Chapter 23

Lichens as an Indicator of Climate and Global Change

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1. INTRODUCTION

Lichens have been observed to respond rapidly to climate change. So far, the changes are as expected with a rather rapid increase of (sub)tropical species in temperate areas, and a gradual decrease of some boreo-alpine elements [1]. So far, comparatively few publications have addressed the issue of lichens in connection with global warming [2]. No lichens have, so far, been reported to be seriously threatened by climate change. Marked shifts in occurrence and distribution have been predicted based on known habitat preferences and projected climate change [3].

Lichens, like most cryptogams, tend to be widespread, much more so than phanerogams or land animals. Also, many of the species seem to be capable of rather rapid dispersal, as shown by the recent arrival of some (sub)tropical species in a temperate area [1].

In this chapter, predicted, observed and uncertain effects related to lichen and climate change are discussed together with the habitats of vulnerable lichens, with special attention to mountain tops in the tropics – the most likely place for possible extinction of lichens as a result of global warming.

Climate Change: Observed Impacts on Planet Earth

2. PREDICTED EFFECTS

As a result of the attention paid to the effects of global warming on various groups of organisms and various ecosystems, some lichenologists have addressed the question of what effects global warming might have or have had on lichens.

Nash and Olafsen [4] predict that global warming in arctic areas may have a positive effect on lichens with cyanobacteria as photobiont, because the conditions for nitrogen fixation will improve. They reasoned that under field conditions of optimal water hydration, lichen photosynthesis is primarily light-limited and nitrogen fixation is temperature-limited in both *Peltigera canina* and *Stereocaulon tomentosum* at Anaktuvuk Pass, Alaska. Thus, they continued, 'where duration of optimal hydration conditions remains unchanged from the present-day climate, the anticipated temperature increases in the Arctic may enhance nitrogen fixation in these lichens more than carbon gain. Because nitrogen frequently limits productivity in Arctic ecosystems, the results are potentially important to the many Arctic and subarctic ecosystems in which such lichens are abundant'. The expected effect will be a spread of these species at the cost of other lichens and/or plants. So far, this has not been unequivocally observed; rather the contrary: lichens have recently decreased in arctic regions, probably due to the increase in phanerogams [5].

Insarov and Schroeter [6] and Insarov and Insarova [7] predict that lichens might, like other groups of organisms, show a response to global warming. As lichens are generally swift colonisers that disperse well, not only negative changes (extinctions) might be observed but also new invasions of more warmth-loving species in areas where they have not occurred before. In order to detect such changes, they installed some base-line monitoring transects across steep climatic gradients, but so far, no results have been reported.

Ellis and co-workers [3,8] predict the response, in terms of changed distribution on the British Isles, of groups of lichens with different current distribution patterns and known ecological preferences, based on the current distribution and on several different climate scenarios. Although numerous historic data are also available, no unequivocal correlation between global warming and past changes in the lichen flora of the British Isles has been shown.

Zotz and Baader [9] describe the different projected scenarios as regards lichens and bryophytes in the different biomes in the world.

Finally, as a result of widespread melting of glaciers, new habitats for (especially) stone-inhabiting lichen are being formed. However, only the pioneer species can be expected to benefit from this.

3. OBSERVED EFFECTS

So far, few studies have demonstrated a correlation between global change and change in lichen habitat. The study by van Herk et al. [1] was the first and only one reported in the meta-analysis by Parmesan and Yohe [10] in their study of ‘globally coherent fingerprint of climate change impacts across natural systems’. The lichen study was based on a long-term (22 a) monitoring involving all the 329 epiphytic and terrestrial lichen species occurring in the Netherlands and were considered in relation to their world distribution. The investigation focussed on the exposed wayside trees in the province Utrecht in the Netherlands. The research was initially started to document changes resulting from changes in sulphur dioxide air pollution levels. When the levels dropped, the effects on the lichens were clearly visible. However, the pattern was disturbed by a new emergent air pollution problem – ammonia from increasingly intensive cattle farming. As different lichens show different responses to this pollutant, the lichen monitoring was continued for a different purpose, viz. a detailed mapping of the areas with problematic ammonia pollution. Changes between 1995 and 2001, however, could not be explained in terms of air pollution variables alone. Analysis, however, showed a positive correlation with temperature, oceanity and nutrient demand, indicating a recent and significant shift towards species preferring warmer circumstances, independent from, and concurrent with changes due to nutrient availability. In short, warmth-loving, oceanic lichens are expanding and boreal lichens are diminishing.

