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Climate Driven Changes in the Functioning of Heath and Moorland Ecosystems

Results after first growing season and mid term status report

Claus Beier (Ed), Albert Tietema, Torben Riis Nielsen, Bridget Emmett, Marc Estiarte, Josep Penuelas, Laura Llorens Guash, Dylan Williams, Carmen Gordon, Bron Pugh, Ferran Roda, Per Gundersen and Antonie Gorissen.

Risø National Laboratory, Roskilde, Denmark
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Abstract Emission of green house gases, partly generated from human activities, reduces the loss of heat from the earth thereby potentially causing climate change. This change in climate has been predicted to result in a 1-3^{o}C increase in temperature with more vigorous rainstorms and prolonged drought periods within the coming 100 years. The consequences of such climatic changes for the terrestrial ecosystems are largely unknown. In order to improve our understanding of the ecosystem response to climate change and thereby to improve the basis for international negotiations and political decisions to avoid or minimise climate change and its effects, a European research project CLIMOOR has been initiated. The project is a cross European research project involving 6 research groups from Denmark, the Netherlands, UK and Spain and is funded by EU and the participating institutions. The project investigates the potential effects of warming and drought on heath and moorland ecosystems at four European sites. The ecosystems are manipulated at field scale by reducing the heat loss at night by IR-reflective curtains and by removing the precipitation during a 2-month period in the summer. The effects of these manipulations on the plants and the soil are studied. This report describes the technique used to apply the climate change at field scale and presents some preliminary results after the first growing season.

EU and the participating institutions fund CLIMOOR.

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Contents

CLIMOOR is a European research project aimed at studying the potential effect of changes in the climate on heath and moorland ecosystems in Europe. CLIMOOR involves ecosystem manipulation at field scale.

1 CLIMOOR objectives

Anthropogenic emissions of CO_2 and other green-house gases are predicted to lead to increased temperature and other global changes. Historical records show the co-occurrence of elevated atmospheric CO_2 and warmer global temperature. Model predictions have further projected an increase in global mean surface temperature of 1-3.5 ^{o}C based on scenarios of increases in concentrations of CO_2 and other green-house gases. Along with these changes a more vigorous hydrological cycle is expected leading to more severe droughts and floods. CO_2 enrichment and warming in combination with the predicted changes in rainfall pattern will have a large influence on the functioning of natural and semi-natural environments both directly and through interactions with land management and pollutant loading. Temperature and water are main drivers for many biological and chemical processes and thereby for ecosystem functioning. Recent studies in terrestrial ecosystems have shown that elevated temperatures and drought have the potential to affect many processes in the ecosystems. However, the effects of global change on ecosystem functioning and storage and fluxes of C are still uncertain. Consequently, CLIMOOR is designed to investigate the effects of warming and drought on ecosystem functioning of heath and moorland ecosystems. These semi-natural systems are important semi-natural communities with high conservation and socio-economic value and are already heavily impacted from land use and atmospheric pollution.

The overall goal of CLIMOOR is to provide insight into effects of climatic changes on the functioning of heath and moorland ecosystems. The output from CLIMOOR will improve the basis for EU and the European countries for the follow up on the Kyoto protocol. The specific objectives of CLIMOOR are:

- To identify the effects of temperature and reduced summer rainfall on the functioning of non-forested semi-natural ecosystems, in particular the effects on:
  - organic matter production and turnover
  - carbon allocation
  - drainage water quality
  - gaseous losses of C and N
  - plant growth and biodiversity
- To relate results across the sites to climate and nitrogen and sulphur deposition
- To carry out a qualitative assessment of the risk of changes in functioning in low vegetation ecosystem to predicted climatic change

2 CLIMOOR Sites

The CLIMOOR project was initiated in May 1998 and manipulations started in March 1999. Manipulations are carried out at 4 sites spanning a gradient in the loading of the most important impact factors to be studied, temperature, precipitation and N-deposition (Table 1; Figure 1). In this way the sites represent the span in the main impact factors given by European conditions and the combination of gradients and experimental manipulation of the temperature and water will allow the evaluation of the interaction of effects of temperature, precipitation and N-deposition.

