A PROPOSAL TO THE OHIO UNIVERSITY RESEARCH COUNCIL

TITLE OF PROJECT: Resolving age-mediated responses of forest carbon sequestration to climate change

NAME OF APPLICANT: Sarah C. Davis

STATUS: X Asst. Prof. ____ Assoc. Prof. ____ Prof. ____ Administrator

DEPARTMENT: Voinovich School of Leadership and Public Affairs
CAMPUS ADDRESS: Building 22, The Ridges
E-MAIL ADDRESS: daviss6@ohio.edu

RE-SUBMISSION: ___ YES (Original Submission Date ______)
X NO

BUDGET: Total Request $7,979
(May not exceed $8,000)

IRB AND IACUC APPROVAL:
To ensure that the University is in compliance with all federal regulations, complete the checklist below. Note: your proposal can be approved prior to IRB or IACUC approval, but funding will be withheld until notification of approval or exemption.

Yes	*No*	*Office of Research Compliance*	*Policy #*
	X	Human Subjects in Research (including surveys, interviews, educational interventions): Institutional Review Board (IRB) Approval #: Expiration Date:	19.052
	X	Animal Species: Institutional Animal Care & Use Committee (IACUC) Approval #: Expiration Date:	19.049

SIGNATURES:

Applicant's Signature		**Chair/Director's Signature**	
Signature	[signature]	Signature	[signature]
Name	Sarah Davis	Name	Geoff Dabelko
Dept/School	GVS	Unit	Voinovich School Environmental Studies
Date	1/27/14	Date	1/29/14
Dean's Signature			
Name	[signature] Mark Weinberg	Signature	[signature]
College	Voinovich School	Date	1/27/14

☐ **Optional:**
If selected for funding, I give permission to the Office of the Vice President for Research and Creative Activity to use my proposal as an example during training and workshop exercises.

Signature: [signature] Date: 1/29/14

Ohio University Research Council Proposal Checklist

Applicants must complete and sign the checklist. The checklist should be included as the second page of the application (following the cover page).

☑ Cover Page	use OURC form
☑ Checklist	use OURC form
☑ Abstract*	1 double-spaced page
☐ Introduction *(for resubmissions only)**	1 double-spaced page
☐ New Project Description *(for established applicants only†)**	1 double-spaced page
☑ Discussion	10 double-spaced pages
☐ Glossary/Definition of Terms* *(not required)*	2 double-spaced pages
☑ Bibliography *(not required)*	3 pages
☑ Biographical information *(applicant(s) and key personnel)*	3 pages per person
☑ Other Support *(applicant(s) and key personnel)*	1 page per person
☑ Budget and Justification	no limit specified
☑ Appended Materials	10 pages; no more than 10 minutes of footage
☑ Recommended Reviewers	5 required
☑ Electronic copy of proposal	Single Acrobat file, containing entire proposal and required signatures

* These sections should be written in language understandable by an informed layperson to assist the committee in its review. Established applicants (*†*) are faculty members who have tenure **and** have been at the university at least three years or administrators who have been at the university at least five years.

****Please note: The committee has the right to return without review any proposals that do not conform to these format requirements.****

Applicant signature: [signature]

Abstract

The work proposed here will resolve the change in forest carbon assimilation that occurs as a result of both climate change and age-related changes in physiology of canopy trees. Results will provide the information needed to predict the change in carbon sink we should expect from forests of the future. Forest biomass plays a crucial part in global carbon cycling, removing 31% of anthropogenic carbon emissions annually. Yet, physiological changes occur in forests as they age, and as the global climate changes. The physiological response of trees that have experienced an increase in atmospheric carbon dioxide (CO_2) concentrations of more than 100 ppm over a lifetime has not been resolved. It has thus far been assumed that the responses measured in young forests subjected to experimentally manipulated atmospheric conditions apply to older forests. This study is designed to test that assumption using a chronosequence of seven forest sites that range in age from 9 to 150 y old. The response of annual wood growth (measured in tree rings) to atmospheric CO_2 and temperature will be compared across ages. Change in the isotopic carbon composition ($\delta^{13}C$) of wood over time and the difference in $\delta^{13}C$ across age cohorts will be used to test the physiological response of trees to age relative to the physiological response to climate. The results of this study will provide key information needed for models that estimate ecosystem carbon balances, future forest conditions, and future climate.

Proposal Discussion (10 pages)

Introduction:

This study will assess the response of tree growth and carbon uptake to climate change, and how that response varies in forest sites of different ages. Trees establishing in young secondary forests are subjected to greater atmospheric CO_2 and increasing average temperatures relative to trees that established decades or centuries earlier. While an older forest presently experiences environmental conditions similar to a young forest, the canopy trees of the older forest developed in very different environmental conditions earlier in life, in some case with atmospheric CO_2 concentrations 120 $\mu l\ l^{-1}$ lower, than young trees today. Despite the difference in growing conditions over the life history of temperate forest sites that established at different times, it has generally been assumed that young and old trees respond similarly to climate change variables (*e.g* Norby and Zak 2011). This study aims to test that assumption by measuring historical trends in wood growth and the carbon (C) isotopic composition in annual tree rings collected from forested sites that range in age from 9 to 150 years old.