The lichens that are expanding most dramatically are those with the green algae *Trentepohlia* as their photobiont. As these lichen species (i.e., the mycobiont) belong to different unrelated taxonomic groups and the effect has been observed in different ecosystems (exposed trees, forests), Aptroot and van Herk [11] argue that it seems likely that the effect of the global warming is, in fact, directly related to the alga, and all lichens with this alga can profit from the expansion of their photobiont. The process as described here is continuing and probably even accelerating. A recent study by van Herk [12] shows that most of the recent changes can be now attributed to global warming (see Figs. 1 and 2).

4. UNCERTAIN EFFECTS

Some observed and reported changes in the lichen flora cannot be unequivocally attributed to global warming. There are several reasons for this but the most common one is that comparable historic or background data are wanting. Also climate change is not the only change taking place and some of the changes occurring locally may interact or even counteract. Examples are isolated finds of warmth-loving species in more boreal countries, like *Flavoparmelia caperata* in Denmark, reported by Søchting [13] and attributed by him to global warming.

Another type of uncertainty is the intermittent and sometimes devastating effects of El Nino on coastal lichens along the Pacific coast of South America and on the Galapagos Islands. These have been documented, for example, by Follmann [14] and attributed directly to El Nino. The question remains

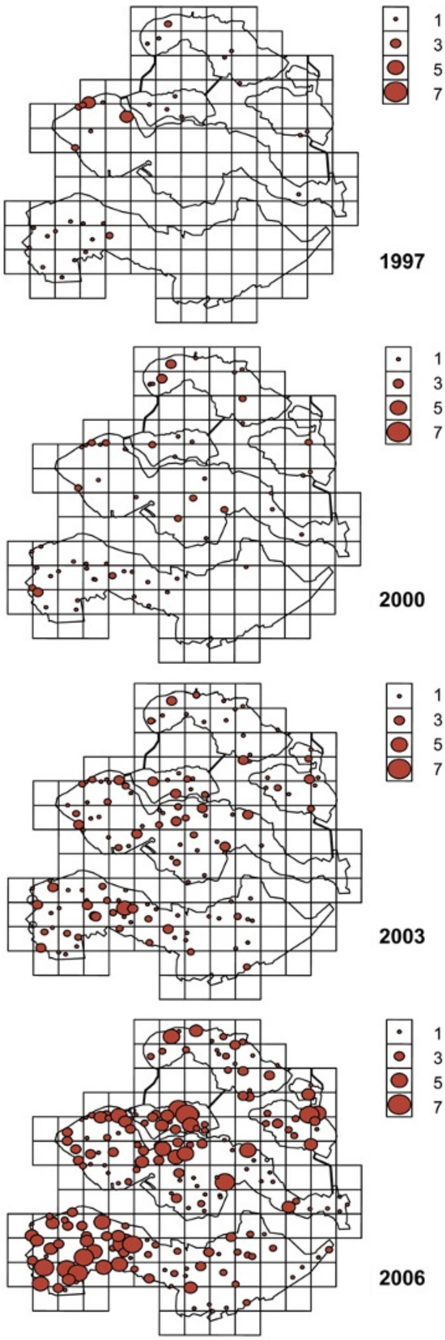

FIGURE 1 The distribution of lichen species with *Trentepohlia* phycobiont in the Netherlands province of Zeeland, in 1997, 2000, 2003 and 2006. The dot size refers to the number of species per site [12].

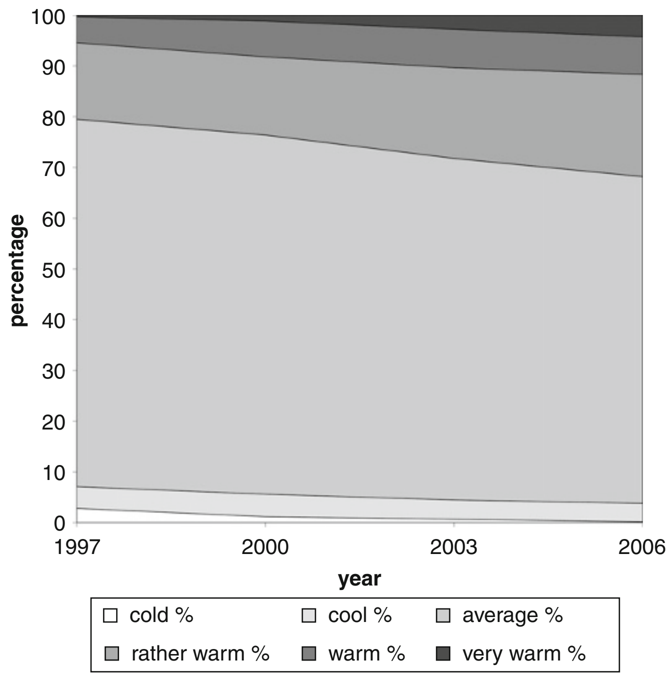

FIGURE 2 Changes of the epiphytic lichen composition in the Netherlands province of Zeeland in relation to temperature preference. The percentages are derived from species' frequencies per year. The total number of species for which a temperature preference is known is given as 100% [12].

