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Natalie A. Rogers, Editor

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Editor's Note

The *New Mexico Journal of Science* is a publication of the New Mexico Academy of Science. Each issue of the *Journal*, which has been published since 1906, contains research papers and articles deemed of interest to the scientists, educators, and citizens of New Mexico. Some volumes address scientific topics of social or economic interest to the state, while others emphasize scientific research in areas where New Mexico is particularly active.

The Academy oversees a New Mexico Junior Academy of Science program that sponsors an annual statewide scientific paper competition for students in New Mexico's high schools. This volume of the *Journal* contains a selection of research papers from that competition.

The New Mexico Academy of Science Research Symposium was held in Albuquerque, New Mexico on November 5, 2016. Oral and poster presentations at the Symposium described scientific research being conducted by undergraduate students, graduate students, and faculty at New Mexico's colleges and universities, and the abstracts of those presentations are once again included in this year's *Journal*. The New Mexico Academy of Science also presented its annual Outstanding Science Teacher Awards at the meeting. We wish to acknowledge the organizations which co-sponsored the 2016 Research Symposium: the New Mexico Experimental Program to Stimulate Competitive Research (NM EPSCoR), and the University of New Mexico's Center for Water and the Environment.

The *New Mexico Journal of Science* is published in an electronic-only format; it can be freely downloaded from the Academy's website at <http://www.nmas.org>. This enables the Academy to reach a much wider readership without incurring the considerable costs associated with the printing and distribution of paper copies.

Natalie A. Rogers, Editor
New Mexico Journal of Science

Public Relations Specialist
New Mexico EPSCoR
University of New Mexico
nrogers@epscor.unm.edu

New Mexico Junior Academy of Science Paper Submissions

Rusty Ludwigsen

Passive Reduction of Involuntary Arm/Hand Tremors: Phase III

Karishma Patel

Oil and Bacteria: Slip Sliding Away

Lillian Petersen

Detecting Climate Change through Means and Extremes

Alex Silverhart

Effect Of Natural Antibiotics on the Antibiotic Resistance of E. coli k12

Passive Reduction of Involuntary Arm/Hand Tremors: Phase III

Rusty Ludwigsen, Early College Academy

In the U.S., millions suffer from life-impairing involuntary shaking of muscles called tremors. Tremors are caused by a variety of diseases, injuries and conditions, including traumatic brain injuries, Parkinson's disease, multiple sclerosis, and medications. Tremors cause difficulty with fine motor control. The objective of this research was to use data gained from the Electromyograph sensors (EMGs) and accelerometers placed on the arm to reveal a direct relationship among a motion damping brace, tremor magnitude, tremor frequencies and muscle activity. The brace, worn between the wrist and elbow, is lined with viscoelastic foam, and constructed with a lightweight ridged plastic outer shell that rests on a writing surface. To test its effectiveness, human volunteers performed fine motor control tasks with and without the brace. Testing was conducted at the UNM Department of Physical Therapy Motion Analysis Lab. The tasks revealed how much the tremor was reduced both numerically, by analyzing the data collected from surface EMGs and accelerometers, and visually, through inspection of the test results. Results showed that the brace is effective at reducing the severity of a tremor and improving fine motor control of six out of the eight subjects. This warrants further research into hand stabilizing equipment.

INTRODUCTION

In the United States, millions of people suffer from life-impairing involuntary muscular movements that result in shaking of extremities, called tremors (Pressman 2014). Disorders or conditions that can produce tremors include Parkinson's disease, multiple sclerosis, stroke, traumatic brain injury, medications, and neurodegenerative diseases (Tremor Fact Sheet 2014). One of the many problems tremors cause is difficulty with fine motor control. During a scientific meeting, the author witnessed two men with obvious tremors in their hands and arms resulting in significant changes to handwriting legibility. This research project has two previous years of testing. The first year tested whether a motion damping brace could reduce the tremor on a shaking, wooden arm. Results found that the brace

reduced the tremor by about 90% (Ludwigsen, 2014). The second year tested an improved brace design on human volunteers to confirm the effectiveness via qualitative data. The brace helped 16 out of the 19 subjects (Ludwigsen, 2015). This year's objective was to quantify the brace's effectiveness, determine tremor frequencies, analyze the effects the brace has on the arm including muscular activity, and postulate possible reasons for why the brace works. It was hypothesized that data gained from the Electromyograph (EMG) and accelerometers placed on the arm would reveal a direct relationship among the brace, tremor magnitude, tremor frequencies and muscle activity. For this year's research, a brace was printed on a 3D printer and tested on human subjects in the University of New Mexico Physical Therapy Motion Analysis Laboratory. Surface Electromyographs

