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Vegetation patterns and responses to elevated CO_2 from natural CO_2 springs at Strmec (Radenci, Slovenia)

Vegetacijski vzorci in odzivi na povišano koncentracijo CO_2 okrog naravnega vrelca CO_2 Strmec (Radenci, Slovenija)

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Abstract. A natural CO_2 spring emitting pure CO_2 was found near Radenci (Slovenia). The vegetation near the spring was characterized to test the hypothesis that vegetation patterns are influenced by elevated CO_2 concentrations. A vegetation map in scale 1:50 was made from which the following conclusions were drawn. Above the concentration of 8000 $cm^3.m^{-3}$ (ppm) there was almost no vegetation. Between the concentration 8000 and 2000 $cm^3.m^{-3}$ it was found that normal vegetational patterns changed due to reduced competition between different species. For example *Polygonum aviculare*, which is characteristic for trampled vegetation, was the most common species and dominated the vegetation pattern. The enriched CO_2 atmosphere had the same effect as the mechanical disturbance. At mid-season, the seeds of *Echinochloa crus-galli* germinated in the highest concentration of CO_2 and were flowering by the end of the growing season. Morphological changes in comparison with plants growing at normal ambient CO_2 concentration were reported as well. V literaturi naveden pojav, da povišana koncentracija CO_2 stimulativno vpliva na pojavljanje vrste *Agrostis stolonifera* se pojasnjuje le s prisotnostjo karbonatov v tleh. The phenomenon, mentioned in literature, that species *Agrostis stolonifera*, which grows around CO_2 springs, is stimulated by elevated CO_2 concentration in the air, was explained only by presence of carbonates in the soil.

Keywords: elevated carbon dioxide concentration, natural CO_2 springs, vegetation map, *Polygonum aviculare, Agrostis stolonifera, Echinochloa crus-gali*, competitional relationship.

Izvleček. Naravni vrelec čistega CO_2 je znan v bližini Radencev (Slovenija). Opisana je bila vegetacija v okolici vrelca, da bi lahko potrdili hipotezo, da povišana koncentracija CO_2 vpliva na vegetacijske vzorce. Vegetacijska karta v merilu 1:50 je bila narejena, na njeni osnovi pa podajamo naslednje zaključke: V koncentraciji nad 8000 $cm^3.m^{-3}$ (ppm) ni razvite skoraj nobene vegetacije. Med koncentracijama 8000 in 2000 $cm^3.m^{-3}$ je bilo ugotovljeno, da se je normalen vegetacijski vzorec spremenil zaradi zmanjšane konkurence med vrstami. Vrsta *Polygonum aviculare*, ki je značilna za pohojeno vegetacijo, je bila na tem območju najpogostejša in dominantna vrsta. Povišana koncentracija CO_2 je imela torej isti efekt kot mehanska motnja. Sredi vegetacijske sezone so v najvišji koncentraciji CO_2 vzkalila semena vrste *Echinochloa crus-gali*, ki je cvetela na koncu sezone. Ugotovljene so bile morfološke razlike v primerjavi z rastlinami, ki so rasle v normalni koncentraciji CO_2. V literaturi naveden pojav, da povišana koncentracija CO_2 v zraku stimulativno vpliva na pojavljanje vrste *Agrostis stolonifera*, ki pogosto uspeva v okolici vrelcev CO_2, pojasnjujemo le s prisotnostjo karbonatov v tleh.

Ključne besede: povišana koncentracija ogljikovega dioksida, naravni vrelci CO_2, vegetacijska karta, *Polygonum aviculare, Agrostis stolonifera, Echinochloa crus-gali*, konkurenca.

Abbreviations: IRGA = Infra Red Gas Analyzer; SNACE = Slovenian Natural Air Carbon Dioxide Enrichment; FACE = Free Air Carbon Dioxide Enrichment; OTC = Open Top Chambe

Nomenclature: FISCHER (ed.) (1994) for vascular plants; MUCINA, GRABHERR ET ELLMAUER (1993) for plant communities and codes.

