce the activity of mycorrhizal fungi (Ohenoja 1978, 1988; Shubin 1988; Kårén, Nylund 1997).

The wood-inhabiting fungi depend on amount and quality of dead wood and on the way the tree die (Stenlid et al. 2008). In our study area the spatial and qualitative differences of dead wood were obvious among the zones. Thus corticioid *Botryobasidium subcoronatum* which occurred in almost all zones is regarded as host generalist with no preference to wood decay stage and diameter (Stokland, Larsson 2011). Another corticioid, *Hyphodontia sambuci*, found only in zone A, have host preference to *Sambucus* spp., nitrophilous plants alien in Lithuania. Polypore *Oligoporus rennyi* confined to medium decayed large-sized coniferous logs frequently occurred in zone B where logs abounded. Apart from *O. rennyi*, fallen pine trunks in zone B harboured a number of other corticioid and polyporoid species growing on their undersides. Zones C and D lacked fallen large diameter pine trunks and therefore bore very few wood-inhabiting basidiomycetes, mainly *Mycena* species.

In all strongly cormorant-affected zones the stressed woody plants were severely attacked by biotrophs, such as *Nectria cinnabarina, Sphaeropsis sapinea, Podosphaera aucupariae* and *Erysiphe vanbruntiana.* The latter species together with a weak pathogen *Auricularia auricular-judae* occurred exceptionally on *Sambucus nigra* and *S. racemosa*, shrubs that were abundant within the colony area.

Unusual substrate/lifestyle switches were noted for several fungus species in the territory of the colony. *Chaetosphaeria ovoidea*, *Diaporthe eres*, *Mycothyridium vestitum*, *Mytilinidion mytilinellum* and *Nitschkia cupularis* usually inhabit dead branches and twigs of various deciduous trees (Munk 1957; Ellis, Ellis 1997), but in the colony area they were recorded on *Pinus sylvestris*. In the most active parts of the bird

colony coprophilous species *Ascobolus foliicola*, *Iodophanus carneus*, *Saccobolus versicolor* and *Sporormiella leporina* were found on various parts of *Pinus sylvestris* and twigs of *Sambucus nigra*. Most of these fungi usually are common on dung of various animals, though *A. foliicola* was also observed on plant remnants and *I. carneus* – on decaying anthropogenic substrates (Kutorga 2000; Treigienė 2004). Similar substrate switches were noted for myxomycetes in the cormorant colony (Adamonytė et al. 2013). Rare hyperparasitic species *Oncopodiella hyperparasitica*, which usually inhabits fruit-bodies of *Lasiosphaeria spermoides* and *Athelia epiphylla* (Ellis, Ellis 1998), was found on decaying wood of *P. sylvestris* covered by cormorant excrements during this study.

Several new species for Lithuania were found during this study. Discomycete *Allophylaria fumosella* is little known and rarely collected, pine needles inhabiting species in Europe, taxonomical position of which remains unclear (Carpenter 1981; Minter 1981; as *Phialina fumosella*). Anamorphic ascomycetes *Junewangia globulosa, Scolecobasidium verruculosum* and *Triadelphia uniseptata,* which mainly occur on decaying wood and bark of small branches are found worldwide on various substrates (Ellis, Ellis 1997). *Triadelphia heterospora,* is a worldwide rare anamorphic ascomycete which originally was described from submerged balsa wood in South America (Shearer, Crane 1971) and later found in rainwater collected from *Sophora japonica* trees in Hungary (Gönczöl, Révay 2004). In our study it was recorded on *Pinus sylvestris* wood in cormorant affected forest parts, in unusual for this species non-aquatic habitat. Another rare anamorphic ascomycete *Dicranidion gracilis* was first described on forest litter from Solomon Islands (Matsushima 1971). Basidiomycete *Jaapia ochroleuca*, which was found on fallen branch of pine in zone E, inhabits decaying coniferous wood (Eriksson, Ryvarden 1976) and is sporadically found in Nordic countries growing on medium-decayed wood with no preference for its diameter (Stokland, Larsson 2011).

CONCLUSIONS

This study of the mycobiota in the Scots pine forest affected by the colony of great cormorants revealed that: 1) species richness of fruiting fungi is reduced in active part of the colony, 2) the species compositions differed among the colony zones and their similarity was rather low, 3) the main direct changes in the trophic structure of fungal communities in the territory occupied by the cormorant colony are the strong decrease of mycorrhizal species, the appearance of coprophilous fungi on forest litter and of specialized fungi on alien and non-forest plants. This inventory study is critical to subsequent studies aimed at understanding as to how fungi function as integral parts of disturbed ecosystems.

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