Background:

The C stored in forest biomass partially offsets CO_2 emissions that contribute to climate change. Globally, forest ecosystems comprise the majority of terrestrial net primary production and remove approximately 31% of anthropogenic C emissions each year (Pan et al. 2011). The strength of this forest C sink is also strongly modulated by anthropogenic forcing of climate changes (*e.g.* Norby and Zak 2011) as well as forest age (*e.g.* Drake et al. 2010a). The projected increase in atmospheric CO_2 from the preindustrial level of 280 $\mu l\ l^{-1}$ to > 550 $\mu l\ l^{-1}$ in 2050 will drive a 3-4^oC increase in global mean temperature (Meehl et al. 2007). The future of temperate forests (and their ability to temper climate change) therefore depends on the physiological response of trees to these changing conditions. Despite the importance of C stocks in old forests, our understanding of responses of long-term C pools to increasing CO_2 and temperature remains unclear and poorly represented in Earth system models. The research proposed here aims to resolve the response of forest carbon uptake to increasing atmospheric CO_2 and temperature over a 150 year period while accounting for age-related forest dynamics.

Free-air CO_2 enrichment (FACE) experiments conducted over the past two decades have greatly enhanced our understanding of the response of young forests (<25 years old) to elevated CO_2, but to date, only one forest site has been experimentally manipulated to assess this response in an older forest (Körner et al. 2005; Bader et al. 2010). In a young pine forest, elevated CO_2 stimulated photosynthetic rates, increased above- and below-ground tree growth, and accelerated respiratory losses from soil, as evidenced by the Duke FACE experiment (Hamilton et al. 2002; Drake et al. 2011). Stimulated growth was also observed in young hardwood trees at the Oak Ridge FACE experiment, but accelerated respiratory losses were not (Norby et al. 2010). The 100 y old trees treated with elevated CO_2 in the Web-FACE experiment did not show plant growth stimulation nor the respiratory increase that was observed in young forest sites even though photosynthetic rates were stimulated by 42-48% (Bader et al. 2010). It has generally been assumed that growth responses to elevated CO_2 and temperature, most commonly measured in young forests, are representative of the responses in forests of all ages despite the physiological changes that occur in trees as they age.

Our understanding of the effect of CO_2 and temperature on long-term C storage in forests is limited by experimental observations that for practical reasons must be constrained to a single life stage of a forest. Even experiments that have run continuously for a decade or more are only relevant to a small portion of the life history of a forest. Datasets from the FACE experiments described above have been interpreted independently from chronosequence studies that measure age-related changes in physiology and growth (results summarized in Table 1). While the results of FACE experiments are extremely valuable for improving model predictions of forest responses to climate change, FACE experiments were generally not designed to test the interactive effect of community change and climate change on tree physiology. The study proposed here will examine the response of tree growth to actual changes in atmospheric CO_2 and temperature over the last 150 years in order to place the results of experimental manipulations of climate variables in context with successional forest changes and age-related physiological changes of trees.

Table 1. General response of ecosystem variables in temperate pine (p) and hardwood (h) forests to increasing age (Drake et al. 2010a); increasing atmospheric CO_2 (Norby et al. 2010; Norby and Zak 2011; Bader et al. 2010); increasing temperature (T) (Melillo et al. 2011); and interactive effect of Age, CO_2, and T.

Response Variables	Age	CO_2	T	Age x CO_2 X T
Leaf area index (LAI)	↓p ↑h	↑p =h	**?**	**?**
Canopy conductance (g)	↓p ↑h	↑	↓	**?**
Photosynthesis (Ps)	↓p ↑h	↑	↑↓	**?**
Autotrophic Respiration (R_a)	↓p **?**h	↑	↑	**?**
Heterotrophic Respiration (R_h)	**?**	↑p,=h	↑	**?**
Aboveground C accumulation	↓p ↑h	↑young,=old	↑↓	**?**
Belowground C allocation	**?**	↑young,=old	↓	**?**
Litter C	↓p ↑h	↑	↓	**?**
Soil organic C	**?**	= p, **?h**	↓	**?**
Total C	↓p ↑h	↑	**?**	**?**

In this study, it is hypothesized that over 150 years of succession, as the forest community becomes dominated by late successional species and growth reaches a steady-state condition, physiological responses to climate change will differ from those observed in a fast-growing early successional community. This research will resolve changes in the physiological activity of late-successional and early-successional communities by measuring the growth and isotopic signature of annual woody increments (tree rings) in dominant canopy trees of forest sites that range in age from 9 to 150 years old.

The isotopic signature of ^{13}C relative to the more stable ^{12}C in woody plant tissue results from the amount of CO_2 that was available in internal leaf spaces during the year that woody tissue was biosynthesized. Measurements of the $\delta^{13}C$, defined as

$$\delta^{13}\mathrm{C} = \left(\frac{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\mathrm{sample}}}{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\mathrm{standard}}} - 1 \right) \times 1000\ ‰,$$

in plant tissue, after corrected for the difference in ^{13}C relative to known historical atmospheric conditions (Keeling et al. 1979), provide an indication of the physiological activity of the canopy leaves of a tree (Farquhar et al., 1989). The physiological activity during a given year of growth as represented in the wood tissue of a tree ring can be estimated from $\delta^{13}C$ because the enzyme responsible for photosynthesis has a greater affinity for ^{12}C; more ^{13}C is incorporate in plant tissue when ^{12}C is limited. The isotopic signature in wood collected from a chronosequence of forest sites thus allows a quantitative way to separate age-related growth dynamics from the physiological response of aging trees to climate change.