Figure 1 CLIMOOR involves ecosystem manipulation in central Denmark, NE Wales, central Netherlands and NE Spain

Table 1 – Main site characteristics for CLIMOOR sites

Sitename Country	Mols DK	Clocaenog UK	Oldebroek NL	Garraf ES
Temperature (^{o}C)	6-8	5-7	7-9	15
Precipitation (mm)	500-600	1500-2000	700	500-600
Soil	Sandy podzol	Peaty podzol	Sandy podzol	Calcareous
Vegetation	*Calluna Vulgaris* *Deschampsia Flexuosa*	*Calluna Vulgaris* *Deschampsia Flexuosa* *Vaccinium Myrtillus* *Empetrum nigrum*	*Calluna Vulgaris* *Deschampsia Flexuosa* *Mollinia caerulea*	*Erica multiflora* *Globularia alypu*
N-input (kgN ha^{-1})	18-22	20-25	30-40	5-7

The combination of geographical transects and field scale experiments is essential because whole-ecosystem experiments are required for understanding and predicting the impact of future global change on the specific ecosystems whereas longer term responses in vegetation patterns are closer connected to distributions along the environmental gradients.

3 The manipulations

Figure 2 Heating roof covering a heath ecosystem at Mols, Denmark. Power to run the manipulations is supplied by a solar panel.

Global warming is basically caused by a reduced loss of long wave IR-radiation from the earth back into the atmosphere because of the green house gas accumulation in the atmosphere. Therefore warming will mainly occur at night as supported by recent analysis of global temperature records showing that the global temperature increase of 0.3 to 0.6 ^{o}C observed up untill today has been due to larger increases during night relative to those during the day. At the same time it is predicted that the input of water will change, leading to prolonged and more severe drought periods during the summer and eventually more water inputs during the winter. The manipulations within CLIMOOR are designed specifically to mimic night-time warming of the ecosystem by reducing the loss of IR radiation at night and to mimic summer droughts by reducing water input during prolonged periods in the spring or summer.

3.1 Warming treatment

The warming treatment in CLIMOOR is created by automatically covering the vegetation by an aluminum curtain at night. The long wave IR radiation usually lost back to the atmosphere is reflected back into the ecosystem resulting in an increase in temperature. This system is anticipated to closely mimic climate change. Compared to many other field scale methods to experimentally manipulate temperature in terrestrial ecosystems such as soil warming cables or wind shelter tents, this method involves very little disturbance. The CLIMOOR manipulations have been operated since March 1999 with an effect of warming the soil and plants in the order of 1-2^{o}C.

Figure 3 Aluminum curtain used to manipulate temperature. The curtain is rolled up on a beam and are automatically rolled out at night.

The warming plots are 20 m^2 surrounded by a light scaffolding carrying the reflective aluminum curtain (Figs. 2, 3 and 4). The curtain is coiled on a beam and connected to a motor. The motor is activated to apply or remove the curtains automatically according to pre-set climatic conditions (Table 2). Each site has 3 heating plots.

Table 2 Climatic factors steering the roof movement in warming and drought roofs. Control roofs only consists of the scaffolding similar to treatment plots but without a roof.

Factor	Plot	Priority	Limit	Function
Light	Warming	1	Day/night	Roof off at day Roof on at night
	Drought	No influence	No	
Rain	Warming	2	Rain/no rain	Roof off if rain during night Roof on if no rain during night
	Drought	1	Rain/no rain	Roof on if rain during drought event Roof off if no rain during drought
Wind	Warming	2	10 m/s	Roof off at high wind during night Roof on below limit during night
	Drought	2	10 m/s	Roof off at high wind and rain during drought Roof on at low wind and rain during drought

3.2 Drought treatment

The drought treatment is carried out for a 6-10 week period in the spring or summer. The drought plots are constructed similar to the warming treatments except that the curtain material is a transparent plastic and the movement of the curtains are governed by the rain and wind only (Table 2). During the drought period the rain sensors will activate the curtain to cover the plots whenever it rains and remove the curtains when the rain stops. Rain collected by the curtain is removed from the plot by gutters. The curtains are removed automatically if the wind speed exceeds 10 m/s. Outside the drought period the drought plots are run parallel to the control plots. Each site has 3 drought plots

Figure 4 The site Oldebroek in the Nethelands showing the study plots with the scaffolding carrying the curtains to manipulate temperature and water.

3.3 Control

Parallel to the treatment plots 3 untreated control plots are put up for comparison. The Control plots has a scaffolding similar to the treatment plots, but without a curtain.