Introduction

Several CO_2 springs were found in the area around Radenci in Northeastern Slovenia, known by its geothermal activity. In most cases, these springs produce mineral water but a few of them also produce CO_2 gas. We found two vents which emit only gas without spring water. Periodically rain water overflows the vents and the gas emission is made visible by the bubbles. One of the vents is located in a mixed forest in which the herbal layer of the vegetation is poorly developed, due to the shadow of the forest canopy. In another site outside the forest, wetland vegetation has developed around the spring. In this paper, the vegetation responses to elevated CO_2 along a transect starting from the spring had been characterized.

Many experiments spanning a wide range of duration have been performed with enriched CO_2 concentrations in glasshouses and in the field using both open top chambers (OTC) and the free air carbon enrichment (FACE) methods. In contrast, there exist only a few reports of the impacts of increased atmospheric CO_2 concentration, in which exposure to elevated CO_2 occurred under natural circumstances and for many years (MIGLIETTA & RASCHI 1993, CAMPBELL et al. 1995, NIKLAUS et al. 1998, LEADLEY et al. 1999). Only exceptionally was reported that a plant species was adapted to elevated atmospheric CO_2 concentrations (SELVI 1994; SELVI 1997; FORTHAM et al. 1997a; FORTHAM et al. 1997b). In recent years FACE experiments (with permanent artificial source of CO_2) were designed in order to simulate a grasslands community – either with existing matrix or sowed (STEWART & POTWIN 1996, LUESCHER et al. 1998, WARWICK et al. 1998, NORTON et al. 1999). Most authors of these studies followed the responsiveness of morphological features and physiological processes (KNAPP et al. 1996, STOCKER et al. 1999). In this paper were reported some basic results with natural vegetation patterns around CO_2 springs which were discussed in the context of the behavior of the local flora. The permanent natural sources of CO_2 offers further opportunities to study different responses of plant communities to this natural surrogate for rising atmospheric CO_2. The research project is part of the Slovenian Natural Air Carbon Dioxide Enrichment (SNACE), which is a bilateral co-operations between Slovenia-Austria as well as between and Slovenia-Italy and was a part of the COST Action 619 program under the overall sponsorship of the European Community.

Materials and Methods

Description of the site

The region of Radenci (NE Slovenia) is known as a mineral water resource area. It represents the western part of Pannonian clastic basin (ŽIŽEK 1999). The spring called Strmec, chosen for vegetation observations, is located in a ditch along the road Ivanjševci – Stavešinci near Radenci, which was built about 15 years ago. There are several small vents in an area of about 100 m^2 along the ditch. The CO_2 displaces under calm conditions all of the air near the vent and along the ditch. This presents a lethal situation for insects, amphibians and even small mammals, which are often found dead around the well and along the bottom of the ditch. It's important that no methane, SO_2 or other gases had been found there.

About 90% of the CO_2 arises from a depth about 1800 meters in Carboniferous and Permian geological bedrock under a pressure of 50 bar, and generated by the past volcanic activity. About 9% of the CO_2 derives from limestone burnt by currently uprising magma and the rest – 1% – comes from an organic source of the sediments of the Pannonic sea (MEISTER et al. 1998). An important fact is that the air in the soils in the wider area is enriched very much with CO_2 (ŽIŽEK 1999). That can strongly reduce O_2 tensions in the soil.

Measurements of CO_2 concentration

Measurements of atmospheric CO_2 concentrations started in 1996 with a portable infrared gas analyzer (IRGA) by A. RASCHI. The preliminary results encouraged us to continue in 1997 when the same IRGA was used in different weather conditions. In addition Draeger diffusion tubes were used several times. These tubes are especially suitable for this work because in addition to being inexpensive, they allow measurements of higher concentration of carbon dioxide over a prolonged period of time (15 min to some hours) by means of reaction with alkaline as indicator. Measurements reported in this paper were taken on December 4 1998 using Draeger tubes. Direct readings on the tubes were corrected for the influence of the air temperature. We measured the CO_2 concentration along a horizontal gradient of decreasing CO_2 approximately every meter starting from the emission point on the soil surface at the bottom of the ditch.