***Objectives*:**

1. To characterize the tree community (species and ages) in sites that range in age from 9 to 150 years old.
2. To collect tree cores from canopy trees in sites where forest regeneration initiated at different periods in history, and date the establishment year of trees in each site.
3. To assess the relative response of trees that vary in age to historical changes in atmospheric CO_2 and temperature using annual growth increments and the $\delta^{13}C$ isotopic signature of wood tissue grown over the life history of the trees.

Experimental Field Site:

The proposed research will be conducted at the Vinton Furnace State Experimental Forest (VFSEF) in McArthur, Ohio, located ~27 miles from the Ohio University campus. The VFSEF is comprised of 4892 ha (12,089 acres) of forestland that is considered some of the most biologically diverse in the state. Dominant tree species include mixed oaks (*Quercus* spp.), red maple (*Acer rubrum* L.), mixed hickories (*Carya* spp.), yellow poplar (*Liriodendron tulipifera* L.), and buckeye (*Aesculus glabra* Willd.). The understory includes several threatened and endangered species (e.g. *Rhododendron calendulaceum* (Michx.) Torr., *Magnolia macrophylla* Michx.), and the forest provides habitat for sensitive species including the timber rattlesnake, bobcat, and cerulean warbler. Elevation at the site ranges from 200 to 300 m, and approximately 102 cm of precipitation is received annually at the site with a mean annual temperature of 11.3°C (52.4°F). Soil at the site is unglaciated and dominated by silt loam. The VFSEF has been dedicated for research use since 1952 and owned by the Ohio Department of Natural Resources (ODNR) since 2010. Permission for this research has already been obtained from the ODNR and the US Forest Service and Dr. Davis (PI of this study) has been approved to access the site (see appended material).

Records kept by the US Forest Service describe the management history at the VFSEF, and there are a series of land parcels within the forest that have been clear cut at different times over the last century but have similar land use histories otherwise; these sites are well-suited for the chronosequence study proposed here. The oldest sites are 150-160 years old, dating from the time when the land was managed by the charcoal iron industry. It is estimated, according to Forest Service records, that these sections were clear-cut between 1860 and the 1880s. Sites that will serve as progressively younger cohorts of trees were cut in 1954 (“cutting practice demo CC”), 1963 (area next to “stand 2”), 1978 (“old field CC”), 1987 (“Rattlesnake Ridge”), 1998 (“NIPF CC”), and 2005 (clear cut with road access from the north). Together, these sites represent seven different forest ages that will be used to compile a chronosequence.

Methods**:**

Two circular plots with a 20m diameter will be established in each of seven different sections of the VFSEF that are estimated to be 9 y, 16 y, 27 y, 36 y, 51 y, 60 y, and 150 y of age. All tree species will be identified in each plot, and the stem diameter, tree height, and canopy diameter recorded. Two increment cores will be sampled from each canopy tree in every plot. All cores will be mounted and prepared for analysis in the Davis lab, part of the Voinovich School at Ohio University.

A chronology for wood growth will be assembled by cross-dating the increment cores from multiple trees, allowing the reconstruction of the establishment history of the forested sites and providing confirmation of the age of each canopy tree. (Even in sites with accurate historical records of the last clear-cut, the establishment year of individual trees will vary.) The incremental width of each ring will be measured using MeasureJ2X software (Voortech Consulting; Holderness, NH, USA) linked to an Olympus 40x boom microscope with a Velmex Unislide and stage assembly in the McCarthy lab, part of the Department of Environmental and Plant Biology at Ohio University (see permission for use in appended material). Basal area growth rates (correcting for diameter of each tree ring) will be calculated from annual wood increment measurements and then compared to climate trends (available from historical records) to determine the response of different age classes to changes in CO_2 and temperature.

The isotopic composition of C in woody increments will also be analyzed. Using a razor blade, annual woody increments will be extracted from each core at 5 year intervals spanning the time from establishment until the most recent year of growth. Each increment extracted will be ground to a powder and analyzed for $\delta^{13}C$ using an elemental analyzer (ECS 4010, Costech Analytical) coupled to a Conflo IV Interface (Thermo, Bremen, Germany) and a Delta-V advantage isotope-ratio mass spectrometer (Thermo) at the University of Illinois at Urbana-Champaign (see letter of agreement in appended material). The $\delta^{13}C$ corresponding to the estimated date of each incremental growth ring will be corrected for the change in atmospheric ^{13}C that has occurred over the last century (following Keeling et al. 1979). The $\delta^{13}C$ of wood tissue is an indicator of the ratio of the internal leaf CO_2 concentration (C_i) to the atmospheric CO_2 concentration (C_a), or C_i:C_a, a variable that changes with stomatal conductance that affects the discrimination of C isotopes (Farquhar et al. 1989).

