THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

COLLEGE OF AGRICULTURAL SCIENCES

THE IMPACTS OF ELEVATION AND CLIMATE ON THE GROWTH OF *PINUS SYLVESTRIS*

DANA JAMES
SPRING 2013

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Environmental Resource Management and Community, Environment, and Development
with honors in Environmental Resource Management

Reviewed and approved* by the following:

Margot W. Kaye
Assistant Professor of Forest Ecology
Thesis Supervisor

Robert Shannon
Associate Professor and Coordinator of ERM Program
Honors Adviser

* Signatures are on file in the Schreyer Honors College

ABSTRACT

The Mediterranean region is predicted to undergo significant warming and drying in the future (IPCC, 2007). This will pose a challenge to sensitive species in the region, and especially to those that are already at their southern limit. One such "rear edge" species is *Pinus sylvestris*, or Scots pine. Scots pine is an important keystone species throughout Europe, and is able to tolerate a variety of climatic conditions. At its southern limit in Spain, Scots pine distribution is limited by high temperatures and drought. Therefore, distributional patterns, recruitment, and growth rates of Scots pine may be expected to change in the future in rear edge populations in Spain as this area is expected to become more drought-prone (hotter and drier).

This study investigates how climate and elevation affect growth rates of Scots pine in the Spanish Pyrenees. By analyzing past and current growth rates of these trees, the scientific community will be able to understand the implications of climate and elevation on the growth of Scots pine at its southern limit in the future. The results of this research indicate that from 1970-1985 the trees at the sites of lower elevation have had higher growth rates, but since 1985 the growth rates of trees at these sites have been significantly declining, while the trees at the higher elevations have not had declining growth rates. This may signify that, in the face of warming and drying in this region, the trees at the higher elevations will be more resilient to the changing climate. Additionally, the results imply that complex topographical features and climate can create quite suitable and habitable microclimates for Scots pine – even for "rear edge" populations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

There are a number of people to thank for making the successful completion of this thesis possible. I would first like to thank Drs. Margot and Jason Kaye for selecting me for an international research experience in Spain during the summer of 2012 (the trip from which the data for this thesis was collected). I would especially like to thank Margot for her support and guidance as my thesis supervisor, and for sharing so much of her knowledge with me. I would also like to thank Dr. Robert Shannon, my faculty reader and ERM honors adviser. I could never have succeeded in balancing my schedule over the past four years without his excellent advising skills.

Chapter 1

Introduction

Global changes in climate are set to have extensive effects on plant growth rates and geographic distributions (IPCC, 2007; Matías and Jump, 2012). Changes in species range are expected to be most pronounced at the latitudinal margins of a population's range. "Rear edge" populations (those at the low latitude edges of a species' distribution) may be disproportionately important to a species' success in terms of evolutionary potential, genetic diversity, and phylogenetic history, and therefore research and conservation and management practices in rear edge populations are vital (Hampe and Petit, 2005).

Forest ecosystems are already rapidly changing around the world, primarily due to climate and land use changes (Vila-Cabrera et al., 2012a). An important keystone species that is prevalent throughout Europe is *Pinus sylvestris* L., more commonly known as Scots pine. Part of the southern/rear edge of this population is found in northern of Spain (Figure 1), typically in an altitudinal range of from 800 to 1600 meters above sea level, although it can be found from 200 to 2100 meters above sea level (Vila-Cabrera et al., 2012a). As evidenced by its distribution, Scots pine is able to tolerate a variety of climatic conditions, including cold winters in the North and arid, Mediterranean conditions in the South (Matías and Jump, 2012). At its southern limit, Scots pine distribution is limited by high temperatures and drought (Carlisle and Brown, 1968; Castro et al., 2004). Climate models predict that the Mediterranean region will face increased warming in the range of 2 - 6 degrees Celsius and decreased precipitation in the future, and that warming and drying will be most pronounced in the summer months (IPCC 2007; Figures 2 and 3). Therefore, distributional patterns, recruitment, and growth rates of Scots pine may be

expected to change in the future in rear edge populations in Spain as this area is expected to