Results and discussion

CO_2 concentration around the wells

Preliminary measurements with the IRGA were used only to determine where to establish the measurement points for Draeger tubes. Since it is well known that CO_2 is very well mixed throughout all layers of the atmosphere, particularly due to convection and strong turbulence, it was measured only on calm days. The concentration along a horizontal gradient of decreasing CO_2 concentrations at the bottom of the ditch on the 4th December 1989 is shown on fig. 1. It was a calm day, with a little snow and temperature around 0. These results show that the concentration was less than 10% of CO_2 in the area more than 1,5 m away from the emission point and from 10–26% inside that area. Aditional measurements with Draeger tubes and IRGA were taken throughout the whole vegetation period in the frame of SNACE reaserch. It were measured during different months and hours of the day and night, reaching up to 50% CO_2 in the air or even up to 100% for soil measurements. (MEISTER 2000, mscr.).

The vegetation map

The vegetation mapping in the scale 1:50 (see fig. 1) was done in the same on-scale map with the CO_2 concentration values in order to compare vegetation patterns with elevated CO_2 concentration. The vegetation around the spring was divided in 8 sub-areas, according to the different floristic structure. The lists of the species for each sub-area are given in the table 1. In the bottom of the ditch, where the concentration is the highest and where during calm days CO_2 accumulates there for longer period, there was almost no vegetation developed. The expected vegetation type in the ditch would have been the association *Epilobio-Juncetum effusi* Oberd. 1957, which was developed in the same ditch with ambient CO_2 concentration. The vegetation pattern changed as the CO_2 concentration increased, possibly due to reduced competition between different species. Typical species for this association are less competitive in elevated CO_2, The dominant species was *Juncus effusus* which became quite abundant, mainly at the edge of the ditch. The most affected sub-area was sub-area 1 (in the bottom of the ditch), where *Polygonum aviculare* was found to be the most competitive species. It was distributed abundantly along