Previous work completed by the PI and others resolved considerable photosynthetic changes across loblolly pine (*Pinus taeda* L.) forest sites that varied in age (Drake et al. 2010a), suggesting that an assumption of consistent physiological responses to climate change may not be appropriate. We found that under present-day atmospheric conditions there is a decline in (a) photosynthesis, (b) conductance, and (c) C_i:C_a, in old forests relative to younger forests (Drake et al. 2010a). The decline in C_i:C_a is inversely correlated with an increase in $\delta^{13}C$ of plant tissue due to the declining discrimination of rubisco against ^{13}C as C_i becomes limited relative to C_a (Farquhar et al. 1982, 1989). There are a number of hypotheses about physiological changes associated with age over time (Odum et al. 1969, Ryan et al. 1997, Gower et al. 1996, Thornley and Cannell 2000, DeLucia et al. 2007), but the concomitant decline in conductance and C_i:C_a have thus far pointed to hydraulic limitation as the most likely mechanism driving this change (*e.g.* Drake et al. 2010b). Age has thus far been assumed to be the cause of hydraulic limitation, but this study will test if there are physiological constraints imposed on different age cohorts as a result of the large differences in C_a to which they have been exposed during development.

The chronosequence at VFSEF will provide a dataset that can be used to experimentally test the response of forests in varying stages of secondary succession to climate change. The contrast between (a) trends in growth (and the $\delta^{13}C$ signature) of wood in a chronosequence dataset against (b) trends in growth (and the $\delta^{13}C$ signature) of wood in individual dendrochronological records of trees can be used to separate age-related physiological change from climate-related physiological change. If trends in $\delta^{13}C$ in the dendrochronological record of the lifetime of old trees is similar to $\delta^{13}C$ trends across age cohorts, then age-related physiology is likely the dominating cause for hydraulic limitation (because each dataset spans a similar age range, but only one varies in C_a). If however the trends in the two dataset differ, then C_a may have a greater effect on forest physiology over time than age.

The mean wood growth and $\delta^{13}C$ of annual increments sampled at each forest site will be regressed against historical C_a and temperature that occurred during each year of growth (separate regression for each site). Mean wood growth and $\delta^{13}C$ at each forest site will also be regressed against tree age (separate regression for each site) and compared to the regression coefficients generated by assessing wood growth and $\delta^{13}C$ differences in the same years across sites of different ages (single regression across all sites representing different ages for a given year). Within a year, trees of different ages may show different responses with similar climate conditions. A mixed model ANOVA will be used to test the hypothesis that growth responses to climate change variables depend on forest age.

Personnel involvement:

Funds for student wages are requested to support the collection, processing, and analysis of tree cores. There is a graduate student already working in the Davis lab that has begun a project investigating the response of forest sites in the Land Lab at Ohio University to climate change; he will assist with the data collection for this study in VFSEF so that sampling protocols are similar in the two studies (allowing a comparison between the forest sites at different locations that are similar in age). This graduate student is already funded during the academic year by other sources, but some wages will be paid hourly to him during the summer and the remaining wages will support an undergraduate assistant that will be hired as needed to accomplish the work. The PI will oversee all work and be primarily responsible for the final data analysis.

***Expected Results*:**

Preliminary data from a chronosequence in the Duke Forest (Durham, NC) indicate that forests of different ages vary in their response to C_a, and that the C_a at the time of establishment is a stronger predictor of physiology than the C_a at present (Figure 1). This trend was observed across a chronosequence of forest sites dominated by loblolly pine (*Pinus taeda* L.) trees that were planted at different times. This technically does not represent natural forest succession, and it is unknown if the same response will be observed across a chronosequence of sites that naturally reestablished. The trees in the forest sites at the VFSEF seeded naturally, and will serve to test if the trends observed in Figure 1 are applicable to natural secondary succession.

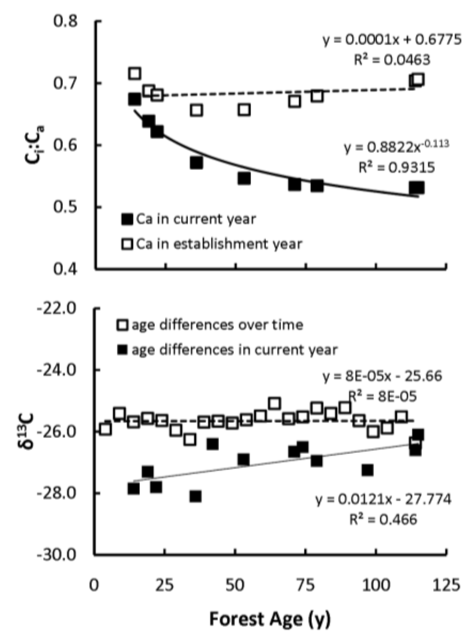

Figure 1. Relationship of C_i:C_a to forest age, assuming C_a in the current year (closed symbols) or assuming C_a in the establishment year of the forest stand (open symbols), upper panel; Relationship of $\delta^{13}C$ of annual woody increments using estimates from different aged forest stands (closed) or using estimates from the same cohort of trees over time since establishment (open), lower panel.

Broader Expected Outcomes:

The results of this work will inform an external grant proposal aimed at resolving the response of belowground C sequestration in aging forests to climate change. Understanding C inputs to aging forests is a first step in resolving the C sequestration of these temperate forests in the future. With the work proposed here completed using funds from the OURC, the PI will be in a stronger position to resolve questions about belowground C cycling that remain unanswered in forest ecosystems. Although the work proposed here is experimental, the results will eventually be used to build a more accurate system-level model of C sequestration in forests, extending previous modeling work completed by the PI that describes that response of forest C sequestration to management and nitrogen availability (Davis et al. 2008, 2009, 2010).