become more drought-prone (hotter and drier).
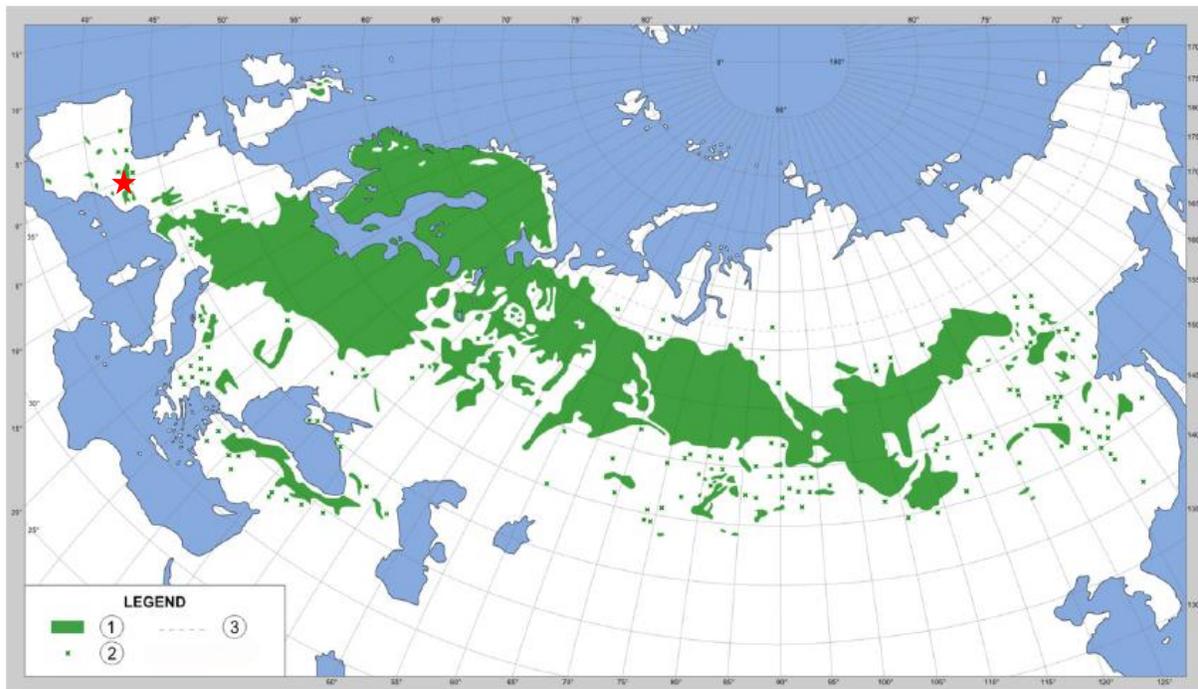
Figure 1: Current distribution of *Pinus sylvestris*: The legend depicts (1) the main range of the species and (2) isolated occurrences of the species. The red star represents the field site Arcalís, in northeastern Spain, where the data for this study were collected. Taken from Matías and Jump, 2012.
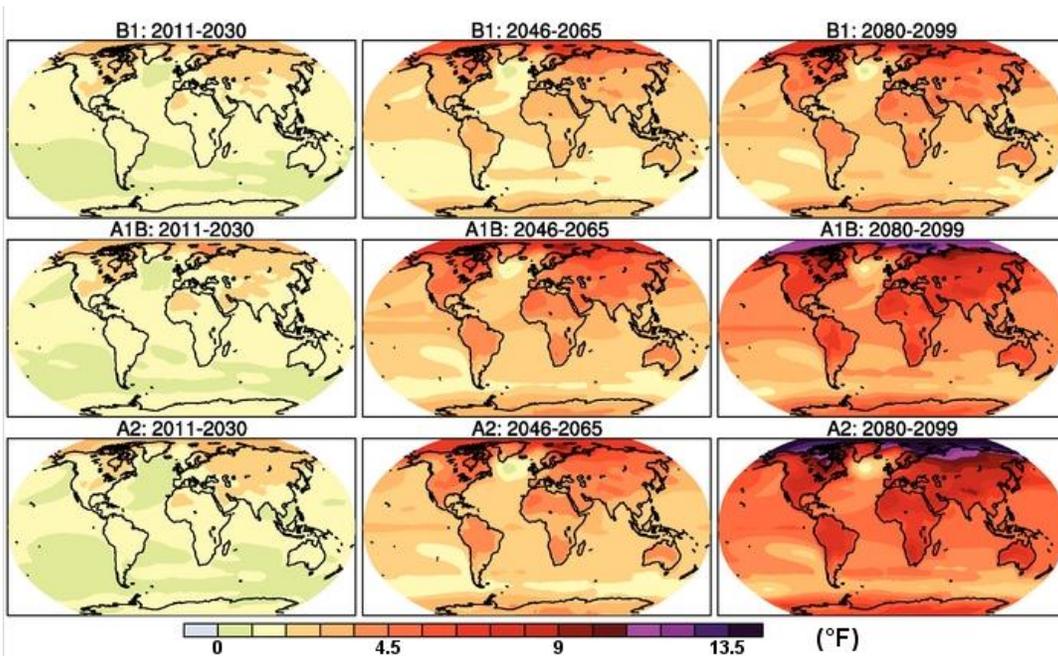
Projected changes in global average temperatures under three emissions scenarios (rows) for three different time periods (columns). Changes in temperatures are relative to 1961–1990 averages. The scenarios come from the IPCC Special Report on Emissions Scenarios: B1 is a low emissions scenario, A1B is a medium–high emissions scenario, and A2 is a high emissions scenario. Source: NRC (2010)

Figure 2. Taken from <http://www.epa.gov/climatechange/science/future.html>

multi-model · A1B · DJF

multi-model · A1B · JJA
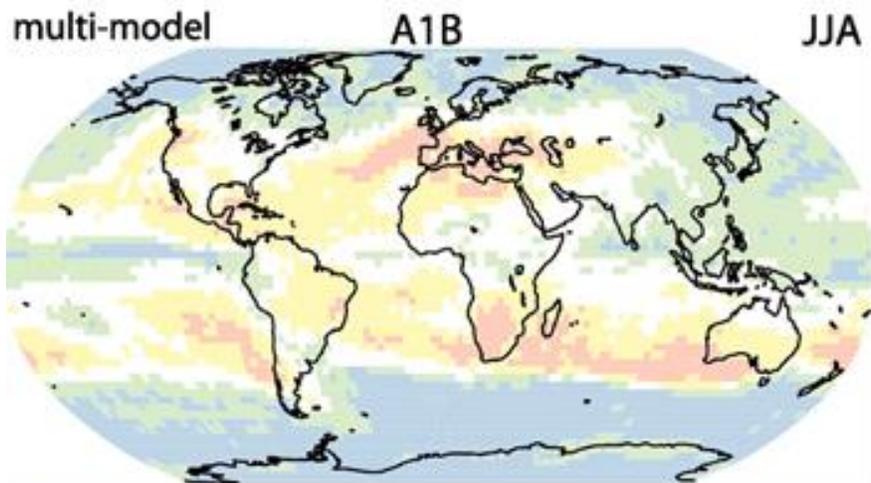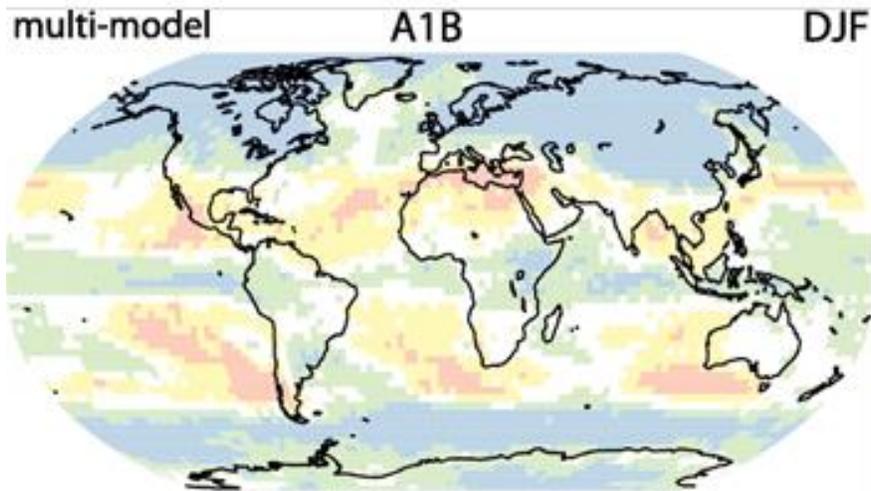
Global precipitation projections for December, January, and February (top map) and June, July, and August (bottom map.) Blue and green areas are projected to experience increases in precipitation by the end of the century, while yellow and pink areas are projected to experience decreases.
Source: Christensen et al. 2007 [EXIT Disclaimer]