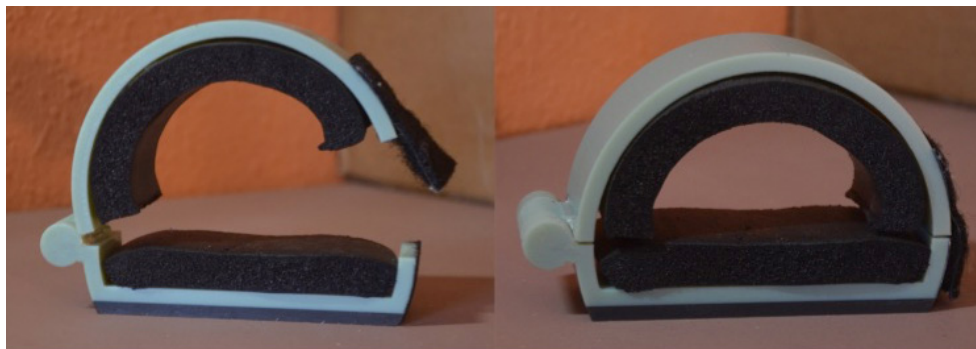


Figure 1. Sketch of the brace used in testing. The brace was constructed of a hard 0.5cm thick plastic outer shell, hinged on one side and clasped with Velcro on the other. It was lined with a 1.5cm thick layer of closed cell foam chosen for its high viscoelasticity and stiffness. The base of the brace was a 0.5 thick layer of rubber to grip the writing surface and help stabilize the arm.



Figure 2. Sketch of the brace and sensors (EMGs) being worn.

(EMGs) and accelerometers were placed on six locations of the arm to collect quantitative data about the brace's effectiveness.

METHODS

The simple brace design is shown in Figure 1. The idea behind the brace was that energy from the tremor would be absorbed by the foam while the brace was stabilized by the table. The brace was worn between the wrist and the elbow as shown in Figure 2. Eight test subjects were recruited that suffered from tremors due Parkinson disease, essential tremors, and familial tremors. All participants were actively experiencing tremors while testing. Several fine motor control writing/drawing tasks (Haubenberger et al., 2011) were developed that would show the reduction of the tremor by visual examination of the tests, and analysis of six sensor locations across the arm. These locations, shown in Figure 5, were the top of the hand, the extensor muscle of the hand, the flexor muscles of the hand, the bicep, the tricep, and the trapezius/shoulder muscle near the neck. The sensors were surface EMGs (Electromyographs, Figure 4) that measured the electrical impulses of the muscles and had a built-in three-axis accelerometer that recorded data in

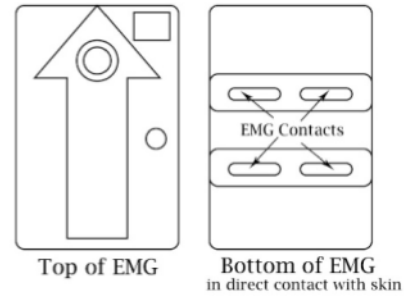


Figure 4. Front and back of the EMG sensor. The EMG are sensors that are 3.175cm X 1.905cm and are attached to the skin of the subject with medical grade 2-faced tape supplied by the EMG manufacturer.

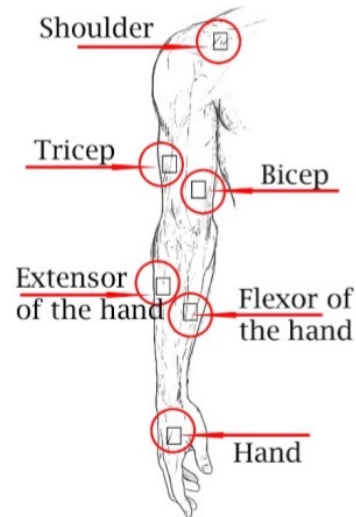


Figure 5. Placement locations of the EMG/accelerometers on the subject's arm.

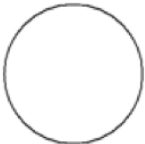




Shapes Used During Testing					
Smooth Shapes		Sharp Shapes		Handwriting Shapes	
					Hello

Figure 3. The pages used in the testing of the brace.

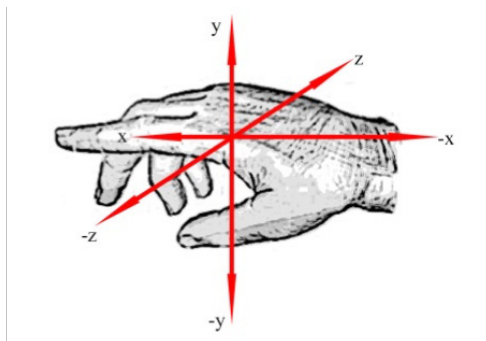


Figure 6. Hand sensor coordinate system

the X, Y, and Z axes. The three axes are shown in figure 6. The sample rate was 148 Hz. for the accelerometer and 1,924 Hz. for the EMGs. Each subject performed seven simple tasks with and without the brace. Four tasks were designed to mimic aspects of letter formation; sharp movements represented formation of letters such as “E” and smooth movements represented formation of letters such as “S”. The fifth task, drawing a spiral is commonly used in the medical field. The sixth task was writing the word “Hello” because it incorporates variety of the motions used in letter formation. The seventh task was holding the hand above the table.

