DOE/ER/60374--T4

Report of progress for 1989-1990

I. Research

Research during 1988-89 focused on several new aspects of the response of the salt marsh ecosystem to elevated CO_2. In previous years we gave highest priority to studies of the effect of CO_2 on biomass production into above and belowground tissues, nitrogen content, light response of photosynthesis of single leaves, leaf water potential and carbon dioxide and water vapor exchange between the plant canopy and the ambient air. Result from the work in 87 and 88 had shown that the C3 plant, Scirpus olneyi, responded vigorously to elevated CO_2 but the two C4 species, Spartina patens and Distichlis spicata did not. The responses of photosynthesis were also reflected in the canopy and ecosystem processes: carbon accumulated in the C3 community into belowground tissues but not in the C4 community suggesting that the main factor in the ecosystem responses would be photosynthesis and that the environmental controls on this process would determine the long-term ecosystem responses to rising CO_2. Thus our emphasis shifted from determining the growth responses to exploring photosynthesis in greater detail while continuing to measure biomass accumulation, but with less frequent harvests.

Several collaborators joined the CO_2 study during the past year. In December 1988, L. Ziska, K. Hogan and A. Smith conducted a three month pilot study on Barro Colorado Island, Republic of Panama to determine the possible effects of elevated CO_2 on endemic tropical species grown in their native environment. During June and July, 1989, Dr. Steve P. Long of the Biology Department, University of Essex spent three months with us working on measurement of quantum yield and photoinhibition. Dr. Kevin Hogan of the Smithsonian Tropical Research Institute also participated in this work. In October, 1989, J. Dacey of the Woods Hole Oceanographic Institution and M. Klug of the Kellogg Biological Station, attempted to determine whether elevated CO_2 causes increased methane production. Although their experiment are preliminary, the results encourage us that we should be following these effects by studies in greater detail. These projects were supported jointly through Smithsonian Institution Post Doctoral Research Fellowships to Long, Ziska and Hogan and by the DOE grant.

The main question at the outset of this project was: How much more carbon will be accumulated in the salt marsh ecosystem in a high CO_2 atmosphere than is being accumulated under present CO_2 concentration? This experiment has raised the possibility that rising CO_2 will make the salt marsh ecosystem a bigger sink for carbon than we have previously thought it to be. By extrapolation, this finding suggests that other, terrestrial ecosystems may also become larger sinks for carbon. The data produced in the short time that this work has been in progress has added another dimension to

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

the continuing debate in the ecological community regarding the eventual effect of CO_2 on ecosystems.

The findings of our research continue to support the conclusion that rising CO_2 will increase carbon accumulation in terrestrial ecosystems. In the wetland system this is promoted through a complex interdependence of processes beginning with increased photosynthesis and including reduced respiration of both green tissues and decomposition of dead stems, storage of carbon into belowground parts, delayed senescence of green stems and improved water and nitrogen use efficiency.

A. Photosynthesis

1. Tropical species (Ziska, Hogan and Smith)

Studies of the effects of elevated CO_2 on tropical species showed that photosynthesis increased in elevated CO_2 and that there was an increased efficiency of utilization of CO_2 after growth in elevated CO_2. This is contrary to the finding of other studies, including the Arctic study, that growth in elevated CO_2 results in down regulation od CO_2 assimilation efficiency.
This work is reported in two publications listed below , Ziska et al., In Review; and Hogan et al., In review.

2. Quantum yield and photoinhibition (S. Long)

This study attempted to determine whether the efficiency of light harvesting in the C_3 plant, Scirpus olneyi, acclimated to elevated CO_2. Quantum yield is the efficiency of CO_2 assimilation per unit of light <u>absorbed.</u> The assimilation of CO_2 is relatively easy to determine but the absorption of photosynthetically active photons is not. Dr. Long used an integrating sphere which was modified to allow simultaneous measurement of net CO_2 exchange and absorption of photosynthetically active photon flux. It was determined that elevated CO_2 increased quantum yield in plants grown in elevated CO_2 and that this increase does not diminish even after three years of exposure to elevated CO_2. This finding was confirmed by two separate methods for measuring quantum yield and it suggests that photosynthesis of plants operating at low light levels within the canopy of wild species will be increased irrespective of whether or not increased CO_2 stimulates photosynthesis of plants exposed to high light.