Figure 3. Taken from <http://www.epa.gov/climatechange/science/future.html>

Because of the predicted warming and drying in the Mediterranean region, the viability of Scots pine in Spain may decrease. Precipitation deficits strongly affect seedling growth in the seedling stage and elevate mortality (Matías and Jump, 2012). Summer drought is the main abiotic limiting factor affecting the recruitment of *Pinus sylvestris* in arid ecosystems and may even halt recruitment entirely (Castro et al., 2004; Matías et al., 2011). This is expected to limit the natural regeneration of Scots pine at its southern range even more drastically than what is currently seen (Matías and Jump, 2012). Additionally, precipitation is the limiting factor affecting growth at the southern limit of Scots pine, and this has demonstrated negative effects on height and radial growth of the species in the Mediterranean climate (Matías and Jump, 2012). At low latitudes and altitudes, the spring and summer water balances are extremely important to increasing radial growth rates (Lebourgeois, 2007). The decrease in precipitation and increase in severe droughts that is predicted for Spain is like to have a detrimental effect on the growth of Scots pine. Other interacting factors, like herbivory pressures and pathogen attack, will also negatively impact juvenile growth (Matías and Jump, 2012).

The stress induced in European Scots pine populations at the rear edge of its distribution from increased temperature and aridity may result in increased mortality, and therefore increased sensitivity to other stress factors that may eventually lead to tree death (McDowell et al., 2008). The combination of these effects may lead to large-scale mortality events throughout the species' southern range (Allen et al., 2010; Anderegg et al., 2012). As recruitment levels of Scots pine will also be depressed, it is likely that regeneration will not occur, but rather replacement by another, more drought-resistant species will result (Matías and Jump, 2012).

An added stressor that also may contribute to Scots pine mortality is pine mistletoe, which exacerbates the water stress of Scots pine trees at the southern limit due to the parasitic

mistletoe taking up water, nutrients, and carbohydrates from the trees (Matías and Jump, 2012). Mistletoe continues to transpire even during drought when the trees have already closed their stomata, increasing stress on the tree increased and sometimes inducing mortality (Galiano et al., 2011). There are many other ways in which mistletoe infestation negatively impacts Scots pine trees, included altered resource allocation and slower growth (Galiano et al., 2011).

An additional stressor to Scots pine trees at the rear edge is fire. Given that the Mediterranean region is expected to have less precipitation and amplified heat stress in the future, fire may become an even more important factor in forest ecosystem dynamics (Giorgi and Lionello, 2008; IPCC, 2007). At the species' southern limit, high intensity crown fires occur most often and regeneration by Scots pine species drastically declines in scorched areas after such high intensity fires; instead, sprouting shrubs or *Quercus* species may recolonize (Matías and Jump, 2012; Retana et al., 2002; Vilà-Cabrera et al., 2012b). Additionally, fires can affect and alter nutrient functioning and cycling in forest ecosystems and this may in turn affect Scots pine growth and recruitment, especially in areas that are already nutrient-limited (Matías and Jump, 2012).

The study site at which the data collection for this paper was carried out was in the Spanish Pyrenees (see Figure 1). The area is located in northeastern Spain, in the autonomous community of Catalonia and the province of Lleida. Notably, there is evidence that drought-induced forest decline is related to severe summer droughts that were experienced in the Arcalís region during 2005 (Galiano et al., 2010).

As areas of lower elevation may become particularly hot and dry in Spain, I predicted that populations of Scots pine in the Pyrenees at lower elevations may become more stressed than those at higher elevations. Therefore, Scots pine trees at lower elevations will have slower

growth rates than those found at higher altitudes. To address this hypothesis, I used radial growth

trends of trees in the Spanish Pyrenees, elevation, and climate data for Spain (including both

temperature and precipitation models) to compare growth rates of *Pinus sylvestris* along an

elevation gradient.

Chapter 2

Methods

The study area is quite close to the town of Arcalís, Spain. In this region, annual rainfall in the distribution area of Scots pine ranges from 520 to 1330 mm and average annual temperatures range from 3.6 to 14.3˚C (Vila-Cabrera et al., 2012a). The Arcalís Scots pine populations have remained largely unmanaged since at least the 1980s (Vila-Cabrera et al., 2012a).

Five different transects were identified at the Arcalís site based on elevation and age. The target tree age for our sampling purposes was around 80 years old. I chose trees of the same age in order to isolate the impact of climate on tree growth rates (both through time and space), and to ensure that the growth response was not due to tree age. My goal was to sample 18 trees at each site; this was not possible at site ARCT1 (where 16 trees were cored). While there were 18 trees cored at site ARCT5, three of these trees were too old to use in this study, and therefore were removed from consideration. At each site, the percent slope and the aspect (degrees) were recorded. Each tree was inspected and excluded if it was infected by mistletoe, a damaged canopy, or injuries to the stem. We took samples from trees that were at least a few meters apart from one another and were distributed across each transect. The transects were oriented parallel to the contour of the slope and were roughly between 500-800 meters long. For trees that were +/- 10 years of 80-90 years old, two core samples were drawn: one from the northward side of the tree and the other from the southward side of the tree. If the transect was on a slope and the north and south sides were not completely in line with the angle, we took the cores parallel to the slope but as close to the true north and south as possible. After coring a tree, the samples were placed in paper straws for storage with appropriate labels. We measured the diameter at breast

height (DBH) of each tree and recorded it, as well as any additional comments or notes in regards to the tree (i.e. if it was slightly too old or had some mistletoe). The cores were then laid out to dry over night to prevent rotting. They were then packed for transport to Madrid and then to State College, PA.

Samples were transported to the lab and prepared for analysis according to the following procedure. The cores were all properly mounted and secured (with the tracheids mounted vertically), labeled with the associated field data, and sanded. The sanding was done using three different sandpapers with progressively finer grains (sandpaper of 220, 320, and 400 grits, repectively) until each core was flat, smooth, and buffed. Once sanding with the power sander was finished, each core was sanded by hand three times once again (using microfinishing films of 30, 15, and 9 microns, respectively), until the tracheid vessels were clearly visible under a microscope.