This work will support education and be of interest to a broad audience of scholars and the public. A graduate student will be trained in the course of this work, and a peer-reviewed publication is expected to be coauthored by the student and PI. With future funding, the results from this study will be compared with those of chronosequences established at other forested sites, eventually leading to a high impact publication. This work will also provide a more detailed history of the sites throughout the VFSEF and will inform future interpretive work, educating both the students of OU and the visitors to the forest. All of these outcomes should contribute to the visibility and reputation of Ohio University.

Ultimately, this work will improve our understanding of forest responses to climate change historically, in the present, and in the future. Once the interactive effect of climate change variables and forest age are resolved, physiological ecosystem models that project forest growth in the future can be improved. This will be the next phase of work for the Davis lab. Recommendations for improvements to Earth system models that project forest responses to climate changes will also be made as a result of this work. Given the large C sink that temperate forests provide and the valuable contribution they make in counteracting climate change, it is extremely important to resolve whether this C sink will decline or increase in the future. The work described here will provide much needed evidence to address this question.

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Biographical Information (3 pages): Sarah C. Davis

<u>EDUCATION AND TRAINING</u>

Postdoctoral Associate	2007-2010	Ecology, Plant Biology	University of Illinois at Urbana-Champaign
PhD	2003-2007	Biology	West Virginia University
BA, BS, Honors	1995-1999	Wildlife Management	Frostburg State University

<u>PROFESSIONAL APPOINTMENTS</u>

Assistant Professor	Voinovich School for Leadership and Public Affairs, Ohio University	*2013-present*
Bioenergy Analyst	Energy Biosciences Institute, University of Illinois at Urbana-Champaign	*2010-2012*
Adj. Assistant Professor	Department of Plant Biology, University of Illinois at Urbana-Champaign	*2010-2012*
Post-doctoral Associate	Department of Plant Biology, University of Illinois at Urbana-Champaign	*2007-2009*
Research & Teaching Asst.	Department of Biology, West Virginia University	*2003-2007*
Assistant Director	Regional Math/Science Center, Frostburg State University	*1999-2003*

<u>PUBLICATIONS (LAST 5 YEARS ONLY)</u>

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Anderson-Teixeira KJ, **SC Davis**, MD Masters, and EH DeLucia. 2009. Changes in soil organic carbon storage under potential biofuel crops. Global Change Biology BioEnergy 1:75-96.

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CONFERENCE LEADERSHIP (AS RELATED TO THIS PROPOSAL ONLY)

- International Soil Carbon Monitoring Standards and Methodologies Workshop, March 21-24, 2011,London, UK –*wrote synthesis paper (published)*
- Harvesting Carbon from Eastern US Forests Workshop, December 10, 2010, San Francisco, CA. – *organizer, discussion facilitator, and lead author of synthesis paper (published)*

PRESENTATIONS (LAST 5 YEARS ONLY)

Davis S. C. Bioenergy systems to mitigate environmental impacts of energy industries. Brown Bag Lunch Seminar Series of the Consortium for Energy, Economics, and Environment. Voinovich School of Leadership and Public Affairs, Ohio University, Athens, OH, October 4, 2013.

Davis S. C. Bioenergy systems that address climate change. Colloquium in Department of Chemical Engineering, Ohio University, Athens, OH, September 30, 2013 (invited).

Davis S. C. Terrestrial carbon dynamics: response to land use and climate change. Colloquium series in Department of Environmental and Plant Biology, Ohio University, Athens, OH, September 20, 2013 (invited).

Davis S. C. Agave: a potential bioenergy feedstock crop for semiarid agricultural land. 16^{th} International Congress on Photosynthesis Research, St. Louis, MO, August 11-16, 2013 (invited).

Davis S. C. Agave: a potential bioenergy feedstock? C4-CAM Meeting, Urbana, IL, August 6-9, 2013 (invited).

Davis S. C. Terrestrial carbon dynamics: responses to land use and climate change. US Forest Service Northern Research Station, Delaware, OH, July 26, 2013 (invited).

Davis S.C. Managing bioenergy for ecological benefits. UC Berkeley Energy Biosciences Institute Seminar Series, Berkeley, CA, November 13, 2012. (invited)

Davis S.C. Effects of management choices on the ecological impact of biofuel crops. Ecological Society of America 97^{th} Annual Meeting, Portland, OR, August 5-10, 2012. (invited)

DeLucia E.H., Anderson-Teixeira K.J., Duval B.D., **Davis S.C.,** Bernacchi C.J., Parton W.J. Impacts of growing perennial grasses for biofuel in the U.S. corn belt. Ecological Society of America 97^{th} Annual Meeting, Portland, OR, August 5-10, 2012. (invited)

Black C. K., **Davis S.C.**, Bernacchi C.J., DeLucia E.H. Elevated temperature and carbon dioxide prime soil-specific increases in heterotrophic respiration. Ecological Society of America 97th Annual Meeting, Portland, OR, August 5-10, 2012.

Paul, R. and **Davis S.C.** Optimizing agroecosystem landscapes for both bioenergy feedstocks and ecosystem services (poster). 3rd Pan American Congress on Plants and Bioenergy, Urbana, IL, July 15-18, 2012.

Straker, K. and **Davis S.C.** Mismatch of life-cycle inventories for bioenergy production and agricultural resource production (poster). 3rd Pan American Congress on Plants and Bioenergy, Urbana, IL, July 15-18, 2012.

