

# COASTAL PLANT GROWTH AND CO<sub>2</sub> ENRICHMENT: CAN THE PRODUCTIVITY OF BLACK NEEDLE RUSH KEEP PACE WITH SEA LEVEL RISE?

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## Introduction

The rate of sea level change has varied considerably over geological time, with rapid increases (0.25 cm yr<sup>-1</sup>) at the end of the last ice age to more modest increases over the last 4,000 years (0.04 cm yr<sup>-1</sup>; Hendry 1993). Due to anthropogenic contributions to climate change, however, the rate of sea level rise is expected to increase between 0.10 and 0.25 cm year<sup>-1</sup> for many coastal areas (Warrick et al. 1996). Notwithstanding, it has been predicted that over the next 100 years, sea levels along the northeastern coast of North Carolina may increase by an astonishing 0.8 m (0.8 cm yr<sup>-1</sup>); through a combination of sea-level rise and coastal subsidence (Titus and Richman 2001; Parham et al. 2006). As North Carolina ranks third in the United States with land at or just above sea level, any additional sea rise may promote further deterioration of vital coastal wetland systems.

Sea level change has been associated with wetland decline and deterioration in coastal regions throughout the United States. In New England tidal marshes, for example, areas dominated by *Juncus gerardi* in the late 1940's, were replaced by forbs over a 40-year period (Warren and Niering 1993). This displacement of *Juncus* was observed in areas where the mean surface elevations were lowest and marsh accretion rates were minimal (ca. 0.1 cm yr<sup>-1</sup>). In contrast, some *Juncus* and *Spartina patens* marshes remained unaffected by rising seas, as they were able to increase surface elevations (through depositional accretions of peat) at rates consistent with proximal sea-level rise (between 0.2 and 0.25 cm yr<sup>-1</sup>). It would appear that the ability of a marsh to accumulate peat is to some degree dependent on autochthonous productivity, wherein higher productivities often yield higher biogenic accretions rates (Cherry et al. 2009).

It has been demonstrated that exposure to elevated atmospheric CO<sub>2</sub> levels will increase growth in many terrestrial and aquatic C<sub>3</sub> macrophytes (e.g., Curtis et al. 1990; Arp et al. 1993; Marsh et al. 2005). Elevated growth due to CO<sub>2</sub> enrichment may be short lived or long-term; depending on prevailing environmental conditions, with soil nutrients as a primary factor limiting sustained elevated growth (Erickson et al. 2007). Nevertheless, many minerotrophic wetlands maintain comparatively high soil nutrients, and it is believed that salinity may be a major contributory factor controlling plant growth; even during CO<sub>2</sub> enrichment (Arp et al. 1993; Touchette et al. 2009). It is possible that elevated CO<sub>2</sub> can promote accelerated productivity in the coastal marsh plant black needle rush (*Juncus roemerianus* Scheele), particularly along the upper marsh regions (or higher elevations) where soil salinities are negligible (Touchette 2006). Under such conditions, peat accumulations from *J. roemerianus* may be able to equal or even exceed sea-level rise. The objective of this study, therefore, was to compare primary productivity of *J. roemerianus* exposed to elevated atmospheric CO<sub>2</sub> (800 ppm) with plants receiving ambient CO<sub>2</sub> (380 ppm) conditions. While it was anticipated that CO<sub>2</sub> enrichment would have some stimulatory response, it was uncertain if this growth could be sustained over extended periods of time (months to years).

## Material and Methods

In June 2008 mature seeds were collected from natural *J. roemerianus* populations along the White River (near Swansboro, NC). The seeds were immediately planted in standard 1020 flats (without holes) containing water-saturated soils fortified with slow-release fertilizer. Once germination began, the plants were immediately transplanted into experimental microcosms (with independent soil, water, and nutrient conditions) and placed into environmental growth chambers (BioChambers Inc., Winnipeg, Canada) that controlled temperature (25°C), light (12:12hr; light: dark cycles), humidity (75% RH), and CO<sub>2</sub> levels. A total of five microcosms (34 cm long, 20 wide, and 10 high) were randomly placed within each chamber. At monthly intervals, five plants from each microcosm were collected and evaluated for maximum height, maximum root length, leaf area, and total biomass. Monthly plant measurements collected from each microcosm were pooled into a single value to avoid replication within microcosms (i.e., psudoreplication).