The process of cross-dating the cores began with cores from the transects located at higher elevations, because theoretically these cores should be the least stressed and therefore perhaps the easiest to date. The cores were dated in pairs from the same tree, for comparison purposes, by first counting out from the pith toward the cambium and labeling every 10th year. Each core was then skeleton plotted on graph paper, with longer vertical lines indicating smaller rings, relative to both the rest of the rings generally but primarily relative to the ring directly preceding it (Stokes and Smiley, 1968). After every core in a transect series was skeleton plotted in this manner, a master chronology was created based on the chronologies created within each pair of cores. The purpose of cross-dating the cores in this manner was to assign exact calendar years to the tree rings, and to identify missing rings in each series. The pith for each core was estimated using a pith locator, where concentric circles printed on a transparent sheet were used

to match the size of tree rings nearest the center of the core and estimate the number of rings between the innermost ring and the pith.

Once cores were dated with skeleton plots and a master chronology, each ring from each tree core pairing from each transect was measured to the nearest 0.01 millimeter on a Velmex TA Unislide. These data were then input into COFECHA, which is a quality-control program that checks for errors during cross-dating and measuring, and for the general quality regarding chronology outputs (NOAA, 2008). Once this quality control check was made, the correlations and mean sensitivities were taken from each COFECHA output. For these analyses, the ring width data were grouped by transect, and the COFECHA outputs were grouped by transect as well. The raw ring width data from the cores were transferred into Excel (by transect) and were used to find the basal area increments for each tree ring of each core. The basal area increment is the area of wood added to the circumference of the tree each year. It is necessary to adjust to the basal area increment from the ring width because as a tree grows larger, it puts on more mass around its entire circumference, and as a result the tree rings appear smaller since the growth is distributed (somewhat) evenly around the circumference of the tree.

To calculate basal area increment, the average ring width per core was found. The diameter of each tree was then divided by two in order to find the radius of each tree. In order to find the basal area increment measurements for each tree, I subtracted the estimated bark thickness so as to only be calculating the measurements on the wood. I started with the outside ring, and calculated its basal area increment by using the radius. Once the basal area increment for that year was found, I subtracted that ring width from the radius to get the new radius for the previous year's growth. I was then able to estimate the basal area increment for that year, and so forth. Once this was completed for every ring on every tree, the average of each tree core pair

was calculated in order to get annual basal area increment by tree. The following equations mathematically describe this process:

$$R_y = \left(\frac{DCH_y}{2}\right) - BT_y$$

$$R_{(y-t)} = R_{(y-t+1)} - RW_{(y-t)}$$

where y = the year the stand was sampled (2012), t = the number of years prior to y (ranging from 1 to the age of the oldest pine tree), R_y = the tree radius measured in the field for year y, DCH_y = tree diameter at core height for year y, BT_y = estimated bark thickness in year y, $R_{(y-t)}$ = tree radius for t years before y, $RW_{(y-t)}$ = ring width measurement for year $y - t$ (Kaye et al., 2005). To calculate the basal area increment after utilizing the above calculations to find the radius, the following equations are needed:

$$BA_{(y-t)} = R^2{}_{(y-t)}\pi$$

where $BA_{(y-t)}$ = tree basal area for year $y - t$ (Kaye et al., 2005). Using this variable, basal area increment can be calculated:

$$BAI_{(y-t)} = BA_{(y-t+1)} - BA_{(y-t)}$$

where $BAI_{(y-t)}$ = tree basal area increment for year $y - t$ (Kaye et al., 2005).

Once the basal area increments were obtained for each tree at each site, the ten years between the estimated pith and measurement start year were deleted in order to account for the variable and unpredictable growth often seen in young trees. The basal area increment measurements were then averaged within each site across each year. For example, in site ARCT1, all of the basal area increment measurements for each tree in the year 2009 were

averaged together. The measurements for each tree in the year 2008 were also averaged together, and so on and so forth. These basal area increment averages were then compared against elevation and time to portray how tree growth is affected by an elevation stress gradient and what the trends in growth over time are at each site. The time period for which the tree cores were analyzed is 1970-2009, so as to ensure that growth patterns were stabilized amongst the trees that varied in age and to use a time period for which all trees could be included. Once the figure was created that compared the basal area increment averages against elevation, I calculated the standard error for each transect and added error bars to the graph. Another figure was created that compared the basal area increment averages for each transect against time. Using these data, I ran a regression in Excel on the basal area increment averages over time for each transect in order to obtain the p-values at the 95% confidence level (α=0.05) so as to explain the overall trends in growth over time.

Chapter 3

Results

One-hundred and seventy cores were collected from five elevations that spanned the ages of 55-133 years. This range indicates that there was, in some cases, a rather large deviation from the intended age target of 80 years. The tree ring series from *Pinus sylvestris* cross-dated well, with correlation coefficients ranging from 0.560 to 0.729. Over the time period of 1970-2009, mean basal area increment measurements ranged from 12.21 cm^2/year (at the second-lowest elevation of 900 meters above sea level) to 6.20 cm^2/year (at the highest elevation of 1537 meters above sea level) (Table 1). The trend in basal area increment measurements is that, generally, the trees at lower elevations had greater increases in basal area increment per year than did those trees at higher elevations (Figure 4). Notably, the trees at the second-lowest elevation (site ARCT2, 1537 meters above sea level) were the trees that grew the most per year in the past few decades. The trees from site ARCT1 (the lowest site, elevation 680 meters above sea level) have been growing the second-fastest, and the trees at site ARCT5, the highest elevation, have been growing the slowest.

The correlations (series intercorrelations), which measure the strength of the common signal in the tree ring chronology, were high across all of the sites (NOAA, 2008). Site ARCT1 had the highest correlation value of 0.729; ARCT2 had a correlation value of 0.701; ARCT3 had a correlation value of 0.688; ARCT3 had a correlation value of 0.714; and ARCT5 had the lowest correlation value of 0.560. The highest correlation values are found at the lower three sites. This can be interpreted as meaning that the sites at the lower elevations are responding more strongly to the same climate signal than the sites at the higher elevations.