whether the intensity of the El Nino effects is changing due to global warming, or not. In any event, lichens appear to have suffered more during the past few decades than ever before.

In some cases the patterns and processes are confused. An example is the reported work by Cezanne and co-workers [15] claiming that changes in lichen were indicators of climate change. However, all the observations were made within a year and the various stations were visited only once; the paper describes the correlation of the lichen vegetation with climatic parameters, but only a spatial pattern is shown. In summary the conclusion made, does not bear up to scientific scrutiny.

5. HABITATS WITH VULNERABLE LICHENS

There are four main habitats where lichens are potentially most vulnerable to climate change in the form of global warming, changes in precipitation and changes in the incidence of fog.

5.1. Low Level Islands with Endemic Lichens

Examples of such islands include Porto Santo [16–18] and Bermuda [19]. The fact that some of the lichens on these islands are endemic suggests that they are either not capable of dispersal and/or their ecological requirements are not met elsewhere. In the event of a marked temperature rise or a change in the incidence of fog, the climate may become unsuitable for these species, and the chances of reaching a suitable substitute location are remote. The risks are highest at islands without mountains, as no suitable habitat will become available higher up the mountains.

5.2. The Extended Regions with Similar Climate but Local Endemism

The main examples are the extensive tropical rain forests. Although the climate and the physiognomy of the vegetation can be very similar over large areas, there can be a considerable amount of local endemism. This endemism is concentrated on the higher tree trunks, and not in the canopy (where wind moves the diaspores) and not at the various habitats at ground level (where bryophytes usually dominate and light conditions are poor). The endemic species usually have large acospores, of the order of 0.1 mm diameter. The risks to these lichen involved in a climate change, are that large expanses of habitat will change simultaneously, and the species with large diaspores have little chance of reaching a relatively remote suitable habitat. Incidentally, this risk may be small compared to the more direct and imminent risk of habitat destruction by logging. Furthermore, it has been pointed out by Zotz and Baader [9] that if tropical coastal regions become warmer, no species may continue to exist that are capable of occupying the habitats that become available as a result of other species shifting to higher elevations.

5.3. The (Ant-)Arctic and Tundra Regions

These areas are very rich in lichens, which often dominate the vegetation, both in biomass and in species diversity. Some lichens have been shown to decline, possibly indirectly as a result of global warming, due to increases in vascular plant biomass [5]. This is a potential threat to the rich (ant-)arctic lichen flora, but cannot be considered as an immediate one, as most (ant-)arctic lichens are relatively abundant and widespread, and a major impact will only occur in the unlikely event of the whole (ant-)arctic biome collapsing.

5.4. High Ground in the Tropics

High mountains in tropical areas sustain a rather depauperate lichen flora consisting predominantly of species widespread in boreo-alpine areas elsewhere in the world, but also including local endemics. These species have nowhere to go, other than literally in air, in the case of global warming. The mountains in New Guinea are examples of this group. They are among the most isolated biomes, as they are not connected to temperate regions, as, for example, the Andes are. Mount Wilhelm, reaching about 4500 m, is the highest mountain in Oceania, and from a lichenological point of view is the best investigated high mountain in New Guinea. It is also the richest in lichen species, as several other mountain tops are grass-covered. This is an isolated mountain, of which only less than 100 km^2 lies above the tree line and is at least partly suitable for boreo-alpine terricolous and saxicolous lichen growth. Among these are many cosmopolitan species [20,21]. The species, virtually on the equator, must be considered as 'boreo-alpine' or 'temperate' in a climatic (not geographic) sense. They cannot be considered as 'circumpolar' or 'bipolar' as is often stated [22]. For these New Guinean lichens their next closest localities are in Taiwan, over 4000 km away, and in the Himalayas, more than 5000 km away. How the species actually arrived remains unknown, although the presence of relatively many species that are associated with bird perching suggests that birds may have played an important role as vector of lichen diaspores, next to or even instead of wind and air currents.