Because all microcosms involving the same treatment are in the same chamber, it is important to note that no statistical distinction can be made between treatment and chamber. Nevertheless, Oksanen (2001) argues the merits

of such experimental designs when the scale (in this case an 18-month study) and complexity (environmental growth chambers) are unavoidably high. Moreover, such designs are not uncommon in environmental chamber experiments involving plants or animals. Therefore, with some prudence, we statistically evaluated the data using repeated-measures ANOVA (Proc GLM using SAS 9.1) with month as the repeated-measures factor and microcosm as a block within treatment. All comparisons were considered significant when p-values were less than 0.05.

## Results and Discussion

The data illustrate that over the course of 18 months, all measured parameters were significantly higher in plants receiving elevated CO<sub>2</sub> (p<0.0001; Table 1). This includes an increase in overall plant height, total plant biomass, and total leaf area (Figure 1-A, -B, and -C). Although maximum root length also tended to be greater in treated plants, this measurement was considerably more variable over time with significant differences occurring somewhat sporadically (Figure 1-D). Furthermore, differences were often observed after considerable time. Differences in height, for example, were first observed 11 months into the study, and differences in leaf area and total biomass were recorded after 13 months.

Table 1. Repeated measures ANOVA tables for the effects of time (month) and CO<sub>2</sub> treatments (CO<sub>2</sub>) on *Juncus roemerianus* biomass, height, root length, and leaf area.

Parameter (Source of Variation)	df	MS	F	p
<i>Total Biomass</i>				
CO <sub>2</sub>	1	0.1490	22.6	<0.0001
Microcosm (CO <sub>2</sub> )	8	0.0078	1.2	0.3072
Month	14	0.1884	28.6	<0.0001
Month x CO <sub>2</sub>	14	0.0220	3.4	0.0002
Error	112	0.0065		
<i>Height</i>				
CO <sub>2</sub>	1	41567	84.8	<0.0001
Microcosm (CO <sub>2</sub> )	8	784	1.6	0.1314
Month	15	39781	81.2	<0.0001
Month x CO <sub>2</sub>	15	1905	4.0	<0.0001
Error	120	490		
<i>Root Length</i>				
CO <sub>2</sub>	1	36814	40.8	<0.0001
Microcosm (CO <sub>2</sub> )	8	1182	1.3	0.2452
Month	15	48589	53.8	<0.0001
Month x CO <sub>2</sub>	15	2777	3.1	0.0003
Error	120	903		
<i>Leaf Area</i>				
CO <sub>2</sub>	1	854.0	31.2	0.0001
Microcosm (CO <sub>2</sub> )	8	35.6	1.3	0.2511
Month	12	729.9	26.7	<0.0001
Month x CO <sub>2</sub>	12	70.4	2.6	0.0052
Error	96	27.3		

Enhanced growth in coastal plants due to CO<sub>2</sub> enrichment is more pronounced in C<sub>3</sub> plants than C<sub>4</sub> (Curtis et al. 1990; Arp et al. 1993). This is consistent with our observations on the C<sub>3</sub> perennial *J. roemerianus* in this study. In the C<sub>3</sub> sedge *Scirpus olneyi*, for example, elevated atmospheric CO<sub>2</sub> levels resulted in higher shoot densities, delayed senescence, and an 83% increase in belowground tissue productivity (Curtis et al. 1990). In contrast, no significant increases in growth were observed in the C<sub>4</sub> grasses *Spartina patens* and *Distichlis spicata* receiving comparable CO<sub>2</sub> levels (Curtis 1990).