Mean sensitivity values represent the relative change in ring width from one year to the next, and mean sensitivity is positively correlated with series intercorrelation (NOAA, 2008). This means that trees with strong common signals are also generally more sensitive (NOAA, 2008). The mean sensitivity of site ARCT1 was 0.312 (the highest value); site ARCT2 had a mean sensitivity of 0.266; site ARCT3 had a mean sensitivity of 0.289; site ARCT4 had a mean sensitivity of 0.304; and site ARCT5 had a mean sensitivity of 0.248 (the lowest value). By comparing these values to the series intercorrelation values, the lower elevations appear to have the stronger climate signal.

Table 1. A comparison among the five different Arcalís sites (varying by elevation) showing their respective characteristics. The correlations (series intercorrelations) measure the strength of the common signal in the tree ring chronology (higher values represent stronger signals). Mean sensitivity values represent the relative change in ring width from one year to the next. The basal area increment is the area of wood added to the circumference of the tree each year. The standard error represents the statistical accuracy of the average BAI measurements (the lower the number, the smaller the potential error). The p-value of the slope of the regression line is the probability that the declining growth trend is significant at the $\alpha=0.05$ level (if the p-value is less than 0.05, the declining trend is significant).

| Site	ARCT1	ARCT2	ARCT3	ARCT4	ARCT5
Elevation (m)	680	900	1025	1318	1537
Number of Trees cored	16	18	18	18	18; only 15 analyzed
Aspect (degrees)	0	340	0	290	320
Slope (degrees)	20	20	20	0	20
Range of years in chronology	1932-2012	1933-2012	1924-2012	1915-2012	1881-2012
Mean est. pith (pith range)	1952 (1930-1964)	1947 (1928-1961)	1939 (1921-1956)	1927 (1910-1936)	1913 (1844-1947)
Correlation	0.729	0.701	0.688	0.714	0.560
Mean sensitivity	0.312	0.266	0.289	0.304	0.248
Ave. BAI (cm^2/year)	9.273	12.210	7.347	6.536	6.197
Standard error of ave. BAI	0.405	0.617	0.350	0.288	0.186
P-value of slope of regression line	P<0.001	P<0.001	P<0.001	0.827	0.092
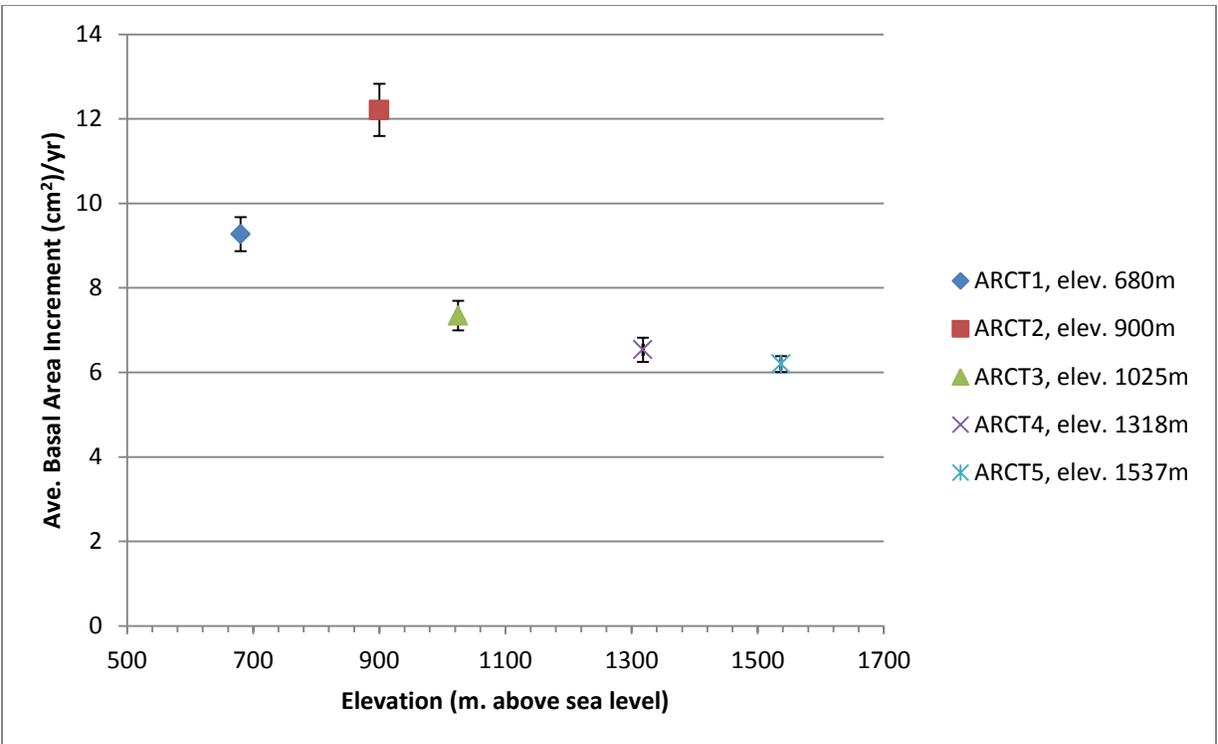
Figure 4. A comparison among all five Arcalís sites of different elevations for 1970-2009 of average basal tree ring growth. The standard error bars represent the statistical accuracy of the average BAI measurements, where n=16, 18, 18, 18, and 15 for each site, respectively.

Overall, radial growth for the time period of 1970-2012 was varied, but for sites ARCT1, ARCT2, and ARCT3 there is a significant declining trend in tree growth (Figure 5a). This is reflected in the p-values of the slope of the regression lines for these sites, as the p-value for each is less than 0.001. Therefore, the p-values are statistically significant for the lower three sites. Sites ARCT4 and ARCT5 (the two sites at the highest elevations) did not display a statistically significant negative growth trend; the p-value for the ARCT4 site was 0.827478, and the p-value for the ARCT5 site was 0.092086 (Table 1). Additionally, there is an obvious and drastic decrease in basal area increment measurements for trees at all sites in the year 2005-2006 (Figure 5b).

