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Functional traits of epiphytic lichens respond to alkaline dust pollution

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ABSTRACT

Dust pollution has a harmful impact on the environment and human health. Lichen trait-based metrics are increasingly used to monitor effects of air pollution, but studies using this technique to monitor the effects of dust pollution are still scarce. Functional traits of lichens along a gradient of long-term alkaline dust pollution were investigated. Species composition was affected along this gradient according to two easily identifiable "soft" traits (growth form and main reproductive strategy) and one expert-assessed "hard" trait (species preference for substrate pH). Particularly, crustose species and lichens with sexual reproduction were related to the most polluted side of the gradient and higher pH, while foliose narrow-lobed species and lichens with asexual reproduction were associated with the opposite side.

1. Introduction

The concentrations of many air pollutants (e.g., SO_2, CO, C_6H_6) have decreased in Europe during the last decades, but particulate matter (PM) is still problematic, and EU limits of PM continue to be exceeded in large parts of Europe (Guerreiro et al., 2015). PM is a complex heterogeneous mixture of solid particles suspended in the air which differ in size (ca. 0.1–10 μm), origin and chemical composition (Grantz et al., 2003). Dust pollution usually refers to primary and coarse PM (larger dust particles) originating from natural or anthropogenic sources; rock quarrying, combustion processes, kiln grinding or road surfaces are the commonest anthropogenic sources. Dust particles originating from these sources are usually dispersed by wind, and generally deposited near to the emission source (e.g., Farmer, 1993; Branquinho et al., 2008; Paal et al., 2013). Desert dust, transported over thousands of kilometres by desert storm, is one of the commonest natural sources of dust pollution (Middleton, 2017).

Dust pollution causes several detrimental impacts; for example, cement dust poses harm to human health, provoking respiratory diseases (WHO, 2013; WBCSD, 2015). Its effects also impact on the environment; alkaline dust emissions increase the pH value and change chemical composition of soil and other substrates, thus altering the composition of plant communities and species richness (e.g., Gilbert, 1976; Farmer, 1993). Long-term alkalization of soil, for example, provokes "nemoralization" of pine forest ecosystems, increasing species richness and frequency of uncommon plants which are not naturally occurring in boreal ecosystems (Paal et al., 2013).

Air monitoring stations that directly measure the PM content in ambient air provide real-time data on pollutant concentrations in its surrounding area. However, such information is usually acquired from a restricted number of monitoring stations due to substantial costs and operational constraints (e.g., constant supply of electric

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power for its operation), limiting its application in environmental monitoring (Conti and Cecchetti, 2001; Guidotti et al., 2003). Although monitoring stations provide information on pollutant concentrations, they do not directly reflect their effects on the ecosystem. Ecological indicators arise as a more cost-effective approach to monitor air pollution issues. They enable us to have higher spatial resolution (i.e. to have a higher number of sampling sites when compared to the restricted number of air monitoring stations), integrating simultaneously the effects at the ecosystem level.

For many years, taxonomic diversity metrics, such as species richness, were employed to quantify ecosystem change in response to environmental drivers. Though undeniably important to depict the component of biodiversity loss, recent studies have shown that for some important pollutants, such as nitrogen (Pinho et al., 2012a), and other global change drivers, these metrics could be unresponsive (e.g., Dornelas et al., 2014; Vellend et al., 2017). In fact, more than species loss, we seem to be currently observing shifts in communities which taxonomic diversity indices are unable to depict. Trait-based metrics are being increasingly considered as better indicators to quantify ecosystem functionality in response to global change drivers (Díaz and Cabido, 2001; Suding et al., 2008; Mouillot et al., 2012). Functional traits refer to characteristics of the organisms (such as morphological or physiological attributes) thought to be relevant to ecosystem functioning and/or its response to the environment (Díaz and Cabido, 2001). Simply put, a trait-based approach facilitates the direct comparison between many species regardless of their taxonomic identity, allowing determination of how the environment (biotic and/or abiotic) selects for different traits across large environmental gradients, without taxonomic or geographical constraints. Hence, these metrics represent a more universal approach, which allows detection of the shifts in species composition accounting for species redundancy and abundance, and with the possibility of making a link with ecosystem functioning.