Exposure to full sunlight often leads to photoinhibition which can be measured as a reduction of the photosynthetic capacity. If elevated CO_2 provides a sink for the additional photons absorbed in full sunlight, it might be expected that it would also relieve possible photoinhibition resulting from high light and other stresses. The approach was to measure the potential capacity for photon capture by comparing the variable fluorescence (Fv) in leaves of plants grown in normal ambient CO_2 concentration with Fv in plants growing elevated CO_2. Steve Long used a recently developed instrument for determining fluorescence yield on leaves in the field. Fv was normalized on the maximum possible fluorescence (Fm) for each leaf used. The ratio Fv/Fm has been found to correlate with quantum yield and is thus a useful measure of the effect of environmental factors on fundamental aspects of photosynthesis. It was found that elevated CO_2 reduces the normal diurnal trend in photoinhibition (as determined by Fv/Fm). This is another indication that rising CO_2 will reduce the effects of environmental stress on higher plants.

3. The effect of elevated CO_2 on photosynthesis at different levels within the plant canopy. (A. Villegas)

Experiments were conducted to determine where the added CO_2 is most effective in increasing carbon assimilation within the plant canopy of the C3 sedge, Scirpus olneyi. Measurements were made throughout several days at two levels within the plant canopy suggest that most of the effects of CO_2 on photosynthesis occurs mainly within the upper 1/3 of the plant canopy.

B. Respiration (W. Pockman)

Studies of dark respiration were continued. Elevated CO_2 caused a reduction in dark respiration of Scirpus olneyi but not in Distichlis spicata and Spartina patens. This response seems to be time dependent in that it appears later in the growing season but not early. We do not know what the mechanism of this response is and thus it's relationship to elevated CO_2 is unclear.

C. Growth (W. Arp, W. Pockman, and P. Utley)

A comparison was made of the growth of aboveground biomass for three years in the C3 plant Scirpus olneyi. The effect of elevated CO_2 on aboveground biomass production is of the order of 10-15% and the year to year variations in growth exceed the effects of elevated CO_2 on above-ground biomass production during any one year. There is no apparent reduction in the relative effect of elevated CO_2 on aboveground biomass production during the three years of the study.

D. Competition (W.Arp)

A comparison of growth of the C3 plant Scirpus olneyi and the two C4 species, Spartina patens and Distichlis spicata in the mixed community, showed that the C3 sedge increased biomass production by 265% between the start of the project in 1986 and the summer of 1989. This did not occur evenly in all sites and was highly dependent on the species mixture which is probably a reflection of the effects of the edaphic environment on the relative responses of each species to the stress of anoxia, salt, water stress, etc. The effects of CO_2 on competition show that C3 species will do much better than C4 species even in communities dominated by perennials.

E. Methane production (J. Dacey and M. Klug)

An attempt was made to determine whether there is an effect of elevated CO_2 on methane production by salt marsh communities. Methane originates in anaerobic systems, such as the salt marsh, and it was hypothesized that increased CO_2 would stimulate greater methane flux where the supply of belowground carbon was increased. It was found that elevated CO_2 stimulated an increase in methane flux in the C4 Spartina patens community and that the effect was highly significant in two of the five sites studied. However, this study occurred in October and data were intensively collected only during three days. Thus the results cannot by taken to be definitive of the effects of CO_2 on the methane budget. Dacey and Klug believe that this study should be attempted in a more rigorous way with greater attention to the geochemistry of methane production than was possible in this brief exercise.