Figure 5a. A comparison among all five sites, with elevations ranging from 680-1537 meters above sea level, of basal tree ring growth over the time period from 1970-2009. Trees at sites ARCT1, ARCT2, and ARCT3 are undergoing a statistically significant declining growth trend.
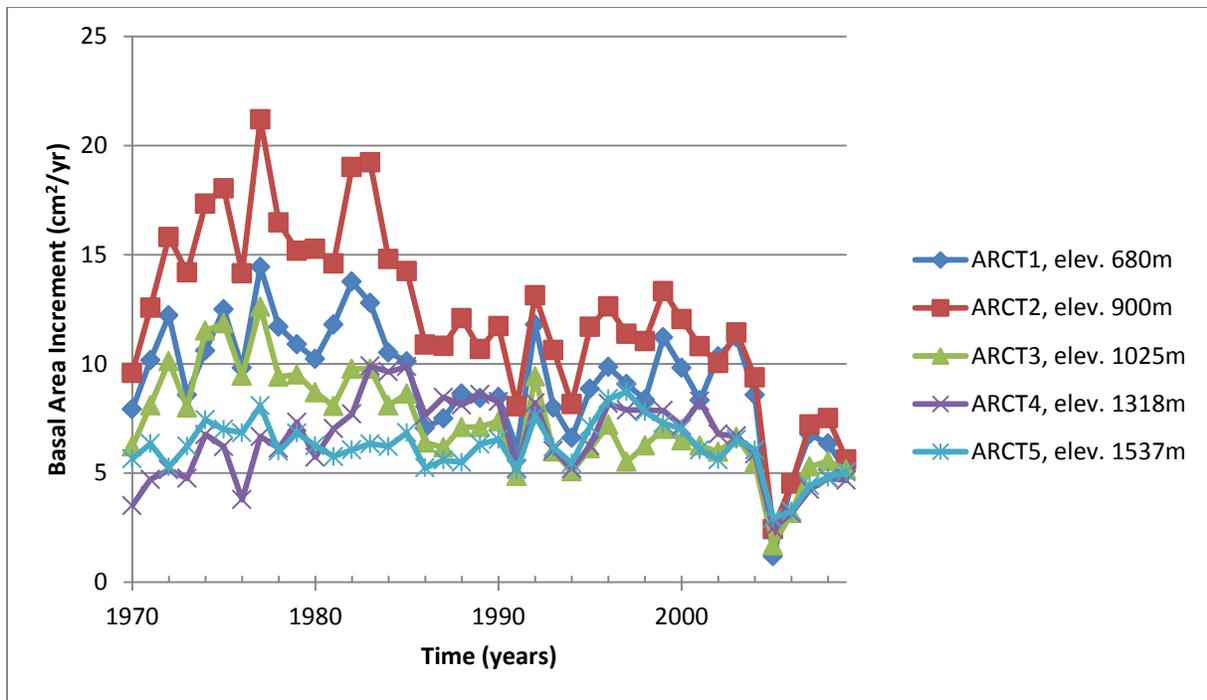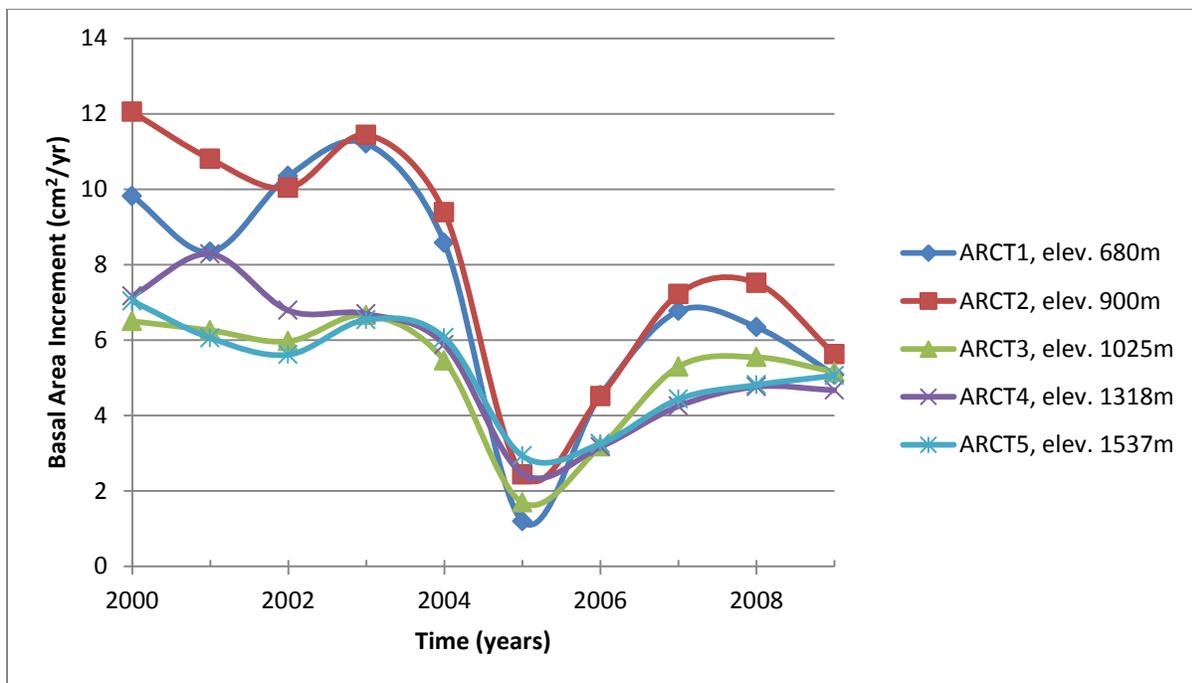

Figure 5b. A comparison among all five sites, with elevations ranging from 680-1537 meters above sea level, of basal tree ring growth over the time period from 2000-2009. It is apparent that trees at all sites underwent a drastic decrease in BAI growth from 2005-2006.

Chapter 4

Discussion

I hypothesized that the Scots pine populations at the higher elevations would have higher growth rates, based on the fact that Scots pine populations in Spain are already at their southern stress (rear edge) limit. Therefore, it was predicted that the tree populations at the higher elevations would grow better, since the elevation increase would be correlated with cooler temperatures and more precipitation, whereas the tree populations at the lower end of the elevation gradient would have to tolerate more frequent stress events, like high temperatures and droughts. The actual outcome was not as predicted. It is actually the populations at the lower elevations (of 680 meters above sea level and 900 meters above sea level) that have higher growth rates. Site ARCT2 (900 meters asl), especially, has been allocating more radial biomass over time than any other site (Figures 4 and 5a).