Figure 5 Group of study plots at Clocaenog, Wales, UK. The plots include warming, drought and control plots. Each site has 3 control plots, 3 warming and 3 drought plots.

Figure 6 Study plot at the Garraf si NE Spain. The ecosystem is dominat ericaceous plants

Figure 7 The site at Mols in Denmark – all roofs are on (just to please the photographer). The study plots are grouped 3 by 3, each group consisting of a heat, drought and control plot.

4 Effect studies

CLIMOOR investigates the effects of the manipulations on the ecosystem functioning. The studies focus on changes in plant and soil processes. Soil organic matter is a major store of carbon and nutrients in the soil and has importance for soil physical properties. Changes in soil organic matter dynamics may have many consequences and thus should be considered within the context of over-all ecosystem functioning. Therefore changes in dynamics of soil organic matter and the consequences for the pools and fluxes of carbon and major nutrients are investigated. Furthermore plant response and species composition are important issues, since global warming and altered hydrology will lead to changes in competitiveness of many plants, especially in vulnerable ecosystems and plants and ecosystems existing at the edge of their ecological niche.

4.1 Plant response

The responses of the plants to the treatments are monitored yearly. The measurements include plant cover (pin point), growth, phenology, leaf properties, light interception, canopy reflectance, leaf gas exchange (photosynthesis and respiration), plant chemistry, litterfall, and litter quality.

Figure 8 Pin point measurements. The change in plant cover and species composition are assessed by number of specific species plant hits and plant heights in permanent study points within each plot.

Figure 9 Gas exchange measurements. The changes in photosynthetic activity and respiration are measured by measuring the exchange of CO_2 at the leaf level.

4.2 Soil Response

Decomposition and mineralisation processes are hypothesised to be among the most affected processes by the heat and the drought. Decomposition of litter from the main plant species is studied by the litterbag technique. Soil C and N mineralisation is studied by the soil buried bag technique or by resin bag technique. The total pool of carbon above and below ground are measured and the response of the ecosystem to increased temperature and drought are related to the distribution of carbon among the above and below ground pools.

4.3 Trace gas emission

Effects of warming and drought on trace gas emissions are studied. Exchange of CH_4 and N_2O between the ecosystem and the atmosphere is measured in static chambers. Static chambers including the dominant plant species are used to study ecosystem exchange of CO_2 and small chambers on bare soil are used to measure soil respiration.

Figure 10 Changes in trace gas fluxes (N_2O and in and out of the ecosystem as affected by the trea are measured in static chambers. The change in t gas concentration is measured in the chamber aft closure.

4.4 Water chemistry

Changes in the soil water chemistry, especially increased leaching of nitrogen, are anticipated to be sensitive indicators for changes in the decomposition processes. However, increased leaching of N may only occur if the effect of treatments on decomposition rates is greater than on rates of primary productivity. Water is collected monthly in precipitation collectors. Soil water is collected from the organic top soil layer by zero tension collectors and below the root zone by tension collectors. The chemistry is measured.

4.5 Carbon allocation

Possible changes in the allocation of carbon and nitrogen within the dominant plant species are studied by an on-site ^{14}C and ^{15}N pulse labelling experiment. Plants are transferred to PVC-columns and labelled by ^{14}C and ^{15}N. Subsequently total carbon and nitrogen and their tracers are determined in shoots, roots, and soil after wet digestion. Carbon budgets are calculated including total net uptake and distribution of ^{14}C and ^{15}N among shoots, roots, soil and root/soil-respiration.

4.6 Risk assessment and socio-economic benefits

Based on the results from the field experiments a qualitative risk assessment will be conducted to assess the potential effect of global change on the carbon storage and biodiversity of European heath and moorlands. Hereby it is the intention that the results from CLIMOOR can play a valuable role in formulating policy to:

- optimise land use and landscape planning, balancing nature conservation, agriculture, tourism and recreation in an environmentally sustainable way
- limit the environmental impacts from transport, energy production and other industrial sectors
- limit the environmental impacts of water use and abstraction within the context of changing global climate.

Figure 11 CLIMOOR plot at Mols Bjerge, Denmark

5 Results

CLIMOOR manipulations have been running since March 1999. With only half a year of treatment, the results obtained so far are limited and preliminary. However, the measurements from the first growing season have shown some interesting results:

5.1 Temperature response

Results from the roofs at all sites have shown the following results:

- the heating effect varies substantially dependent on the weather conditions and location. In general a temperature increase of c. 1°C has been obtained at the three northern sites Denmark, Wales and The Netherlands and an increase of c. 2°C has been obtained in Spain (Fig. 12).
- the edge effect is very small meaning that the roofs warm the vegetation and the upper soil effectively to the border of the roof.