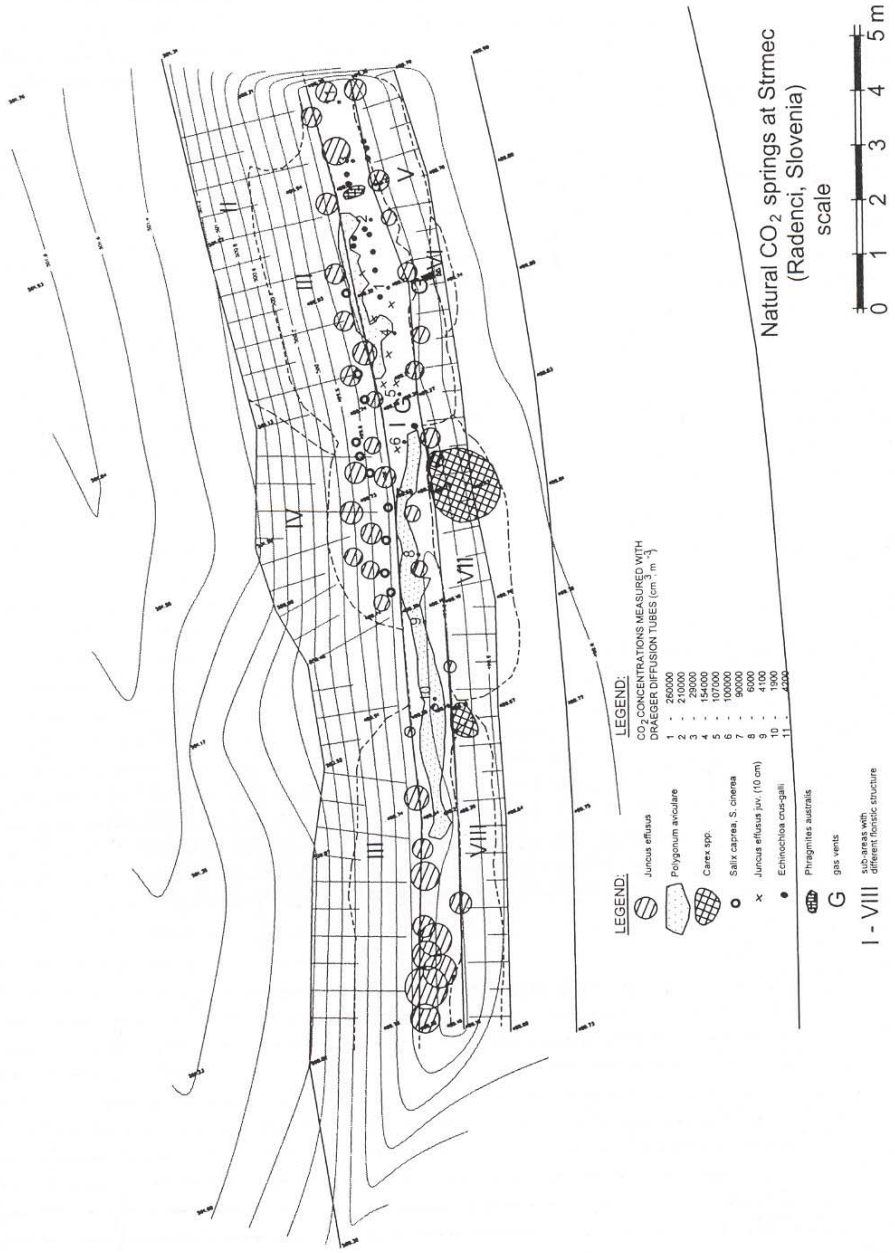

Fig. 1: CO_2 concentrations and vegetation map in the scale 1:50 at the springs of Strmec

Tab. 1: Sub-areas I to VIII with specific floristic structure (see the map on fig. 1). P = present, D = dominant

sub-areas:	I	II	III	IV	V	VI	VII	VIII
species:								
Polygonum aviculare	P							
Juncus effusus	P		D					
Echinochloa crus-galli	P							
Phragmites australis	P							
Dactylis glomerata		P	P		P			
Rubus sect. Rubus		P		D				
Gallium mollugo		P						
Chenopodium album		P						
Rumex acetosa		P						
Lotus corniculatus			P		P			
Carex canescens			P					
Plantago lanceolata			P					
Taraxacum officinale aggr.			P			P	P	P
Vicia cracca			P				P	P
Achillea millefolium aggr.			P		P	P	P	
Agrostis stolonifera			P	D			P	
Betula pendula (juv.)			P					
Chamaecytisus hirsutus				P				
Tanacetum vulgare				P				
Carex hirta				P			D	D
Populus nigra (juv.)				P				
Salix caprea (juv.)				P				
Salix cinerea (juv.)				P				
Erigeroon annuus				P				P
Trifolium repens					P	P		P
Leontodon autumnalis					P			
Poa annua					P	P		
Ranunculus acris					P		P	P
Daucus carota					P			P
Juncus articulatus					P			
Equisetum arvense					P		P	P
Conyza canadensis					P			
Plantago major						P	P	
Juncus bufonius						P		
Carex gracilis							P	
Arrhenatherum elatius							P	P
Plantago media							P	
Veronica chamaedrys							P	D
Vicia sepium							P	P
Rumex crispus							P	P
Cichorium intybus							P	
Polygonum persicaria							P	
Rumex acetosella							P	P

Genista tinctoria							P	
Stellaria holostea							P	P
Ranunculus repens							P	D
Lythrum salicaria							P	
Setaria glauca							P	P
Medicago lupulina								P
Trfolium pratense								P
Pastinaca sativa								P
Galinsoga parviflora								P
Glechoma hederacea								P
Number of species:	4	5	10	9	11	6	22	21

the ditch, where the concentration was the highest. The species *Polygonum aviculare* is characteristic for a mechanically disturbed vegetation of the class *Plantaginetea majoris*, and it appears also as weed species in *Chenopodietea vulgaris* and *Secalietea* classes, but is rarely found in *Calthion* alliance of the *Molinio-Arrhenathere tea* class, to which the association *Epilobio-Juncetum effusi* belongs. It was found that the elevated atmospheric CO_2 concentration or limiting O_2 concentration in the soil had the same effect on the distribution of *Polygonum aviculare* as the mechanical disturbance. This effect made *Polygonum aviculare* more competitive in absence of other species, which could not survive in the high atmospheric CO_2 concentrations or lack of O_2 in the soil. Another interesting fact was the appearance of young seedlings of *Juncus effusus*, (see the map) in the bottom of the ditch, where adult plants were not present. The plants did not grow taller than 10 cm and they remained sterile.

