EFFECTS OF EXPERIMENTAL INCREASE OF TEMPERATURE AND DROUGHT ON HEATHLAND VEGETATION

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Increase of temperature and drought on heathland vegetation

Key words: environmental change, heathland vegetation, climatic manipulation

Abstract. Effects of simulated environmental changes on heathland vegetation were investigated in Oldebroek, the Netherlands. As response to strong disturbance, decrease of the presence/coverage of lichen species was observed; bryophytes have shown various reactions. In the drought plots the normally predominant species are decreasing, while others reach their maximum coverage here.

Introduction

Global changes in the climate are a potential threat to biodiversity and may cause irreversible effects (Kappelle *et al.* 1999). As identified by the European Environmental Agency (Anonymous 2004) the lack of studies on the effects of global climatic change on species diversity is one of the areas needing greater attention of researchers.

INCREASE is an EU-funded infrastructure of six large-scale climate change experiments designed to study climate change effects on shrub lands. The experiments combine two different "space for time" substitution approaches to study climate effects on ecosystems: observational studies (performing along a precipitation and temperature gradient in Europe) and manipulative experiments. The research involves non-intrusive technologies for realistic climate manipulations (temperature and drought manipulations) and non-destructive sampling methodologies and by synthesis of long data records.

The few studies that exist on how bryophyte and lichen species richness or diversity is affected by temperature enhancement show diverse results, from no changes to decreases in abundance of bryophytes, and from decreases to increases in abundance of lichens (Jonasson 1992; Molau & Alatalo 1998; Press *et al.* 1998; Jägerbrand *et al.* 2006). Thus, so far, the response pattern of brophyte and lichen richness/diversity to global change has not been clearly defined.

The aim of this work was to give a full checklist of bryophytes of the investigated plots and to investigate whether species richness and species composition of the bryophyte assemblage are affected by temperature and drought.

Materials and methods

Site description

The Dutch experimental site Oldebroek (52°24’N; 5°55’E) is located at the Artillary Practice Ground (ASK) of the Dutch Army near the towns of ‘t Harde and Oldebroek, province of Gelderland, the Netherlands (Fig. 1). The site is part of a large heathland area called Oldebroekse heide. Climate is temperate and humid, with yearly rainfall 1072 mm, and annual average temperature 10.1°C. The heathland vegetation found here is dominated by *Calluna vulgaris*, *Deschampsia flexuosa* and *Molinia caerulea* with some scattered *Betula pendula* and *Pinus sylvestris* trees and bushes of *Juniperus communis.* The plots are mainly covered with *Calluna vulgaris* of a maximum height of 75 cm.

The heathland is managed by regular vegetation cutting back, or more drastically by sod-cutting to prevent grass encroachment by removing nutrients. The soil is a well drained, sandy to loamy sand podzol, with a groundwater class of VII. In the Duch system class VII means that groundwater level is always lower than 1.8 m soil depth. The site is located at an elevation of 25 m above sea level and is almost flat (slope 2%).

Remarkably high N leaching was observed at the heath with 18 and 6.4 kg N ha^{-1} $year^{-1}$ of NO_3-N and NH_4-N leached from the control plots, respectively, indicating that this site is nitrogen saturated. Increased soil temperature of 0.5-1.0°C in the warmed plots almost doubled the concentrations and losses of $N0_3$-N and DON (dissolved organic nitrogen) at this site (Kopittke *et al.* 2012). However, NO_3 leaching and the effect of warming have decreased during the last years (Schmidt *et al.* 2004). Due to the high N deposition, the growth of biota is limited only by phosphorous (Van Meeteren *et al.* 2007). Finally, it is supposed that climate change affects the overall water holding capacity of the soil, leading to decreased moisture contents even in winter (Sowerby *et al.* 2008).