F. Carbon budget (W. Pockman and P. Utley)

Net ecosystem photosynthesis was compared for the three years 87, 88, and 89, showed that the effects of elevated CO_2 continue to cause increased CO_2 assimilation. For 1989, more carbon accumulated in the community dominated by the C3 sedge, Scirpus olneyi, than in either the C4 dominated or mixed community.

G. Ecosystem water balance (W. Arp, W. Pockman and P. Utley)

Elevated CO_2 reduced water loss in all three communities studied. The range of reduction in evapotranspiration was 20-40% of the rate in normal ambient CO_2. This resulted in an increase in water use efficiency of between 60 and 90%, the results varying somewhat between communities and at different times during the season. Midday and dawn tissue water potential was increased in elevated CO_2 for all species by an amount which varied between species and at different times of the season but which was approximately 0.2-0.5 Mpa at midday.

H. Decomposition (D. Whigham)

An experiment to determine the rate of decomposition of dead material was conducted. Shoots with leaves and stems were enclosed in mesh bags and returned to the sites where the material had been collected. At the end of the season, material remaining was determined. Shoots of C3 Scirpus olneyi plants grown in elevated CO_2 were the slowest to decay while there were no differences between treatments in plant material from the other two species. This conclusion is consistent with the earlier measurements of the effects of elevated CO_2 on the respiration rate of the microbial community on dead stems.

II. Publications.

Drake, B. G., P. W. Leadley, W. J. Arp, D. Nassiry, and P. Curtis. 1989. An open top chamber for controlling CO2 concentration and measuring net ecosystem gas exchange. Functional Ecology, 3:363-371.

Curtis, P. S., B. G. Drake, P. W. Leadley, W. J. Arp, and D. F. Whigham. 1989. Growth and senescence in plant communities exposed to elevated CO2 concentration on an estuarine marsh. Oecologia 78:20-26.

Curtis, P. S., B. G. Drake, and D. F. Whigham. 1989. Nitrogen and carbon dynamics in C3 and C4 estuarine marsh plants grown under elevated CO2 in situ. Oecologia 78:297-301.

Curtis, P.S., Balduman, L.M., Drake, B.G., and D.F. Whigham. The effect of elevated atmospheric CO2 on belowground processes in C3 and C4 estuarine marsh communities. In press. Ecology.

Mooney, H.A., Drake, B.G., Luxmore, R.J., Oechel, W.C., and L.F. Pitelka. Predicting ecosystem responses to elevated CO2 concentrations. In press BioScience.

Ziska, L.H., Chamberlain, S., and B.G. Drake. Long term photosynthetic response in single leaves of a C3 and C4 salt marsh species grown in elevated atmospheric CO2 in situ. In press. Oecologia.

Drake, B.G., Leadley, P.W., Arp, W.J., Curtis, P., and D.F.Whigham. The effect of elevated atmospheric CO2 on C3 and C4 vegetation on Chesapeake Bay. In: (Arnsen, A. and T. Madsen, ed's; The Physiological Ecology of Aquatic Plants, Symposium Proceedings, Aarhus, Denmark, September, 1988) In Press.

Publications in review.

Drake, B.G., Ziska, L.H.,Bunce, J.A., Arp, W.J., Hogan, K. and Smith A.P. Dark respiration in plants grown in elevated CO2. Nature.

Ziska, L.H., K.P. Hogan, A.P. Smith, and B.G. Drake. Growth and Photosynthetic response of nine tropical species with long-term exposure to elevated carbon dioxide. Oecologia.

Hogan, K.P., L.H. Ziska, A.P. Smith, and B.G. Drake. Changes in photosynthetic capacity, quantum yield, and fluorescence characteristics of three tropical species due to long term exposure to elevated CO2. Oecologia.

Long, S.P. and B.G. Drake. The effect of the long-term CO_2 fertilization in the field on the quantum yield of photosynthesis in the C3 sedge, Scirpus olneyi. Plant Physiology.