Kampwerth, M. and **Davis S.C.** Production and water use efficiency of *Agave* spp. for bioenergy in the southwestern US. 3rd Pan American Congress on Plants and Bioenergy, Urbana, IL, July 15-18, 2012.

Davis S.C. Managing bioenergy agro-ecosystems for negative carbon emissions. GCEP Workshop on Energy Supply with Negative Carbon Emissions, Stanford University, June 15, 2012. (invited)

Davis S.C. Perspective on water cycling in ecosystem models. Water in Bioenergy Agro-ecosystems Workshop, Gleacher Center, Chicago, June 12-13, 1012. (invited)

Davis S.C. Managing bioenergy to mitigate climate change. IDEAS Bioenergy Symposium, UNC Charlotte, March 13-14, 2012. (invited)

Parton W.J., **Davis S.C.**, Del Grosso S., Adler P.R., DeLucia E.H. Ecological modeling of bioenergy production systems using DayCent. Ecological Society of America 96th Annual Meeting, Austin, TX, August 7-12, 2011.

Black C.K., **Davis S.C.**, Bernacchi C.J., DeLucia E.H. Heterotrophic respiration from soil increases with atmospheric carbon dioxide and temperature (poster). Ecological Society of America 96th Annual Meeting, Austin, TX, August 7-12, 2011.

Duval, B.D., **Davis S.C.**, Parton W.J., Long S.P., DeLucia E.H. Greenhouse gas reduction with conversion from pasture to energy cane production. Ecological Society of America 96th Annual Meeting, Austin, TX, August 7-12, 2011.

Davis S.C., Dohleman F.G., Long S.P. Global potential for *Agave* as a biofuel feedstock. Berkeley Bioeconomy Conference, March 24-25, 2011. (invited)

Davis S.C. Carbon dynamics: perspectives from ecosystem models. NSF INTERFACE Meeting: How do we improve earth system models? March 2-3, 2011. Captiva Island, FL. (invited)

Davis S.C., Drake J.E., DeLucia E.H. Carbon sequestration in response to rising atmospheric CO_2 in active and abandoned pine plantations of the southeastern US (poster). American Geophysical Union Fall Meeting. December 13-17, 2010. San Francisco, CA.

Davis S.C., W.J. Parton, S.J. Del Grosso, C. Keough, E. Marx, E. H. DeLucia. 2010. Second-generation biofuel feedstocks improve greenhouse gas economics of agriculture in the Mississippi watershed. 2nd Pan American Congress on Plants and Bioenergy, August 8-11, 2010, São Pedro, Brazil.

Davis, S.C. 2010 Carbon budgets of harvested ecosystems that vary in form and function: from monocultures to diverse deciduous forests. Ecological Society of America, August 1-6, 2010, Pittsburgh, PA, USA.

Black C.K., **S.C. Davis**, C.J. Bernacchi, E. H. DeLucia. 2010. Response of soil respiration to ecosystem warming and elevated atmospheric carbon dioxide (poster). Ecological Society of America, August 1-6, 2010, Pittsburgh, PA, USA.

Davis, S. 2010. Greenhouse gas mitigation potential of bioenergy feedstock crops. Seventh Annual Bioenergy Feedstocks Symposium. Champaign, IL, January 11-12, 2010. (invited)

Davis, S., T. Yannarell, M. Masters, K. Anderson-Teixeira, J. Drake, R. Darmody, R. Mackie, M. David, E. DeLucia. 2009. Restoration of soil organic carbon with cultivation of perennial biofuel crops (poster). American Geophysical Union. December 14-18, 2009. San Francisco, CA.

Davis, S. C. Tony C. Yannarell, Evan H. DeLucia. 2009. Carbon sequestration mediated by plant-soil-microbe interactions in tallgrass prairie communities (poster). American Society of Plant Biologists. Honolulu, HI, July 18-22, 2009.

Kent, A. D., **S. C. Davis**, D. P. Keymer, N. R. Gottel. 2009. Ecology and exploitation of endophytic diazotrophic bacteria in biofuel crops. Energy Biosciences Institute Retreat. Champaign, IL, June 19-22, 2009.

Yannarell, A. C., **S. C. Davis**, R. I. Mackie. 2009. Assessing the influence of two perennial grass biofuel crops on soil bacterial community composition. ASM, May 17-21, 2009.

Davis, S. C. Nitrogen budgets in a carbon-based economy. Department of Plant Biology Colloquium, Urbana, IL, April 3, 2009. (invited)

Davis, S. C. Sustainability of nutrient budgets in bioenergy agro-ecosystems. EBI Internal Discussion Seminar Series. March 6, 2009.