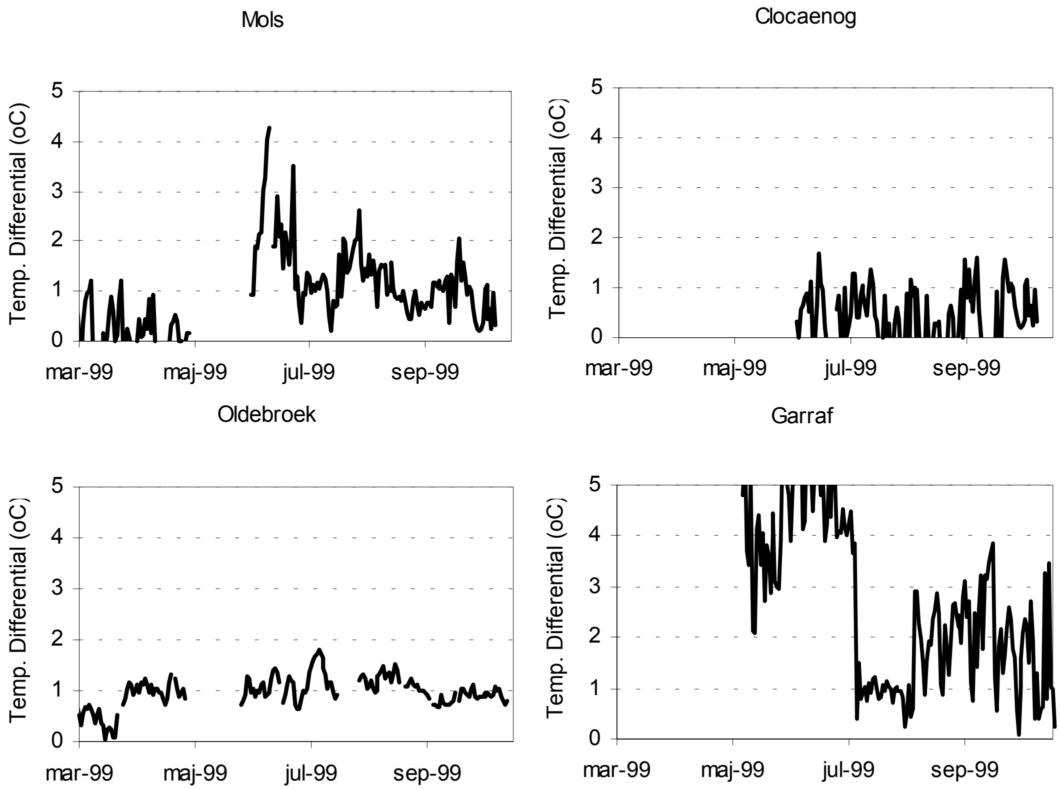

Figure 12 Average temperature differential between Heating roofs and Control plots in 2-5 cm soil depth at the four CLIMOOR sites.

5.2 Vegetation response

The vegetation response is mainly assessed by measuring species types and plant heights at a large number of points in each plot (pin point method). This method enables changes in species composition, competition and species specific growth to be recorded.
The first results from Denmark have shown that warming cause an increased growth of the dominant grass species *Deschampsia flexuosa*, whereas the dwarf-shrub *Calluna vulgaris* is unaffected (Fig. 13). Summer drought affects growth of both species negatively. Additional results suggest that both warming and drought increase grazing on *Calluna vulgaris* by the heather beetle (*Lochmaea suturalis*) larvae, thereby pushing the ecosystem balance further towards grassland.