These results indicate that lower elevations in the Spanish Pyrenees are actually more conducive to the growth of Scots pine trees, and that the trees are not as stressed as was previously thought at this limit – Scots pine can clearly grow at these lower elevations and lower latitudes with high success, suggesting that this slope is not at the dry limit of the species. Additionally, the results imply that complex topographical features and climate can create quite suitable and habitable microclimates for Scots pine – even for "rear edge" populations.

As mentioned in the introduction, drought-induced forest decline has been an effect of an intense summer drought in Arcalís during the year 2005 (Galiano et al., 2010). This drought was extremely severe; every site at every elevation was impacted. The effect that it had on tree growth/basal area increment measurements was drastic, as every site had a sharp and dramatic decrease in the basal area increment measurement for 2005-2006 (Figure 5b). Sites ARCT1 and

ARCT2 underwent around an 88.9% decrease in growth from the previous year, and sites ARCT3, ARCT4, and ARCT5 underwent about a 60.0% decrease in growth from the previous year. Site ARCT1 was the most severely impacted by the drought in 2005, while site ARCT5 was actually the least severely impacted by the drought (Figure 5b). Basal area increment showed a negative trend at all sites, but the negative trend was only statistically significant for sites ARCT1, ARCT2, and ARCT3 at the 95% confidence level. These three sites have had steadily decreasing basal area increment growth since 1970.

These trends are likely due to climatic changes that are occurring and have been occurring in the Mediterranean region in the past few decades. Climate data indicate that the Mediterranean region has been warming and drying since the period of industrialization, and this is predicted to continue into the future (IPCC, 2007). The Arcalís study site is located at the "rear edge," or southern limit, of the distribution of the Scots pine species. While from 1970-1985 Scots pine trees at the lower three elevation transects were allocating more stem biomass than their counterparts at the higher two elevation transects, from 1985-present the trees at the lower three sites have been steadily decreasing in basal area increment measurements. This indicates that, historically, the lower three elevations were quite favorable to the growth of Scots pine trees. However, as the region has gotten warmer and drier, the trees at these sites have been growing more slowly, while the trees at the higher elevations have been less affected (i.e. there is no significant declining growth trend). In the future, it is clear that with the increasing likelihood of droughts, the Scots pine trees at the lower sites will be increasingly stressed (carbon and hydraulic stress) (Anderegg et al., 2012). The trees at ARCT4 and ARCT5 will be less negatively affected, and perhaps will even have increasing basal area increment measurements as the region warms.

Another stressor will also likely negatively affect growth rates of Scots pines trees at lower elevations as the climate changes: other studies have indicated that pests and pathogens that negatively affect plant species will increase in prevalence as the temperatures get hotter and precipitation decreases (Zeppel et al., 2011). This increase could lead to more incidents of tree mortality, especially for trees in forests that are already experiencing drought-induced stress.

It is important to note the limitations of this study. First, despite controlling for age as much as possible, there were still some differences in stand ages of the Scots pine populations that were sampled. Additionally, stand density (how many trees were growing per unit area) was not controlled for, so it is possible that competition among trees could have been a confounding factor. I also did not control for soil type, so different soils could have created more/less favorable growing conditions for the different Scots pine stands at the different transects.

Chapter 5

Conclusion

Contrary to what was predicted, the Scots pine populations located at the sites of lower elevations actually had greater basal area increment growth from one year to the next. This illustrates that the Scots pine trees at lower elevations are actually currently located in a more suitable climatic zone, or at least in more favorable microclimates, than those at higher elevations, despite likely receiving less precipitation and enduring higher temperatures.

With climate models predicting that the Mediterranean region will continue to have increased average temperatures and decreased precipitation, it is likely that severe droughts and heat spells will occur in Spain in the future. The data collected for this research paper demonstrate what kind of response in tree growth we can expect from Scots pine populations in the Spanish Pyrenees. The intense summer drought in 2005 negatively affected the growth of each of the Scots pine populations, as there was a sharp decrease in radial biomass allocation for Scots pine trees at every site in the 2005-2006 year. This may indicate that, in the future (with higher temperatures and less precipitation predicted for the Mediterranean region), the ideal growth zone for Scots pine will shift upwards in the Pyrenees, along an elevation gradient, so that the higher sites will be more favorable to the Scots pine species. This is supported by the statistically significant declining growth trends seen at the three lower sites, which indicate that the climate at these sites is already moving toward a higher-stress situation for Scots pine trees.

The reason for this potential future shift in the ideal range for Scots pine trees is the environmental lapse rate, which causes temperature changes with altitude. In dry regions, like the Mediterranean, the adiabatic lapse rate is a decrease in temperature of about ten degrees Celsius

per 1000 meters increase in elevation. Therefore, along the elevation gradient between our sites in the Spanish Pyrenees, there was a change in temperate of about seven degrees Celsius between the lowermost and uppermost sites (with the uppermost sites being seven degrees cooler) (Vila-Cabrera et al., 2012a). This signals that, over time, we may expect the lower populations of Scots pine to be less successful, and the Scots pine populations will likely shift up the mountain in the future as the drought tolerance for the lower limit becomes too extreme.

Further studies will need to research the dynamics of rear edge populations of indicator species like Scots pine, especially in light of the future climate predictions. Since the Mediterranean regions is a "hotspot" for increased warming, decreased precipitation, and biodiversity loss, it is especially necessary to study the ecosystem dynamics in this region. Additionally, while the Arcalís sites have remained largely unmanaged, many other sites in Spain do have a history of intense management, and while Vila-Cabrera and others have undertaken a comparative study of unmanaged and managed populations of Scots pine in Spain, there is still ample room for further study in this area in order to better understand the implications of historical management practices and how to best manage Scots pine (and other) forests in the future.

References:

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J.H., Allard, G., Running, S.W., Semerci, A., Cobb, N., 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manage. 259, 660–684.

Anderegg, W.R.L., J. A. Berry, D.D. Smith, J.S. Sperry, L.D.L. Anderegg, and C.B. Field, 2012. The role of hydraulic and carbon stress in a widespread climate-induced forest die-off. *Proceedings of the National Academy of Sciences.* 109: 233-237.