Davis, S. C. Nitrogen budgets in carbon based economy. Cary Institute of Ecosystem Studies, Millbrook, NY February 19, 2009. (invited)

Other Support (1 page)

A. Previous University Funding

1. 2013-14: *Belowground carbon cycling response to climate change and forest age* (OU Research Challenge Program)- $2500

   funds used to pay student to help establish research plots designed to study carbon cycling in forested area of the university Land Lab, located on the Ridges part of Ohio University campus
2. 2013-14: *Integrated supply chain analysis for a second-generation bioenergy industry* (OU Research Challenge Program)- $3500

   funds used to pay students to help cultivate bioenergy crops to be studied as environmentally sustainable alternatives to corn grain-based ethanol; this was conducted on the OU campus in collaboration with a local business owner that purchased the biomass to test preprocessing technology for bioenergy
3. 2013-14: *Developing environmentally compatible bioenergy production* (OU Research Challenge Program)- $2500

   funds used to pay student to help with study of CAM species that might be environmentally sustainable alternatives for bioenergy agriculture in semi-arid and arid growing regions
4. Start-up funds upon hire in 2013 (Voinovich School of Leadership and Public Affairs, OU Research Office)- $250,000

   funds used to establish a research laboratory equipped to measure (i) carbon and nitrogen in solid samples, (ii) greenhouse gases that can be sampled using chambers installed in experimental field sites, (iii) gas exchange in plants and soil; lab also equipped to collect and process samples from (i) soil, (ii) wood/ trees, (iii) plant tissue; new agricultural research plots and greenhouse experiments were also established on campus; a graduate student was support that will complete a master degree this spring (2014) and publish the first research produced from the new bioenergy research established on The Ridges

B. **Externally Funding**

1. **Successfully Awarded (last 3 years only)**
   - i. 2013-17: *Agave as a feedstock crop in the southwestern US* (Energy Biosciences Institute)- $400,000
   - ii. 2013-14: *BP Biomass Handbook* (BP)- $17,208
   - iii. 2012: *Agave* as a feedstock crop in the southwestern US (EBI)- $61,878
   - iv. 2011-2012: Assessing the Carbon Footprint of Combined Corn and Cellulose Ethanol Production (Environmental Protection Agency)- $15,000
   - v. 2010: Harvesting Carbon from Eastern US Forests workshop (EBI)- $8000
   - vi. 2010: Agave for Bioenergy workshop (EBI)- $21,000
2. **Attempted Funding**
   - i. *Belowground carbon cycling response to climate change and forest age* (2013 US DOE- Early Career): $1,021,039

     Highly ranked, but was criticized for including only one chronosequence; the work proposed here would help to address this in subsequent proposals
   - ii. *Integrated supply chain analysis for a second-generation bioenergy industry* (2013 US DOE- EERE): $4,158,530
   - iii. *Developing environmentally compatible bioenergy production* (2013 Sungrant Program through USDA and DOE): $112,131

C. Sustainability: This proposal will support a continuation of work on carbon sequestration in managed forest ecosystems that has been supported in the past but requires additional preliminary data to develop a stronger proposal for submission to DOE or NSF.

Budget and Justification (1 page)

Student Wages: Student labor will be required to collect, prepare, and analyze tree cores from the seven sites described in the proposal. Labor will include support for a student to work 360 hours (~20 hours per week for 12 weeks during the summer of 2014; and 10 per week for 12 week during the academic year). At a wage of $11/h (consistent with current student wages at the Voinovich School), the total requested for 1abor wages is………………..………………**$3960**
with fringe benefit costs of ……………………………………………………………**$584**

Consumable Supplies: materials required for sample preparation include

Paper tubes for transporting tree cores……………………………………………..**$54**

Sandpaper, multiple grades………………………………………………………..**$100**

Wood mounts for tree cores………………………………………………………...**$50**

Microtubes for grinding……………………………………………………………**$310**

Beads for grinding……………………………………………………………………..**$25**

Tin capsules for wrapping samples………………………………………………..**$176**

Other; Isotopic composition analysis is expected to cost $4 per sample (see quote in appended material). At the 150 y old site, an estimated 20 cores (2 from each of 10 trees) with samples extracted every fifth increment will yield approximately 600 samples, but increments for a given year from each pair of cores collected from a single tree will be ground and homogenized together for isotopic analysis so that only 300 need to be sent for analysis (150y /5y increments x 10 cores). Approximate ages of the other sites to be analyzed are 9 y (~10 samples), 16 y (~30 samples), 27 y (~50 samples), 36 y (~70 samples), 51 y (~100 samples), 60 y (~120 samples). The total number of samples to be analyzed are therefore 680 and will cost………………**$2720**

Total Requested………………………………………………………………………… **$7979**

All other materials for collecting, processing and analyzing samples are available in the Davis lab, including tree coring equipment, a power sander for preparing samples, beadbeater for grinding samples, wrapping equipment, trays for storing and transporting samples, dessicant chamber, and microbalance for weighing prepared samples. Analyses of tree core growth will be accomplished using facilities available in the Department of Environmental and Plant Biology as described in methods (appended letter describes access to facilities). A graduate student that is currently supported by GA funds paid by the Voinovich School will assist with this research, data analysis, and the writing of a scholarly paper based on the results that will be published in a peer-reviewed journal.

Appended Materials

1. **Letter from Dr. Todd Hutchinson at USDA Forest Service describing access to VFSEF**

2. **Letter from Dr. Brian McCarthy describing access to dendrochronology equipment in Department of Environmental and Plant Biology**

3. **Letter from University of Illinois detailing agreement to analyze isotopic composition of samples collected**

USDA United States Department of Agriculture
Forest Service
Northern Research Station NRS-02
359 Main Road
Delaware, OH 43015
Phone: (740) 368-0100

Date: January 27, 2014

Use of Vinton Furnace State Experimental Forest for Study

The Vinton Furnace State Experimental Forest (VFSEF) is located in Vinton County, Ohio. Silvicultural and ecological research have been conducted on the VFSEF since 1952. Approval for new research projects on the forest is obtained by submitting a proposal to the Research and Monitoring Subcommittee (RMS), which includes members from several government agencies, the forest industry, and non-governmental organizations. Based on the recommendation of the RMS, final approval comes from the Research Advisory Committee (RAC), comprised of the Ohio Division of Forestry, Ohio Division of Wildlife, and the U.S. Fish and Wildlife Service.