Long S.P. and B.G. Drake. Light inhibition of photosynthesis in a doubled CO_2 atmosphere. Planta.

Publications in preparation.

Leadley, P., B.G. Drake, W. Arp, and W. Pockman. A system for exposing wild species to elevated CO_2 and measuring net ecosystem gas exchange.

Drake, B.G., Leadley, P.W., Arp W. and W. Pockman. Net ecosystem carbon dioxide exchange for three salt marsh communities during long term exposure to a doubled CO_2 atmosphere.

Arp. W. A., B.G.Drake, P.W. Leadley, and W. Pockman. Evapotranspiration, water use efficiency and water balance of C3 and C4 species exposed in situ to a doubled CO_2 atmosphere.

Drake, B.G., W.A. Arp, P.W. Leadley and W. Pockman. The effect of elevated atmospheric CO_2 concentration on the Carbon budget for three salt marsh communities exposed to a doubled CO_2 atmosphere.

Arp. W. A., B.G. Drake and D. Whigham. Effects of elevated atmospheric CO_2 concentration on competition between perennial C3 and C4 species on a Chesapeake Bay wetland.

Drake, B.G and S.P.Long. The effect of elevated atmospheric CO_2 on photosynthesis and crop production. (commissioned review for Advances in Photosynthesis).

III. Other activities

Papers presented at national meetings

Annual Meeting of the American Society of Plant Physiologists, Toronto Canada, 30 July- 3 August, 1989.

B.G. Drake, P.W. Leadley, L. Ziska & W.J. Arp. Elevated atmospheric CO_2 reduces dark respiration in two halophytes.

Ziska, L. Chamberlain, S. and B.G. Drake. The effect of elevated Co2 during growth in the field on photosynthesis of C3 and C4 salt marsh species.

Annual Meeting of the Ecological Society of America. Toronto, Canada, 6-10 August, 1989.

Drake, B.G., P.W. Leadley, W.J. Arp, P.S. Curtis and D.F. Whigham. The effect of two years of elevated CO_2 treatment on a Chesapeake Bay Wetland.

Curtis, P.S., B.G. Drake, D.F. Whigham, L.M. Balduman and M.L. Sutton. Belowground responses of marsh plants to elevated atmospheric CO_2.

Ziska, L. Chamberlain, S. and B.G. Drake. The effect of elevated Co2 during growth in the field on photosynthesis of C3 and C4 salt marsh species.

Arp W.J., B.G. Drake, P.W. Leadley, and W. Pockman. Evapotranspiration, water use efficiency, and water potential in Chesapeake Bay wetlands communities exposed to elevated CO_2.

International Estuarine Research Foundation, Baltimore, Maryland, 8-12 October, 1989

Drake, B.G., W.J. Arp, P.S. Curtis, P.W. Leadley and D.F. Whigham. Global climate change and vegetation: The long-term effect of elevated CO_2 on Chesapeake Bay wetlands.

Invited seminars on the effect of rising CO_2 on vegetation and ecosystem processes.

U.S. SCOPE workshop on Large Scale CO_2 Enrichment of Ecosystems, National Academy of Sciences, 6 January, 1989,

Michigan Biological Station, Hickory Corners, MI July 12

World Resources Institute, Washington, D.C. August 2

University of Virginia, October 5

Woods Hole Oceanographic Institute, November 9

Rothamsted Experimental Station, Harpenden, England November 22.

U.S. Water Conservation Laboratory, Phoenix, Arizona, 9 January, 1990

U.S. Environmental Protection Agency, Corvallis Oregon, 16 January, 1990

National Council for Air and Stream Improvement, Washington, D.C., 19 March, 1990

U.S. SCOPE Committee on Direct Effects of CO_2 on ecosystems,National Academy of Sciences, Washington, D.C. 17 April, 1990

Southern Regional Meeting, NCASI, Nashville, TN June 14