

The effects of interaction of biotic and abiotic factors on CO₂ fluxes in polar environments

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Abstract

Climate changes affect significantly the Arctic regions, with air and soil temperatures increases, snow cover decrease and glacier retreat (IPCC 2013). The Arctic ecosystems play a key role in the global carbon (C) cycle (McGuire et al. 2009; Lafleur et al. 2012) since northern soils account for approximately 50% of the estimated global below-ground organic C (Tarnocai et al. 2009). In particular, climate changes may turn cold biomes from sinks to sources depending on the balance between Gross Ecosystem Photosynthesis (GEP) and ecosystem respiration (ER) and the resulting Net Ecosystem Exchange (NEE) (Lafleur et al. 2012). Annual fluctuations of CO₂ exchanges are strongly influenced by snow melting, permafrost thawing, leaf development (Uchida et al. 2010), leaf senescence and soil freezing (Christiansen et al. 2012). The transition between late spring/early summer, at the onset of the growing season, is important because ecosystems shift from low CO₂ release under snow cover, to CO₂ uptake after snow melting (Lüters et al. 2014).

The Svalbard archipelago provides a representative example of the Arctic tundra presenting high variability in soil characteristics, moisture, vegetation and CO₂ fluxes over short spatial scales. Regarding the effect of biotic factors, CO₂ fluxes have been compared with different vegetation communities (Elberling et al. 2007; Morgner et al. 2010), plant coverage and growth (Uchida et al. 2010) and photosynthetic characteristics and biomass (Muraoka et al. 2008). The photosynthetic capacity, is species-specific and may be influenced increasing of temperature and CO₂ concentration (Bunce 2008; Heimann and Reichstein 2008). In particular, the response of photosynthesis to CO₂ concentration and temperature allows accurate description of plant photosynthetic capacity that allows improvement of global C budget models for terrestrial ecosystems (Fan et al. 2011). Moreover, photosynthetic performances may be associated with carbon isotope discrimination (Δ) that is related to the ratio between intercellular and atmospheric CO₂ concentration (C_i/C_a), a key parameter describing the photosynthetic performance at leaf level (Schmidt et al. 2015 and references therein).

The study was carried out near Ny Ålesund (Brogger Peninsula, Svalbard archipelago), where we selected several species (*Carex rupestris*, *Cassiope tetragona*, *Dryas octopetala*, *Salix polaris* and *Saxifraga oppositifolia*), representative of the High Arctic tundra. We provide new data on NEE and ER during the transition seasons, comparing the late spring/early summer (beginning of the growing season, BGS) with the late summer/early autumn (end of the growing season, EGS). We hypothesized that trends in these fluxes would be different in the two seasons, as well as the factors affecting NEE and ER. Furthermore, we analyzed photosynthetic performances, carbon isotope discrimination, phenology and leaf area index to identify biotic factors influencing NEE.

The NEE and ER values found in our study differed between vegetation communities (Fig. 1), in agreement with previous studies of tundra vegetation in Svalbard (Lloyd 2001; Elberling 2007). Mean seasonal NEE support the conclusion that all communities released CO₂ (i.e. acted as “CO₂ sources”) in both transition seasons (Fig. 1A and 1B). At our study site, the CO₂ release was higher at the BGS than at the EGS. This may indicate the occurrence of pulse periods with significant primary production at the EGS. The CO₂ release could also be the prevalent process occurring at the

BGS during the snowmelt period, before the completion of leaf development (Uchida et al. 2010). Our data show that GEP (calculated as the difference between NEE and ER) follows species-specific patterns (Fig. 1). The *D. octopetala* and *S. polaris* exhibited a larger GEP at the EGS, as might be expected of deciduous species, whose GEP is very low at the BGS and increases throughout the development of the vegetative stages. The evergreen shrub (*C. tetragona*) and the grass (*C. rupestris*) showed the opposite pattern, with higher GEP at the BGS, as they are either already photosynthetically active (*C. tetragona*), or are able to develop rapidly their new leaves (*C. rupestris*). The evergreen forb *S. oppositifolia* exhibited similar GEP both at the BGS and at the EGS and the different NEE was due to changes in ER.

