The response of lichen growth forms to fire frequency: a case study in oak forests of the southern Russian Far East

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Abstract. Epiphytic lichens are used as sensitive indicators of environmental changes. Lichen growth forms are related to biotic and abiotic factors. In the present study, we investigate the response of lichen growth form diversity to fire frequency. In the oak forests of the southern Primorsky Krai, we established 43 sampling plots of 25 m x 25 m each. All plots were assigned to four fire history regimes defined by the combination of fire marks. A total of 168 epiphytic lichen species were recorded. They were classified into 12 groups of growth forms. The linear regression model demonstrated that the taxonomic diversity of epiphytic lichens and the growth form diversity were highly and positively correlated. Increasing fire frequency resulted in limited damage to growth form diversity of the epiphytic lichen communities, whereas species diversity drastically decreased with increasing fire frequency. The diversity of most growth form groups were connected with the gradient of fire frequency. Diversity of growth forms tolerant to a wide environmental variety, such as foliose species with narrow lobes, crustose granular verrucose, and compact crustose, drastically decreased under regular fire events. In contrast, growth forms adapted to sheltered and humid environments, such as foliose gelatinous, foliose inflated, and foliose with broad lobes, were absent on the plots with regular and frequent fire events. Thus, due to the close relationship between morphological traits and specific environmental conditions, certain groups of growth forms can be used as indicators of fire regimes of forests.

1. Introduction
Fire plays an important role in regulating species diversity, vegetation dynamics, and ecosystem processes in forests. Fire affects communities both directly, by consuming organisms, and indirectly, by altering environments that result in changed species assemblages and diversity.

Lichens are a crucial component of forests; they contribute to nutrient cycling, biomass, and biodiversity [1–4]. Moreover, lichens are useful indicators of environmental changes [5]. Researches concerning the fire influence on epiphytic lichen communities focused on species diversity, composition, and percent cover. Published data demonstrated that lichen richness and abundance decreased significantly under high-severity fire, and changed postfire environments prevented reestablishment of lichen communities [6]. The recovery of taxonomical lichen diversity occurred more rapidly than the recovery of projective cover [7]. Regular fire altered lichen species assemblages and decreased lichen vitality [8].

To understand ecological processes in postfire communities, it would be useful to study not only taxonomic species diversity but also functional traits. Species functional traits are directly related to
environmental conditions and ecological processes, and they can be used as reliable indicators of environmental changes across diverse regions [9]. Numerous studies showed that lichen species diversity was influenced by regional differences, whereas species traits, such as growth forms and reproductive strategies, were more independent of geographic position and determined by the microclimatic characteristics of the habitat [9–11]. Species functional traits were connected with the adaptation of communities to the environment; therefore, these traits can provide information about ecological processes [12]. For example, lichen growth forms depended on forest type, light availability, precipitation, and air pollution [9–11]. Reproductive strategies were affected by pH and the level of forest disturbance [9, 10]. Among lichen functional traits, growth forms seemed to be the most responsive parameter to anthropogenic impact, climate change, and forest structure [9, 10, 13]. Another essential advantage of functional traits usage is easier identification of species traits than taxa. Nevertheless, relatively little is known about detailed responses of epiphytic lichen functional traits to fire in forest ecosystems. In this study, we examined the effects of different fire regimes on patterns of lichen growth form diversity in the oak forests of the southern Russian Far East.

2. Models and methods
The study area was located in foothills of Sikhote-Alin and Vostochno-Manchzhske mountains in the southern part of Primorsky Krai, which was the southeasternmost region of the Russian Far East. The study region has been subject to widespread ground fires for many decades, most of the anthropogenic origin. The landscapes were composed of low mountain landforms with gentle and mean steep slopes; an average elevation was in the range of 200-300 m a.s.l. The study area experiences a monsoon climate with dry winters and wet summers. The original coniferous forests were transformed into secondary broad-leaved forests due to harvesting and fire. Now the most common vegetation type is secondary oak forests [14].