CLIMATIC MANIPULATION

At Oldebroek there were a total of 9 plots of 20 m^2 each that have been under climatic manipulation since 1998. There were 3 replicated plots of each treatment; 3 control plots, 3 night time warming plots and 3 repeated summer drought plots. In the warming plots a reflective curtains was drawn across the plots at night thus preventing loss of infrared radiation, leading to an increase in mean daily temperature in the topsoil of 0.5 to 1.0 ºC. The curtains were controlled by a light sensor. In case of rain during the night, the curtains were withdrawn so the water balance was kept intact. Drought plots were protected from rain by a rain cover for 2-3 months during every growing season since 1999. A rain sensor controlled the curtains to ensure that they only cover the plots during rain events. At the end of summer 2009, 2 m^2 of the vegetation of all plots was cut and all the cut vegetation removed, allowing investigation on the interaction between climate change and manipulation.

SAMPLING METHOD

Bryophytes were inventoried in October, 2011. It was done with a minimum disturbance of the plots and only selected species were collected for ulterior determination. In every plot 5 quadrates of 20 × 20 cm were chosen randomly and coverage of bryophyte species was estimated within these quadrates. Total number of sampling quadrates were 45 (15 control, 15 temperature and 15 drought quadrates).

Nomenclature follows Catalogue of Life (http://www.catalogueoflife.org).

Results

Allover 19 species: 7 vascular plants, 1 alga, 1 lichen and 10 bryophytes were observed in the investigated plots (Table 1). The dominancy of *Hypnum cupressiforme* and *Calluna vulgaris* was observed in each plot, both of them showed significantly decreased coverage in the drought plots.

Six bryophyte species were in the control plots, five in temperature plots and eight in the drought plots. Four species are present only in the control plots, three only in the temperature plots and one only in the drought plots. *Dicranum scoparium* is present in all three types of plots, reaching its highest coverage at the temperature plots. *Pohlia nutans* reaches its highest coverage in drought plots and is present in less proportion in the other two plots. *Polytrichum juniperinum*, also reaching its highest coverage in drought plots, is missing from temperature plots and present only in 2% in the control plots. *Cladonia* sp. lichen species is equally present in control (11%) and temperature plots (10%) but completely missing at drought plots.

Analysing flora elements and strategy of bryophytes we found that most of the species (8) are cosmopolitans, five of them are perennials and other five are colonists. Most of the species found have wide ecological amplitude concerning the water and temperature requirements (Table 2).

Percentage of colonist species is significantly higher in drought plots (Fig. 2).

Discussion

It was observed that climatic manipulation modifies the composition of both the bryophyte and vascular plant flora.

Concerning vascular flora: the dominant vascular plant species is *Calluna vulgaris*; a gradual decrease of its coverage can be detected in the temperature and drought plots. Besides *Calluna vulgaris*, other vascular plants are represented here by *Nardus stricta* which usually occurs on poor acidic sandy, peaty soils and is strongly calcifuge. *Molinia caerulea* grows best in acidic soils and can live under extreme conditions. The replacement of ericaceous dwarf shrubs by grasses such as *M. caerulea* is a major threat to heathland conservation (Mobaied *et al.* 2012). Both of them could be observed only in the control plots. *Rumex acetosella* is often one of the first species to appear in disturbed areas, especially if the soil is acidic; it is widely considered to be a noxious weed. In the warmed plots it has a cover of 10%, reaching its highest coverage of 28% in the drought plots, whereas it was missing in the control plots. Other plants present on the experimental site are: *Juniperus communis, Prunus serotina* and *Carex pilulifera*, all are present only in the temperature plots. Large-scale geographical investigations are important because *Prunus serotina* (originally, native to North America) is an invasive species in north-western Europe (Reinhart *et al.* 2005). A single shoot of *Carex pilulifera* occured in one of the warmed plots. This species has a wide distribution in Europe (Jermy *et al.* 2007); it typically inhabits soils with a pH of 4.5–6.0.