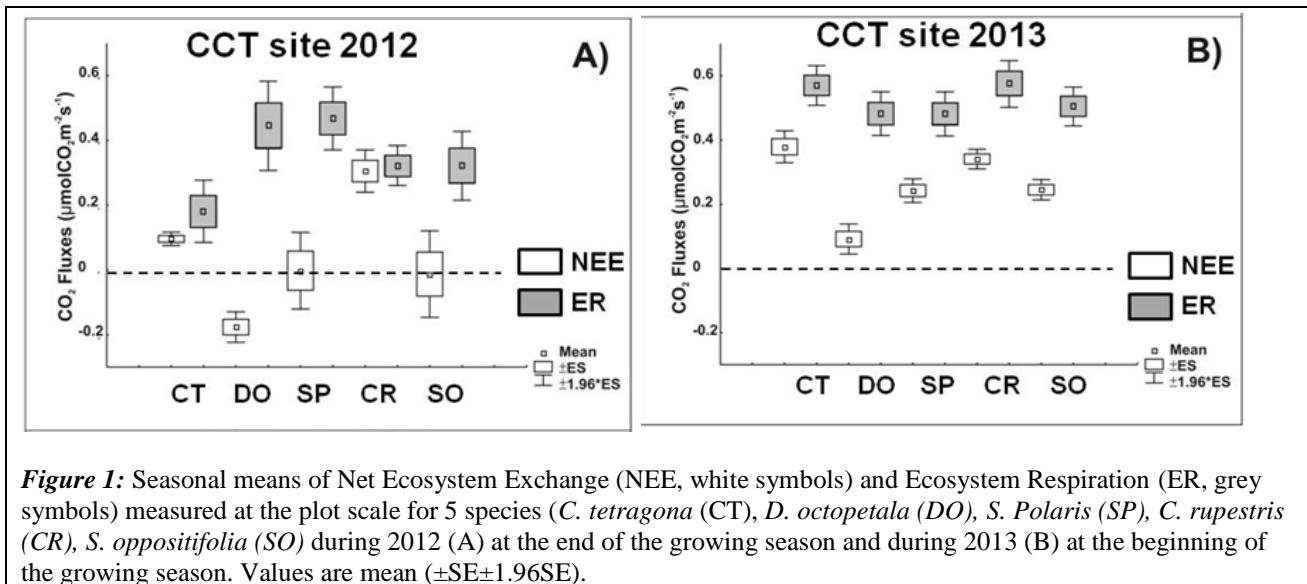


Figure 1: Seasonal means of Net Ecosystem Exchange (NEE, white symbols) and Ecosystem Respiration (ER, grey symbols) measured at the plot scale for 5 species (*C. tetragona* (CT), *D. octopetala* (DO), *S. Polaris* (SP), *C. rupestris* (CR), *S. oppositifolia* (SO)) during 2012 (A) at the end of the growing season and during 2013 (B) at the beginning of the growing season. Values are mean (\pm SE \pm 1.96SE).

Soil temperature was the key factor affecting ER for all vegetation types, as previously reported by Elberling (2007) at a different location on Svalbard islands. In the current study, soil moisture did not influence ER, probably because the study site is characterized by relatively well-drained soil conditions.

The LAI has been identified as one of the most important biotic factors explaining the majority of NEE variance in Arctic and sub-Arctic environments (Shaver et al. 2013) as also noted here. Considering the role of photosynthetic capacities separately, our data indicate that species-specific photosynthetic capacities are key biotic factors affecting NEE at inter-community level. Their use provides clear understanding of the NEE patterns observed among the selected target species. Leaves of *S. polaris* and *D. octopetala* exhibited the highest assimilation rates (*A*) measured at environmental conditions, while *S. oppositifolia* showed the lowest. The high value of *A* in *D. octopetala* is consistent with the high stomatal conductance recorded for this species. The assimilation rates measured at increasing atmospheric CO₂ concentration showed similar trends for all species analysed and do not show a saturation at high CO₂ concentration. This lack of saturation possibly indicates a high ribulose phosphate regeneration capacity (Farquhar et al. 1980), and it can be relevant in a context of future increases in atmospheric CO₂ concentration (Norby and Luo 2004). When evaluating the dependence of the *A* rates from leaf temperature, all species analyzed were characterized by a clear decrease of *A* at increasing leaf temperatures, although with species-specific patterns. The decrease of *A* at increasing leaf temperatures indicates adaptation of these species to cold temperatures and may provide an indication on potential vulnerability of these species to a warmer climate, with *S. polaris* being potentially less challenged than *D. octopetala* or *S. oppositifolia*. The species considered showed variations in Δ values, reflecting differences in the ratio C_i/C_a integrated over the period of development of the plant material analysed. The Δ values

varied from 19.9‰ in *S. polaris* to 22.2 ‰ in *D. octopetala*, indicating higher photosynthetic activity in the latter. The carbon isotope approach together with the gas exchange approach offer a tool for future monitoring of C fluxes in Arctic regions.

Measurement of CO₂ fluxes performed at different spatial scales (from leaf to plot) demonstrated that spatial variation in CO₂ fluxes is influenced by both biotic and abiotic factors. Among the biotic factors, our data emphasize the importance of species-specific photosynthetic capacities, coupled with phenological stage and LAI. Among the abiotic factors, temperature is crucial in affecting ER and, in most cases, NEE, as well as in shaping photosynthetic performances in some species. Our data highlight the need to understand and quantify the ecological role of dominant species in natural communities and their contribution to the C cycle (as sinks or sources).

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