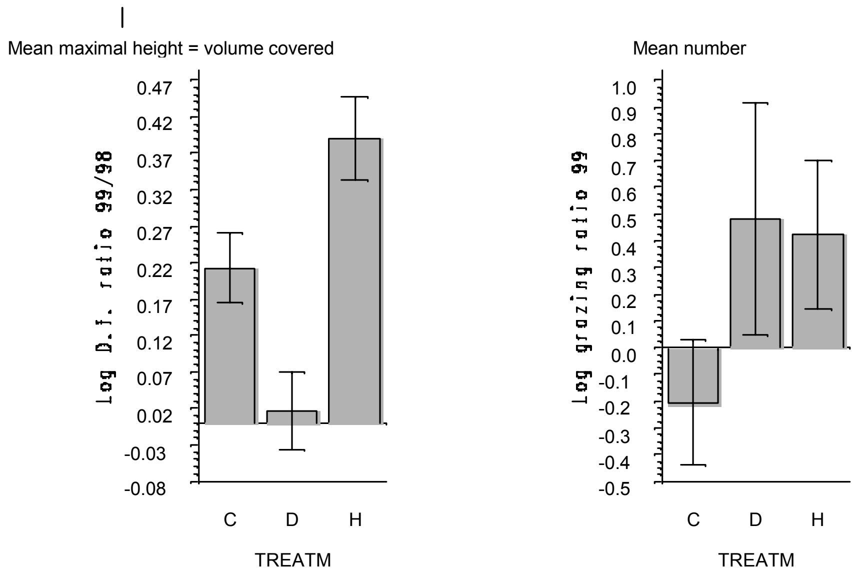

Figure 13 Vegetation changes at Mols (DK) due to drought (D) and warming (H) compared untreated plots (C).
Left: The vertical axis shows the log-transformed ratio between the mean maximal height (M) 1999 and 1998. A ratio of 0 means unchanged vegetation. A positive ratio indicates an increa of <u>*Deschampsia flexuosa*</u>*. Warming has caused a larger increase of M compared to the contro (intermediate) and to drought (near 0). All treatment means are significantly different.*
Right: The grazing ratio 99 is the ratio between heather beetle grazed and non-grazed <u>*Callun*</u> *shoots in 1999. A log transformed value of 0 means equal amounts of grazed and non-grazed shoots. Drought or warming cause a more heavy grazing. Drought or warming tends to incre grazing (not significant).*

Despite a small increase in temperature achieved at Clocaenog, Wales, an increased overall plant cover has been observed (Fig. 14) mainly due to a significant increase in the production of *Vaccinium myrtilus* with similar trends observed for the other two dwarf shrub species, *Calluna vulgaris* and *Empetrum nigrum*. Drought caused a decrease in overall plant cover (Fig. 14). This decline was due to a reduction in the cover of *Vaccinium myrtilus* and the bryophyte *Pleuroizium schreberi*.

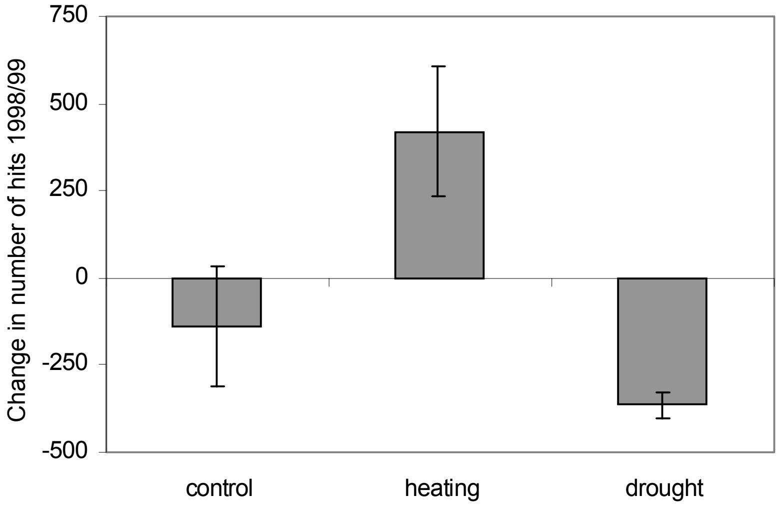

Figure 14 Change in plant cover (± s.e) at Clocaenog (UK). in response to heating and drought treatments (P < 0.02 level)

5.3 Soil water response

Warming is anticipated to affect the decomposition of the organic matter in the soil. This will potentially be reflected in changes in the soil water composition, especially an increase in nitrogen content may be expected. The results from the site in Wales have in fact shown increased N concentration in soil water leaching from the organic soil layer in the heating plots (Fig. 15).