Concerning cryptogams***:*** dominant moss species is *Hypnum cupressiforme* which has a great coverage in control and temperature plots and significantly decreases (by 10%) in drought plots. *Hypnum cupressiforme* is an extremely polymorphic species, reflected in the more than 60 varieties that have been described. Recently Frahm (2009) has described the infraspecific taxa of this group. This species has wide ecological amplitude as well as a cosmopolitan world distribution (Table 2.) and is found in all climatic regions. Two phenotypes of *H. cupressiforme* occurred here: one adapted to shade, with slender shoots and darker olive green in shadow – always under *Calluna* shrubs and one more robust, yellow-green observed in more light exposed places (between *Calluna* shrubs). In a single quadrate where the vegetation was cut in 2009 (which means a strong disturbance) *Hypnum* disappeared and instead of it a jelly layer with green algae (*Aphanothece* sp.) appeared. Embedded in this algae layer *Polytrichum juniperinum* and *Cladonia* sp. lichen could be detected. *Polytrichum juniperinum*, being a xerophyte species (Table 2), also reaches its highest coverage in drought plots (14%) and missing from temperature plots, present only in 2% in the control plots. According to Smith (1978) *P. juniperinum* commonly grows on well drained acidic soil on heaths, moorland and rocks. *Cladonia* lichen species is equally present almost in the same proportion in control and temperature plots but completely missing at drought plots. *Campylopus introflexus* is well represented in drought plots (2%) but also found in control plots (0,66%). It is an invasive moss species in Europe and it has wide ecological tolerance (Table 2). It is widespread in the Southern hemisphere and it was first discovered outside its native range in 1941 in Great Britain (Richards, 1963). In the Netherlands it was discovered in 1963 (Barkman & Mabelis

1968) and as a result of rapid spread, Greven (1992) reported more than 200 records. Bernth (1998) showed that this species has a significant negative effect on the germination of seeds of *Calluna vulgaris* in the field. *Dicranum scoparium* is a moss species considered to be indifferent to soil pH and it is a characteristic, constant species in *Callunetum* and can be found in all three types of plots. Remarkable was the high cover (59%) of *Dicranum scoparium* in the warmed plots compared to the control plots (24%), although it is a moderately hygrophyte, mesophyte species according to Dierßen (2001) (Table 2). Gimingham (1961) described *Calluna* communities in Northern Europe, including reports of *Dicranum scoparium* in heath associations throughout Scandinavia, Germany, Denmark and the Netherlands. *Ceratodon purpureus* occurring at the drought plots is considered to be a coloniser of disturbed sites. This species is most abundant on exposed sandy soils but tolerates a wide range of soils and it is a considerably xerophyte species (Table 2). *Dicranella heteromalla* also occurred only in the drought plots. It is common and sometimes abundant except on calcareous substrate (Smith 1978). *Pohlia nutans* reaches its highest coverage in drought plots (11%) and is present in less proportion (3, respectively 5%) in the other two plots. This species is common on heaths, tolerates mineral-rich habitats and occurs at industrial sites especially those with heavy-metal pollution (Smith 1978) and it has a wide ecological tolerance (Table 2). *Polytrichum longisetum* is present only in the temperature plots (4%), although it has a wide ecological tolerance concerning the temperature requirement, but moderately hygrophyte (Table 2). This moss species grows on acidic, well drained soil on heaths and moorlands (Smith 1978). The liverwort species *Lophozia ventricosa*, common in many acidic places (Landwehr 1980), was found in the temperature and drought plots, missing from the control plots; although this species has a moderately hygrophyte character and requires a somewhat colder temperature range (Table 2). *Cephaloziella hampeana* was found in one of the control plots forming a small patch and covering 4%. This species usually grows on acidic or neutral substrates (Smith 1990) and it requires a little bit colder temperature range, but it has wide ecological tolerance concerning the water requirement (Table 2).

Conclusions

The main findings of this study are:

1. The dominant vascular (*Calluna vulgaris*) and bryophyte (*Hypnum cupressiforme*) species reach their highest coverage in the control plots and show significantly lower coverage in temperature and drought plots due to climatic manipulations.

2. Occurrence of colonist species (*Ceratodon purpureus)* and species adapted to disturbed areas (*Rumex acetosella* and *Prunus serotina*) were observed only in temperature and drought plots, while *Cladonia* sp. lichen is missing from the manipulated plots.

3. There is a strong increase in the percentage of colonist and stress tolerant perennial species (e .g. *Ceratodon purpureus, Dicranella heteromalla*, *Polytrichum juniperinum, P. longisetum*) in the drought plots.

It is also concluded that to get a more complete picture about the bryophyte assemblages of the investigated plots, more sampling work is needed to take into account the yearly climatic differences and natural fluctuation in the species composition.