Dr. Sarah Davis submitted a proposal on November 18, 2013, to conduct a study at the VFSEF addressing forest response to climate change, based on tree growth patterns in a chronosequence of different-aged stands. **Final approval for Dr. Davis' proposed study was given by the RAC on December 11, 2013**. This approval provides Dr. Davis with full access to the study sites and permission to conduct manipulative research (e.g., extracting increment cores).

We fully support Dr. Davis's study and we will also provide logistical assistance (access, maps, stand history information) as needed.

Sincerely,

Todd Hutchinson
Research Ecologist
Chair, VFSEF Research and Monitoring Subcommittee
USDA Forest Service
Northeastern Research Station
359 Main Road
Delaware, OH 43015

Phone: 740-368-0064
Fax: 740-368-0152
Email: thutchinson@fs.fed.us

OHIO UNIVERSITY

College of Arts and Sciences
Office of the Dean
Wilson Hall Admin, College Green
Athens, OH 45701-2979

T: 740.593.2979

Dr. Sarah C. Davis
Voinovich School of Leadership and Public Affairs
Bldg. 22, The Ridges
Ohio University
Athens, OH 45701

Dear Sarah:

This is to acknowledge that you have free and open access to the use of my laboratory (416 Porter Hall) for the purposes of doing dendrochronology research. We have an Olympus 40× boom microscope, Velmex UniSlide, digital decoder, and Dell laptop available for your use.

Sincerely,

Brian C. McCarthy, Ph.D.
Associate Dean of Faculty, Research, & Graduate Studies, and
Professor of Forest Ecology

E: mccarthy@ohio.edu

CC: Connie Pollard, PBIO Admin

ENERGY
BIOSCIENCES
INSTITUTE

Institute for Genomic Biology
1206 W. Gregory, Room
Urbana IL 61801, USA

Dr. Davis,

I would be willing to analyze your plant and/or soil samples on our Elemental Analyzer/Isotope Ratio Mass Spectrometer Continuous Flow system (Costech 4010 EA, Delta V Advantage IRMS) for $4.00 per sample. Data output will include percent Carbon, percent Nitrogen, delta 13C, and delta 15N. Samples should be pre weighed and wrapped in tin capsules and sent with an excel sheet containing some kind of Identifier and the mass of the weighed sample. Quality control outputs of machine precision for isotope ratios will be included with the data. An invoice will be sent at the completion of the analysis.

Michael Masters
Field Research Specialist

Recommended External Reviewers

1. **Dr. Miguel Gonzalez-Meler**
   Professor
   UIC Biological Sciences, SES 3223 M/C 066
   845 West Taylor Street
   Chicago, IL 60607
   Office: (312) 355-3928
   Fax: (312) 413-2435
   Email: mmeler@uic.edu

   Research areas: physiological and ecosystem ecology, global change and stable isotope ecology

2. **Dr. Jason Hamilton**
   Associate Professor and Chair, Environmental Studies and Science
   Department of Environmental Studies and Sciences
   252 Ctr for Natural Sciences
   Ithaca, NY 14850
   (607) 274-1439
   Email: jhamilton@ithaca.edu

   Research Areas: Plant Ecophysiology, Global Change Biology, Education for Sustainability, Integrative Education, Non-Timber Forest Products

3. **Dr. Heather McCarthy**
   Assistant Professor
   University of Oklahoma
   149 George Lynn Cross Hall
   770 Van Vleet Oval
   Norman, OK 73019
   405-325-7793 (Office)
   405-325-7793 (Lab)
   Email: heather.mccarthy@ou.edu

   Research areas: Plant Biology, Environmental Science, Ecology and Evolutionary Biology, Ecosystems Ecology, Global Change Biology, Physiological Plant Ecology, Forest ecology, Urban ecology

4. **Dr. Shawna Naidu**
   School of Molecular & Cell Biology
   University of Illinois at Urbana-Champaign
   407 South Goodwin Avenue

505 S Goodwin
M/C 120
Urbana, IL 61801
(217) 333-6774
(217) 265-0927 (fax)
Email: shawna@illinois.edu

Research areas: ecophysiology, carbon cycling

5. **Dr. Peter Curtis**
Professor of Ecology
Department of Evolution, Ecology & Organismal Biology
The Ohio State University
318 W. 12th Avenue
Columbus, OH 43210
614-292-0835 office, room 276 Aronoff Laboratory
614-292-2030 fax
Email: curtis.7@osu.edu

Research Areas: climate change, forest ecology, restoration ecology

6. **Dr. Dan Richter**
Professor of Soils and Forest Ecology
Division of Environmental Sciences & Policy, Nicholas School of the Environment
Duke University
A205 Lab; Lev Sci Res Ctr Science Dr. Durham, NC 27708
(919) 613-8031, (919) 613-8041
fax: (919) 684-8741
Email: drichter@duke.edu

Research area: ecosystem and soil sciences; management of forests, soils, and watersheds