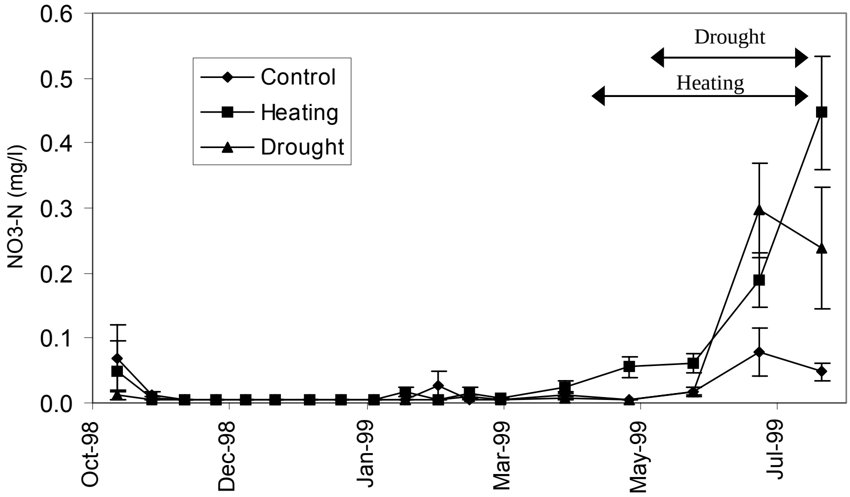

Figure 15 Change in soil water nitrate concentrations in the soil organic horizon in res
to heating and drought at Clocaenog, (UK). Standard errors are shown.

5.4 Mineralisation response

Decomposition of fresh litter is studied with litterbags in all CLIMOOR sites. In the Dutch site of Oldebroek the bags contained a mixture of *Calluna* shoots and flowers. The experiment in Oldebroek started in the beginning of June, during the drought period. The drought period ended about 2 month after the start of the litterbag experiment.

The study has shown that drought during the initial phase of the decomposition process has a profound effect on mass loss (Fig. 16). However, after 6 months of incubation 4 months after the end of the drought, this initial difference in mass loss has completely disappeared. Increased temperature in the warming treatment resulted in a significant higher mass loss in the period between 1.5 and 3 months after the start of the experiment. This significant difference has disappeared after 6 month, although the warming treatment continued during the whole incubation period.

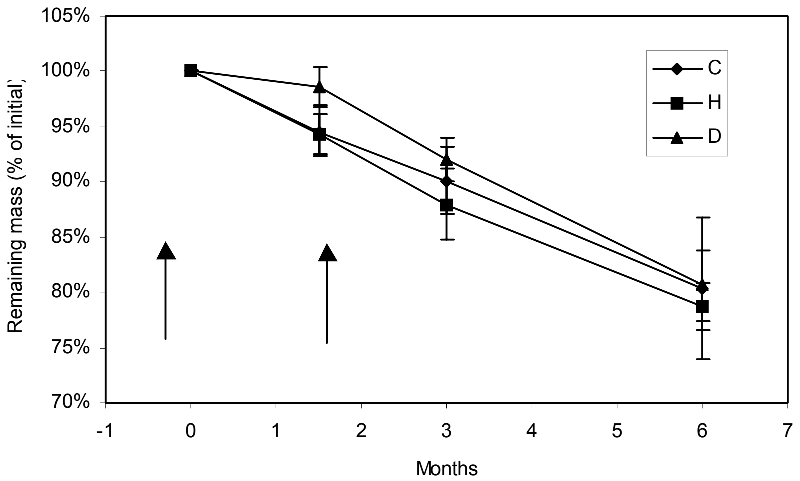

Figure 16 Remaining mass loss as a percentage of initial mass in decomposing fresh litter j Oldebroek (NL). The three lines indicate the three Climoor treatments (C=control; H=heat D=drought). Numbers are means and standard deviations of all litterbags of each treatmen bags per treatment). The two arrows indicate the start and the end of the drought treatment warming was carried out during the whole incubation period.

5.5 Photosynthetic activity

Seasonal changes in NDVI (Normalized Difference Vegetation Index) has been measured in the Spanish site. NDVI is a reflectance index, indicative of green biomass. NDVI increased in the warming treatment in the wetter seasons, spring and especially autumn, after the large rains of September-October (Fig. 17). Similar behaviour was found, although with less intense growth, in the control plots. In contrast, there was no increase in the drought plots.