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Table 1. Average coverage (expressed as percentage) of species in the three plots of the control, warming and drought treatments.

Species	Control	Warming	Drought
Calluna vulgaris L.	96	91	84
Carex pilulifera L.	0	0.26	0
Juniperus communis L.	0	0.50	0
Molinia caerulea (L.) Moench	0.50	0	0
Nardus stricta L.	0.50	0	0
Prunus serotina Ehrh.	0	0.26	0
Rumex acetosella L.	0	10	28
Aphanothece sp.	0.80	0	0
Cladonia sp.	11	10	0
Campylopus introflexus Brid.	0.66	0	2
Cephaloziella hampeana (Nees) Schiffn.	0.26	0	0
Ceratodon purpureus Brid.	0	0	1.85
Dicranum scoparium Hedw.	24	59	16
Dicranella heteromalla (Hedw.) Schimp.	0	0	0.50
Hypnum cupressiforme L.	90	91	80
Lophozia ventricosa (Dicks.) Dum.	0	0.93	0.20
Pohlia nutans (Hedw.) Lindb.	3	5	11
Polytrichum juniperinum Hedw.	2	0	14
Polytrichum longisetum Sw. *ex* Brid.	0	4	0

Table 2. Bryophyte species and their distribution, strategy type, water and temperature requirement according to Dierßen (2001)

Species name	Flora element	Strategy	Humidity	Heat balance
Campylopus introflexus (Hedw.) Brid.	disj cosmopol	perennial, dominant	moderately hygrophyt – considerably xerophyt	mesotherm – moderately thermophyt
Cephaloziella hampeana (Nees) Schiffn.	circpol+Macar	colonists	moderately hygrophyt – considerably xerophyt	moderately cryophyt – mesotherm
Ceratodon pur-pureus (Hedw.) Brid.	cosmopol	colonists	mesophyt – considerably xerophyt	considerably cryophyt – considerably thermophyt
Dicranum sco-parium Hedw.	cosmopol	competitive perennials	moderately hygrophyt – mesophyt	considerably cryophyt – considerably thermophyt
Dicranella het-eromalla (Hedw.) Schimp.	cosmopol	colonists	mesophyt	mesotherm – moderately thermophyt
Hypnum cupres-siforme Hedw.	cosmopol	perennials, stress tolerant	mesophyt – moderately xerophyt	tempindiff
Lophozia ventri-cosa (Dicks.) Dum.	circpol	pioneer colo-nists	moderately hygrophyt – mesophyt	considerably cryophyt – mesotherm
Pohlia nutans (Hedw.) Lindb.	cosmopol	pioneer colo-nists	moderately hygrophyt – moderately xerophyt	considerably cryophyt – moderately thermophyt
Polytrichum juniperinum Hedw.	cosmopol	competitive and stress tolerant per-ennials	moderately – considerably xerophyt	considerably cryophyt – considerably thermophyt
Polytrichum longisetum Sw. *ex* Brid.	nearly cosmo-pol	competitive and stress tolerant per-ennials	moderately hygrophyt	considerably cryophyt – moderately thermophyt

Fig. 1. Location of the experimental site (NL – the Netherlands, BE – Belgium, GE – Germany)

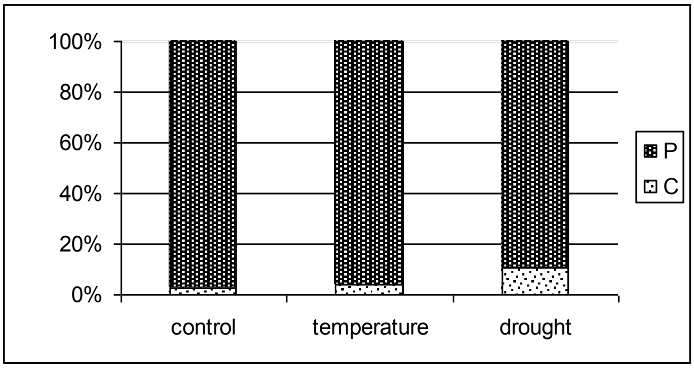

Fig. 2. Percentage of two life strategies (P – perennials, C - colonists) in different plot categories calculated on the basis of species coverages