At the same place in the middle of the season the seeds of *Echinochloa crus-galli* started to germinate in the highest concentration of CO_2 and lowest O_2 concentration in the soil. At the end of the season the plants were flowering. Morphological changes in comparison with "control" plants from a nearby field, were also observed: the plants exposed to high CO_2 were taller (from 14 to 27 cm), the leaves were shorter and straighter. The number and the size of the flowers were more or less the same as seen with control plants, except that only a few fruits developed. It seems that the germination of this species could either be stimulated by elevated CO_2 concentration or could be an effect of tolerating low O_2 concentration in the soil. The grasses *Agrostis stolonifera* and *A. canina* were mentioned in literature to respond positively to elevated CO_2 concentration (Miglietta & al. 1993a, Miglietta & al. 1993b). At Bossoleto (Tuscany, Italy) *A. stolonifera* represents a dominant species at CO_2 concentrations of about 600 to 1500 $cm^3.m^{-3}$ and on this basis it was thought to be tolerant of high CO_2 concentrations. At the site of this study *Agrostis stolonifera* was found in moderately elevated CO_2 concentrations (sub-area III and V). The interesting phenomenon was the absolute dominance of this grass around the nearby mineral water springs, which have only a small amount of dissolved CO_2 but a lot of $HCO3^-$ ions dissolved in the mineral water. This suggests that *Agrostis stolonifera* is stimulated only by carbonates in the soil rather than by CO_2 in the atmosphere. This statement is supported also by Bachmann's results (Bachmann 2000), who reported that elevated CO_2 increases carbonates in the soil.

Povzetek

Na območju SV Slovenije, kjer je znana geotermalna aktivnost, smo proučevali izvir ogljikovega dioksida (mofeto) Strmec pri Stavešincih v Ščavniški dolini. Gre za čisti geogeni CO_2 brez primesi metana ali drugih plinov. Emisije so na dnu obcestnega jarka, z rahlim padcem; v jarku je le občasna stoječa voda, ki na ni izvirska ampak meteorna.

Želeli smo potrditi hipotezo, da povečana koncentracija CO_2 vpliva na vzorec vegetacije, ki se razvije v območju vpliva. Posamezna poročila o takšnem vplivu naravno povečane concentracije CO_2 so bila že objavljena iz vrelcev v Toskani (Italija).

Izdelali smo vegetacijsko karto območja v merilu 1:50, v katero smo vrisali tudi izmerjene vrednosti koncentracije CO_2 . Ugotovili smo, da na območju, kjer koncentracija presega 8000 $cm^3.m^{-3}$ (ppm) vegetacija skoraj ni razvita. V območju koncentracije 2000 do 8000 $cm^3.m^{-3}$ pa smo ugotovili spremembe v "normalni" (pričakovani) strukturi vegetacije, kar razlagamo s spremenjeno konkurenčno sposobnostjo med posameznimi vrstami. Tako je bila na dnu jarka dominantna vrsta ptičja dresen (*Polygonum aviculare*), ki je sicer značilna za pohojena tla z močno moteno vegetacijo, ker je tam zaradi odsotnosti drugih vrst konkurenčna. Torej ima povečana koncentracija CO_2 isti efekt kot mehanska motnja. Sredi vegetacijske sezone je vzkalila navadna kostreba (*Echinochloa crus-galli*) na območju, kjer je koncentracija CO_2 največja. Primerki so bili nižje rasti in morfološko slabše razviti, nekateri so producirali tudi semena.

Iz literature je znan primer da povečana koncentracija CO_2 stimulativno vpliva na rast in dominanco plazeče šopulje (*Agrostis stolonifera*) v koncentraciji med 600 in 1500 $cm^3.m^{-3}$. Tudi na mofeti Strmec najdemo to vrsto na zmerno povečani koncentraciji CO_2. Zanimiva pa je absolutna dominanca te vrste na vrelcih mineralne vode v soseščini, kjer je emisija CO_2 minimalna. Vzrok za njeno dominanco je po našem mnenju v visoki koncentraciji karbonatov, ki so prisotni v mineralni vodi, ne pa v povišani koncentraciji zračnega CO_2.

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