With respect to soil accretion, C<sub>3</sub> production may need to exceed 1,000 g m<sup>-2</sup> yr<sup>-1</sup> to increase the elevation by 1cm (Cherry et al. 2009). In this study, using the maximum observed production estimate of 0.2 g plant<sup>-1</sup> month<sup>-1</sup> and estimated 1,200 shoots per square meter (with ca. 16 shoots per plant; this study) along the upper marshes in coastal North Carolina (Touchette 2006), accretion estimates would be around 1.8 mm yr<sup>-1</sup>. While this rate is in close approximation with other studies (e.g., often between 1 to 15 mm yr<sup>-1</sup> in another CO<sub>2</sub> enrichment study; Cherry et al.

2009), our approximation assumes no mass loss to herbivory, decomposition, and erosion, as well as no reductions in productivity during winter months when both temperature and light intensities are lower. Furthermore, this estimate is based on maximum observed growth and does not consider any decreases in growth as the plant approaches full maturity. Nevertheless, under optimal growing conditions and no coastal subsidence, *J. roemerianus* may theoretically be able to keep pace with the lower range of projected sea-level rise at  $0.1 \text{ cm yr}^{-1}$ . Clearly, further research is necessary to better determine the likelihood of *J. roemerianus* being able to keep pace with sea-level change.

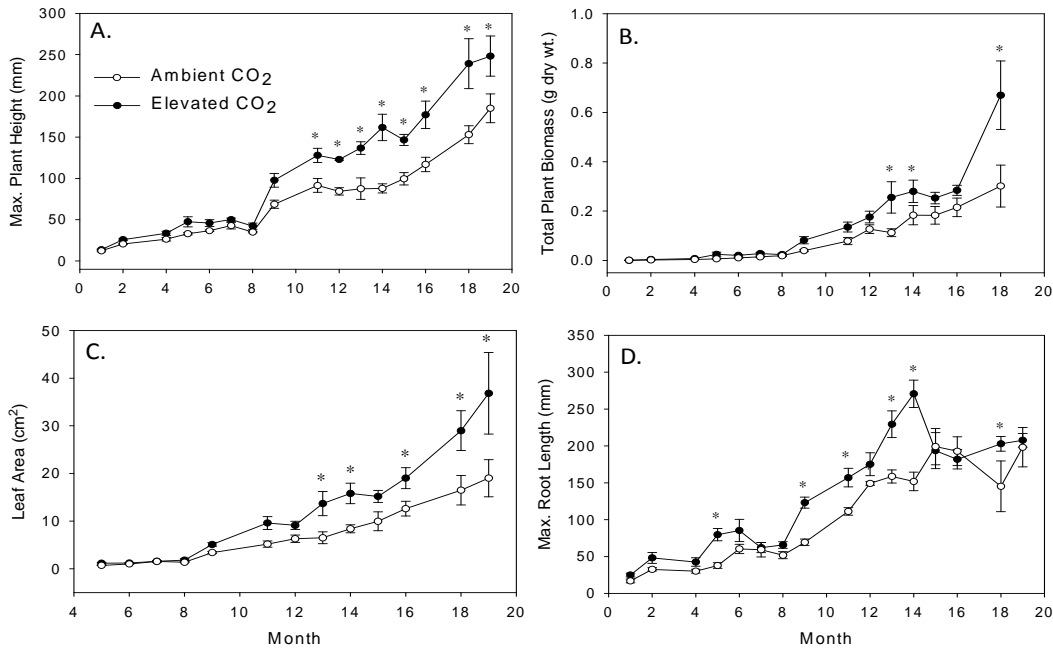


Figure 1. Plant measurements for *Juncus roemerianus* grown in ambient CO<sub>2</sub> (open circles) and elevated CO<sub>2</sub> (solid circles). Measurements include maximum plant height (panel A), total plant biomass (panel B), leaf area per plant (panel C), and maximum root length (panel D). Significant differences for each sample date are indicated by an asterisks. Data are presented as means ± 1 standard error.

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