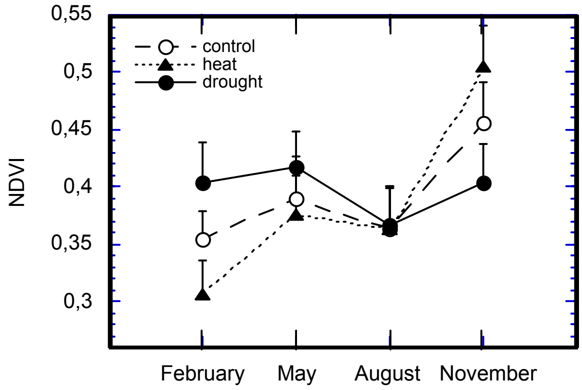

Figure 17 NDVI (Normalized Difference Vegetation Index) indicating green biomass duri first growing season at Garraf, ES.

Measurements of transpiration and net photosynthetic rates of *Calluna vulgaris* in Denmark, Wales and Holland, and *Erica multiflora* in Spain were done in the beginning of the summer 1999 after two-three months of warming and drought treatments in Denmark, Holland and Spain, and after two months of warming but only three weeks of drought treatment in Wales. Net photosynthetic and transpiration rates showed a gradient decrease from northern to southern European sites, following the natural geographical gradient in water availability and temperature. No effect of warming treatment was found at any of the sites, whereas the drought treatment caused reduced rates of photosynthesis and transpiration in Denmark and Holland (Fig. 18). No effect was found in Spain where drought plot conditions were not very different from the other plots after a quite dry 1999 spring season, and in Wales where drought treatment had only been running for three weeks when gas exchange measurements were conducted.

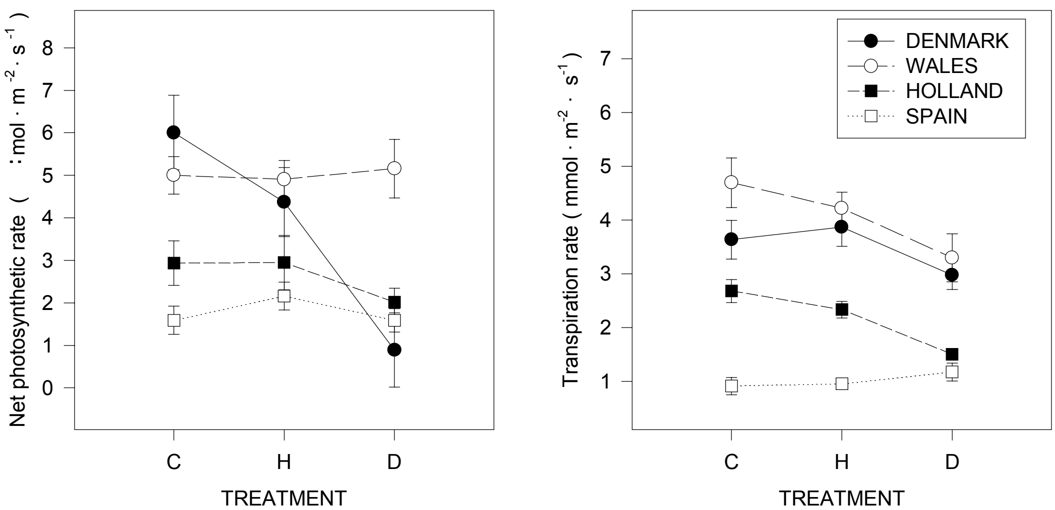

Figure 18 Photosynthesis and transpiration at the four CLIMOOR sites as a function of treatment. Treatments are: C-Control, H-Heating, D-Drought.

6 Status and summary

CLIMOOR is now half way through the project period. Achievements to date include:

- The experimental set-up works well. The technically challenging task to develop and set-up a passive night time warming facility working on battery/solar panel power supply and electronically steered according to pre-set climatic conditions has been successful. Minor technical problems do occur occasionally but in general the basic concept works well.
- The night time warming facility heats the soil/plants by 1-2 ^{o}C.
- Heating and drought have caused measurable and significant effects on the ecosystem functioning within 6 months of treatments starting indicating the sensitive nature of these ecosystems. The treatment effects differ among sites – effects on the soil, soil water or the plants. The compartment most affected at each site does not comply with expectations.
- Further years of treatment are necessary to determine the longevity of these initial responses and the probable steady state under the climate scenario of warming or prolonged summer drought.

7 CLIMOOR - contacts and adresses

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Project home page
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Abstract (max. 2000 characters)

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