The alpine lichen zone on Mount Wilhelm is restricted to a narrow altitudinal belt, above the tree limit at 3900 m to about 4300 m. This belt is known in botanical and tourism descriptions of the vegetation and the climb, as the 'dead lichen zone', because the abundant *Thamnolia* is mistaken for dead lichens. The area consists of a granite bedrock with large boulders, vertical cliffs and horizontal stretches with some soil compaction supporting heath-like dwarf shrub vegetation. This is a small zone where the recently described endemic *Sticta alpinotropica* [23] occurs on rocks, and the equally endemic *Thamnolia juncea* [24] is found in the (sub-)alpine grassland. The known world populations of both species amount to only a few square metre. Below the tree limit, the availability of various susbstrates for lichens is much wider, and the lichen diversity in the cloud forest belt is very high. This is the zone where numerous endemic species occur, for example, of the genera *Anzia* [25] and *Menegazzia* [26].

6. CONCLUSION

Lichens are unequivocally responding to global change. The effects are, so far, apparent only in the last two decades (since ca. 1990) and in the temperate region only. Lichens have indirectly suffered from global change effects in arctic regions. The most severe effects of climate change, leading to probable extinctions, is expected (but has not been observed as yet) on high mountains in tropical regions.

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REFERENCES

1. C.M. van Herk, A. Aptroot, H.F. van Dobben, Lichenologist 34 (2002) 141–154.
2. A. Aptroot, Bull. Br. Lichen Soc. 96 (2005) 14–16.
3. C.J. Ellis, B.C. Coppins T.P. Dawson, Biol. Conserv. 135 (2007) 396–404.
4.. T.H. Nash, A.G. Olafsen, Lichenologist 27 (1995) 559–565.
5. J.H.C. Cornelissen, T.V. Callaghan, J.M. Alatalo, A. Michelsen, E. Graglia, A.E. Hartley, D.S. Hik, S.E. Hobbie, M.C. Press, C.H. Robinson, G.H.R. Henry, G.R. Shaver, G.K. Phoenix, D.G. Jones, S. Jonasson, F.S. Chapin III, U. Molau, C. Neill, J.A. Lee, J.M. Melillo, B. Sveinbjörnsson R. Aerts, J. Ecol. 89 (2001) 984–994.
6. G. Insarov, H. Schroeter, in: P.L. Nimis, C. Scheidegger, P.A. Wolseley (Eds.), Monitoring with Lichens – Monitoring Lichens, Kluwer, Dordrecht, 2002, pp. 183–202.
7. G. Insarov, I. Insarova, Bibl. Lichenol. 82 (2002) 209–220.
8. C.J. Ellis, B.C. Coppins, T.P. Dawson, M.R.D. Seaward, Biol. Conserv. 140 (2007) 217–235.
9. G. Zotz, M.Y. Baader, Prog. Bot. (2009) 70, 147–170.
10. C. Parmesan, G. Yohe, Nature 421 (2003) 37–42.
11. A. Aptroot, C.M. van Herk, Environ. Pollut. 146 (2007) 293–298.
12. C.M. van Herk, Bibl. Lichenol. 99 (2008) 207–225.
13. U. Søchting, Graph. Scr. 15 (2004) 53–56.
14. G. Follmann, Cryptogamic Bot. 5 (1995) 224–231.
15. R. Cezanne, M. Eichler, U. Kirschbaum, U. Windisch, Sauteria 15 (2008) 159–174.
16. H. Krog, H. Østhagen, Norweg. J. Bot. 27 (1980) 185–188.
17. H. Krog, Lichenologist 22 (1990) 241–247.
18. R. Haugan, Mycotaxon 44 (1992) 45–50.
19. L.W. Riddle, Bull. Torrey Bot. Club 43 (1916) 145–160.
20. A. Aptroot, P. Diederich, E. Sérusiaux, H.J.M. Sipman, Bibl. Lichenol. 64 (1997) 1–220.
21. H. Streimann, Bibl. Lichenol. 22 (1986) 1–145.
22. D.J. Galloway, A. Aptroot, Cryptogamic Bot. 5 (1995) 184–191.
23. A. Aptroot, Lichenologist 40 (2008).
24. R. Santesson, Symb. Bot. Ups. 34 (1) (2004) 393–397.
25. I. Yoshimura, H.J.M. Sipman, A. Aptroot, Bibl. Lichenol. 58 (1995) 439–469.
26. P.W. James, A. Aptroot, P. Diederich, H.J.M. Sipman, E. Sérusiaux, Bibl. Lichenol. 78 (2001) 91–108.