Carlisle, A., & Brown, A. H. F., 1968. Pinus sylvestris L. *Journal of Ecology, 56*(1), 269-307.

Castro, J., Zamora, R., Hódar, J. A., & Gómez, J. M., 2004. Seedling establishment of a boreal tree species (pinus sylvestris) at its southernmost distribution limit: Consequences of being in a marginal mediterranean habitat. *Journal of Ecology, 92*(2), 266-277. doi: 10.1111/j.0022-0477.2004.00870.x

Galiano L, Martı´nez-Vilalta J, Lloret F., 2010. Drought induced multi-factor decline of Scots pine in the Pyrenees and potential vegetation change by the expansion of co-occurring oak species. Ecosystems 7:978–91.

Galiano, L., Martínez-Vilalta, J., Lloret, F., 2011. Carbon reserves and canopy defoliation determine the recovery of Scots pine 4yr after a drought episode. New Phytol. 190, 750-759.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. Global Planet. Change 63, 90–104.

Hampe, A., & Petit, R. J., 2005. Conserving biodiversity under climate change: The rear edge matters. *Ecology Letters, 8*(5), 461-467. doi: 10.1111/j.1461-0248.2005.00739.x

IPCC, 2007. Climate Change, 2007. The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge.

Kaye, Margot W., Dan Binkley, and Thomas J. Stohlgren, 2005. "Effects of Conifers and Elk Browsing on Quaking Aspen Forests in the Central Rocky Mountains, USA." *Ecological Applications* 15.4: 1284-295. Web.

Lebourgeois, F., 2007. Climatic signal in annual growth variation of silver fir (Abies alba Mill.) and spruce (Picea abies Karst.) from the French Permanent Plot Network (RENECOFOR). Ann. For. Sci. 64, 333–343.

Matías, L., Gomez-Aparicio, L., Zamora, R., & Castro, J., 2011. Effects of resource availability on plant recruitment at the community level in a mediterranean mountain ecosystem. *Perspectives in Plant Ecology, Evolution and Systematics, 13*(4), 277. doi: 10.1016/j.ppees.2011.04.005

Matías, L., & Jump, A. S., 2012. Interactions between growth, demography and biotic interactions in determining species range limits in a warming world: The case of pinus sylvestris. *Forest Ecology and Management, 282*, 10-22. doi: 10.1016/j.foreco.2012.06.053

McDowell, N., Pockman, W.T., Allen, C.D., Breshears, D.D., Cobb, N., Kolb, T., Plaut, J., Sperry, J., West, A., Williams, D.G., Yepez, E.A., 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytol. 178, 719–739.

NOAA. "COFECHA Output." N.p., n.d. Web. 27 Mar. 2013. <http://www.ncdc.noaa.gov/paleo/treering/cofecha/cofecha.html>.

Retana, J., Espelta, J.M., Habrouk, A., Ordóñez, J.L., Solà-Morales, F., 2002. Regeneration patterns of three Mediterranean pines and forest changes after a large wildfire in NE Spain. Ecoscience 9, 89–97.

Stokes, Marvin A., and Terah L. Smiley. *An Introduction to Tree-Ring Dating*. Chicago: University of Chicago, 1968. Print.

Vilà-Cabrera, A., Martinez-Vilalta, J., Galiano, L., & Retana, J., 2012a. Patterns of forest decline and regeneration across scots pine populations. *Ecosystems* 16.2: 323-335.

Vilà-Cabrera, A., Rodrigo, A., Martínez-Vilalta, J., Retana, J., 2012b. Lack of regeneration and climatic vulnerability to fire of Scots pine may induce vegetation shifts at the southern edge of its distribution. J. Biogeogr. 39, 488–496.

Zeppel, M., Adams, H.D., and W.R.L. Anderegg, 2011. Mechanistic causes of tree drought mortality: recent results, unresolved questions and future research needs. *New Phytologist*. 192: 800-803.

ACADEMIC VITA

Dana James

dmj5128@psu.edu

_____

Education

B.S., Environmental Resource Management, 2013, The Pennsylvania State University, University Park, PA

B.S., Community, Environment, and Development, 2013, The Pennsylvania State University, University Park, PA

Honors and Awards

- Gamma Sigma Delta Honor Society of Agriculture   **2010-2012**
- World Food Prize Symposium Student Scholarship from Penn State   **2012**

Professional Experience

Research Experience:

Marcellus Shale/Community Development Research   Fall 2012
- Using the qualitative data program NVivo to categorize different attitudes toward and perceptions of Marcellus Shale development on communities based on recent newspaper articles and interviews
    - Evaluating articles based on perceptions of economic development, health risks, environmental effects, policy implications, etc.

Dendrochronology Research   Fall 2012
- Analyzing tree cores collected at five different elevations in the Pyrenees of Spain to assess the effects of elevation on a tree's growth rate and its ability to allocate resources

Global Change Ecology Research   Summer 2012
- Studied the effects of global change (i.e. climate change, land use change, etc.) on plants and soils in Spain through an NSF grant

Work Experience

Teaching Assistant at Penn State   Spring 2012
- Helped students in Environmental and Resource Economics with assignments, test preparation, and general questions

Poverty Resolutions International Development Intern   Fall 2011
- Advanced the educational programs in the US about dollar-a-day poverty:
  - Collaborated with other interns to plan events and establish outreach
  - Edited scholastic presentations and created introductory documents

Northumberland County Conservation District Intern   Summer 2010
- Installed fish habitat structures and stream restoration projects
- Participated in bacteria testing, water sampling, and soil sampling
- Created and edited abandoned (acid) mine drainage records; produced associated GIS work

Editorial Experience

- Editor of the CED Undergraduate Research Journal   2011-2012

Research Interests

I have broad interests in social and environmental justice, particularly in an international development context. Specifically, I am interested in the role that food security/sovereignty, natural resource conservation, and local places have in relation to achieving justice.

Publications and Papers

James, Dana. (2011). "A Book Review of A Sand County Almanac and Sketches Here and There." Available from   <http://agsci.psu.edu/ced-urj/2011>

James, Dana. (2012). "Belief Persistence as it Relates to Climate Change." Available from <http://agsci.psu.edu/ced-urj/ced-urj-2012>