In 2006-2017 in oak forests, we established 43 sampling plots, each of 25 m x 25 m. A detailed description of lichen cover on oak (Quercus mongolica Fisch. ex Ledeb.) was made for each sample plot according to the standard method [15]. All lichen species were classified according to their growth form based on the thallus morphological structure [16] following current methods of growth form classification [11, 17]. Foliaceous lichens were further divided into groups depending on the color (protection against high solar radiation) and the water capacity. Overall, 12 groups of growth forms were distinguished: crustose leprous (e.g. Chrisothrix candelaris (L.) J.R.Laundon), compact crustose (Caloplaca cerina (Ehrh. ex Hedw.) Th.Fr.), crustose granular verrucose (Ochrolechia trochophora (Vain.) Oshio), dimorphous radial (Varicellaria velata (Turner) Schmitt et Lumbsch), squamulose (Rinodina xanthophaea (Nyl.) Zahlbr.), foliaceous with narrow lobes (Myelochroa aurulenta (Tuck.) Elix et Hale), foliaceous yellow (Candelaria concolor (Dicks.) Stein), foliaceous dark (Melanelixia huei (Asahina) O.Blanco et al.), foliaceous gelatinous (Leptogium saturninum (Dicks.) Nyl.), foliaceous with broad lobes (Lobaria spathulata Yoshim.) foliaceous inflated (Menegazzia terebrata (Hoffm.) A.Massal.), fruticose with flat lobes (Ramalina sinensis Jatta). We used a linear regression model to investigate the relationships between epiphytic lichen taxonomic diversity and growth form diversity.

Data analysis was made using the software SPSS 13.0 and Excel.

We assigned plots to fire frequency regimes defined by a combination of fire marks according to N.R. Sukhomlinov [18]. The first category consisted of the sites with regular fire events; tree trunks had the signs of fire damage; deadwood and litterfall were absent. The second category included the sites with frequent fire events, tree trunks often had the signs of fire damage; litterfall was formed in two-three years; deadwood occurred rarely, having signs of fire damage. The third category comprised sites with infrequent fire events; tree trunks rarely had signs of fire damage; litterfall was formed for several years; deadwood was covered with moss. The fourth category had the sites unburned for a long time; there were no signs of fire on tree trunks and deadwood; litterfall was formed for many years.
3. Results and discussion

In total, 168 lichen species were collected. These species were classified into 12 groups of growth forms. The linear regression model demonstrated that the epiphytic lichen taxonomic diversity and the growth form diversity were highly and positively correlated ($R^2 = 0.7$, $p < 0.001$). Our results were in agreement with studies in various regions of the world, where a higher number of growth forms was related to higher species diversity of epiphytic lichens [e. g. 11]. Thus, these results, in accordance with previous findings, showed that diversity of growth forms can be used as an indicator of the overall epiphytic lichen diversity, including diversity changes under fire influence.

An increasing fire frequency produced decreasing taxonomic diversity and growth form diversity. Fire frequency caused varying intensity in reducing taxonomic and species trait diversity in the observed forests (figure 1). Increasing fire frequency resulted in limited damage to growth form diversity of the epiphytic lichen communities (figure 1a). The reduction of growth form diversity was limited to 77% (infrequent fire), 62% (frequent fire), and 48% (regular fire) with respect to the sites unburned for a long time. Lichen species diversity drastically decreased with increasing fire frequency (figure 1b). In the category of infrequent fire, the species diversity reduced to half with respect to unburned sites. In the category of frequent fire, the species diversity was only approximately 30% and, in the category of regular fire, taxonomic diversity was only approximately 14% with respect to unburned sites. There is no information on the comparative effect of fire frequency on the taxonomic and species trait diversity of epiphytic lichens. However, this dramatic decrease in taxonomic diversity stands in agreement with what was found in the pine forest of Karelia. Four years later after the fire, the average number of epiphytic lichens per plot was only 5% with respect to unburned sites [7]. The study of epipithic lichen communities of dry grasslands revealed that the functional diversity of lichen cover under infrequent fire regime decreased with less intensity in comparison with the higher reduction of taxonomic diversity [19]. It indicated that lichens recovered functional diversity in the case of an essential reduction of species richness [19].