Lichens are extremely dependent on the atmosphere for nutrition due to their physiological and metabolic features (Nash, 2008); they absorb nutrients directly from the atmosphere, including atmospheric pollutants. This is the key reason why they have more than 100 years of history as excellent ecological indicators to track the effects of air pollution and other major global change drivers (e.g., Nimis et al., 2002; Loppi, 2014; Sujetovienė, 2015; Matos et al., 2017). The earlier works were based on taxonomic diversity metrics (Hawksworth and Rose, 1970; Gilbert, 1973). As atmospheric pollutants that exerted an overall deleterious effect on all species (like SO_2) decreased as a result of emission control policies, taxonomic diversity was increasingly replaced by other metrics. In fact, shifts in communities have been observed in response to nitrogen pollution (e.g., Frati et al., 2007; Pinho et al., 2011, 2012a), fires (Giordani et al., 2016), land use intensity (Stofer et al., 2006) and thus lichen trait-based metrics are being increasingly used to track the effects of several global change drivers. Lichen traits related to tolerance to eutrophication are used to track the effects of nitrogen pollution resulting from cattle load or even to establish the European critical levels for ammonia (Pinho et al., 2012b; Giordani et al., 2014). Lichen trait-based approach has been used not only in pollution and environmental monitoring studies (Ellis, 2012; Giordani et al., 2012), but also, for example, in planning conservation activities for lichens, where the analytical scheme 'common species/driver/trait/driver/rare species' was employed, based on which recommendations for conservation management of alvars were proposed (Leppik et al., 2015).

Previous studies concerning dust pollution from anthropogenic activities have demonstrated that long-term dust pollution influences lichen diversity, abundance and community structure, directly or through effects on lichen substrates, due to pH increase of substrate or its hypertrophication (e.g., Loppi and Pirintsos, 2000; Seaward and Coppins, 2004; Marmor et al., 2010; Degtjarenko et al., 2016a), together with negative impacts on genetic variation of a widespread lichen-forming fungus (Degtjarenko et al., 2016b). Dust emission is expected to increase in future due to expansion of industrialization and urbanization, especially with the synergistic effect of climate change (Fiore et al., 2015). Moreover, increased erosion and dust storm events are expected in the future due to climate change, potentially contributing to an overall increase of dust particles (Middleton, 2017). Hence, it is timely and important to investigate the suitability of trait-based metrics to track dust pollution under a global change perspective so that we can take measures to control and mitigate its effects on human and ecosystem health. The aim of our research was to study the lichen functional traits along a gradient of long-term, alkaline dust pollution released from limestone quarrying, and estimate the applicability of trait-based metrics to track the effects of dust pollution.

2. Material and methods

2.1. Study area

The study area is located in northern Estonia (Harju County) and has a characteristic temperate climate with a mean annual temperature of 6 °C, a mean annual precipitation of 672 mm, and an average wind speed of 3.7 m/s (Estonian Weather Service, 2017). The study took place in forests and urban forest parks, dominated by Scots pine (*Pinus sylvestris*, hereafter "pine"), in the surroundings of four large limestone quarries: Vasalemma (59°14′22″N, 24°18′19″E), Harku (59°23′51″N, 24°34′18″E), Väo (59°26′6″N, 24°53′43″E), and Maardu (59°26′58″N, 25°1′55″E) (Fig. 1; see Marmor and Degtjarenko (2014) and Degtjarenko et al. (2016a) for more detailed descriptions of the study area).

Quarrying and limestone use have a very long tradition in Estonia, dating back to the 13th century (Ministry of the Environment, 2011). The excavation of limestone from these four quarries amounts to half of the total quarried limestone in Estonia per year, amounting to c. 2.6 million m^3 (Geoguide Baltoscandia, 2012), mostly used as a compound in civil engineering and for the cement industry (Perens and Kala, 2007). In general, dust emissions from the aforementioned quarries contain a high amount of $CaCO_3$ (>50%) and MgO (c. 14%), small amounts of SiO_2, Al_2O_3, and Fe_2O_3 (Perens and Kala, 2007; Reinsalu, 2008). The pH of pure limestone in water solution is very high, for example the pH of cement dust (using limestone as raw material) in water suspension is c. 12.3–12.6 (Mandre, 2000). Dust from limestone mining is emitted to the atmosphere by drilling–blasting and crushing operations and by transportation of extracted material (Geoguide Baltoscandia, 2012). The actual amount of released dust pollution is unknown, but the maximum allowed quantity of PM reported by the Environmental Board of Estonia varies immensely from 1.2 to 220.0 tonnes per year (in Maardu and Vasalemma, respectively; Environmental Board, 2017).

2.2. Sampling

Sampling was carried out during spring and summer of 2013. Sampling was stratified along the distance to the pollution source. Lichens were sampled in 32 plots of 25 m radius located at different distances (3 m–3340 m) in all possible directions from the perimeter of the nearest limestone quarry (Vasalemma – 10 plots, Harku – 10 plots, Väo – 5 plots, Maardu – 7 plots) along a gradient of dust pollution within four distance ranges (0–500; 501–1000;