![Figure 1](image1.png)

**Figure 1.** Mean number of lichen growth forms per plot ± standard error (a) and mean number of lichen species per plot ± standard error for the different categories of fire regimes.

The diversity of most growth form groups was associated with the gradient of fire frequency (figure 2). Foliose species with narrow lobes prevailed at any fire frequency. This growth form reached up to 50% of the total growth form diversity. These species are tolerant of a wide variety of environmental conditions [16]. It was shown that the number of foliose species with narrow lobes increased at a high level of air pollution, in dry conditions, and in secondary forests [10, 17, 20]. V. N. Tarasova with co-authors demonstrated that communities of epiphytic lichens after fire event consisted of species with this growth form [7]. The second large group was crustose granular verrucose. This group comprised 19% to 21%. These species were resistant to a wide range of environmental conditions, including anthropogenic impact [16, 20]. Compact crustose lichens comprised 8 to 14%. It
was demonstrated that the occurrence of this growth form was negatively affected by high anthropogenic impact [20]. The three groups of growth forms adapted to a wide variety of environmental conditions occurred at the sites of all categories of fire disturbance. When fire frequency decreased, their diversity increased more than twice (figure 2a, b, c).

Figure 2. Mean numbers of foliose with narrow lobes (a), crustose granular verrucose (b), compact crustose (c), foliose gelatinous (d), foliose inlated (e), and foliose with broad lobes (f) growth forms at the different categories of fire regimes.
Foliaceous, folicose, fruticose with flat lobes, and crustose leprous were found at sites of all categories of fire regimes. In contrast to foliaceous with narrow lobes, compact crustose and crustose granular verrucose, that group was not numerous at all sites. They were heliophytic and preferred sites with a high level of irradiances. Foliaceous yellow lichens included nitrophilous species that developed at high levels of nitrogen compounds. This group benefits from occupying postfire communities. Their diversity did not change with fire frequency. The diversity of fruticose species with flat lobes dramatically decreased at regular fire events, but more light availability probably contributed to their survival.

Environmental changes caused by fire resulted in increased heat, aridity, and solar radiation. Consequently, an increase in fire frequency negatively influenced the diversity of growth forms intolerant to dry conditions. These growth forms included foliaceous gelatinous, inflated, and folicose with broad lobes. They were absent at the sites with regular and frequent fire events. Previous studies demonstrated that these growth forms were very sensitive to the high level of urbanization [17,20]. The negative effect of urbanization on gelatinous growth form may be associated with dry conditions, on the one hand, as they need liquid water to start photosynthesizing. On the other hand, these species can reach a high level of water saturation, contributing to the rapid accumulation of pollutants [17]. These physiological processes may explain the negative effect of fire on this growth form. Postfire habitats were characterized by warmer and drier conditions and a higher level of pollutants.

Squamulose growth forms were absent at the sites with regular fire events. This growth form was reported as sensitive to air pollution [17, 20]. Our results indicated that even infrequent fire events caused a dramatic reduction of lichen taxonomic diversity, whereas the diversity of growth forms demonstrated a limited decrease. Fire frequency produced a negative effect on all groups of epiphytic lichen growth forms. Diversity of growth forms tolerant of a wide environmental variety, such as foliaceous species with narrow lobes, crustose granular verrucose, and compact crustose, drastically decreased under regular fire events. In contrast, growth forms adapted to sheltered and humid environments, such as foliaceous gelatinous, folicose inflated, and folicose with broad lobes, were absent on the plots with regular and frequent fire events.

4. Conclusion
Lichen growth forms were significantly related to environmental changes caused by fire frequency. Due to the close relationship between morphological traits and specific environmental conditions, certain groups of growth forms can be used as indicators of fire regimes of forests. Since the diversity of growth forms was positively correlated with the total epiphytic lichen diversity, and there were no significant relations to regional floristic features, growth forms can be used for comparative analysis of biodiversity under fire throughout the world. Lichen growth forms are easier to identify than taxa and, therefore, can be considered as a rapid assessment of environmental conditions.

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