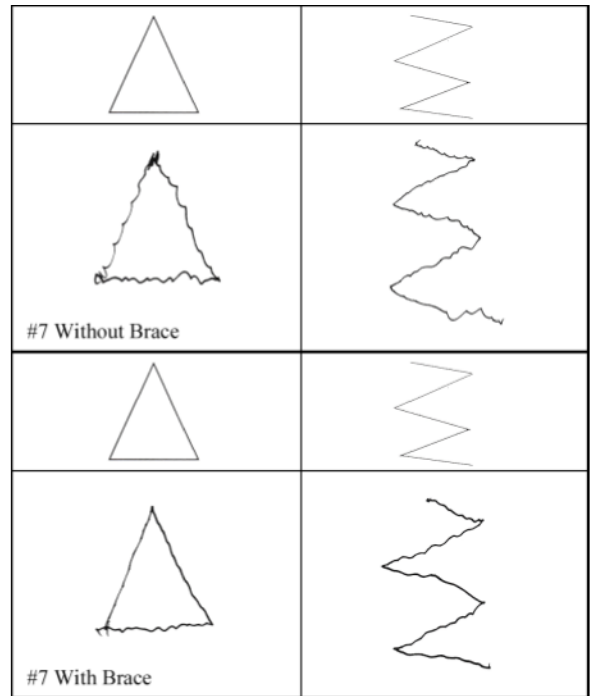


Figure 8. Subject number 7 results for sharp corner shape drawing with and without the brace.

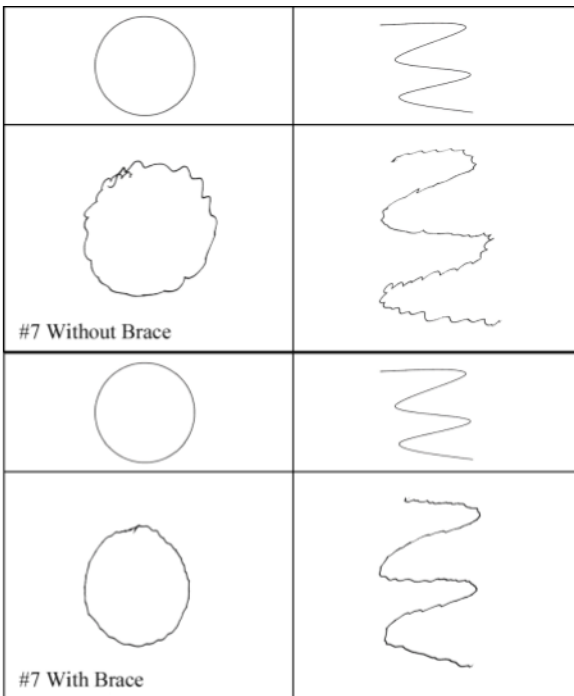


Figure 7. Subject number 7 results for smooth shape drawing with and without the brace.

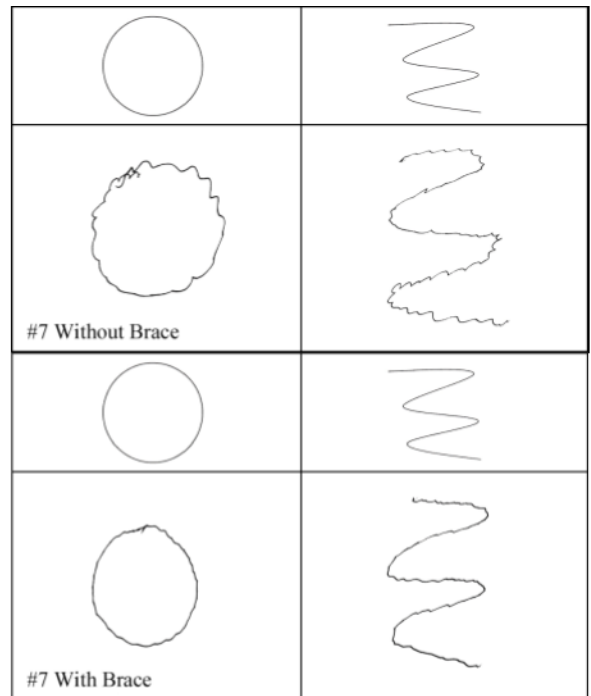


Figure 9. Subject number 7 results for drawing spiral and writing hello with and without the brace.

RESULTS

Based on subjects' statements, visual appearance of the test results and examination of the acceleration data, the brace helped six out of eight subjects. The data from subject number seven was the most dramatic, best illustrates the potential of the brace and is presented as the example in this paper. Figures 7 to 9 show the physical

tests of subject number seven. Figure 10 shows a graph of lateral acceleration of the hand vs time. There is a predominant frequency of about five to six Hz. without the brace. When wearing the brace this frequency is much less obvious. This graph also shows wearing the brace reduced the peak-to-peak acceleration of the hand by 40% to 70%.

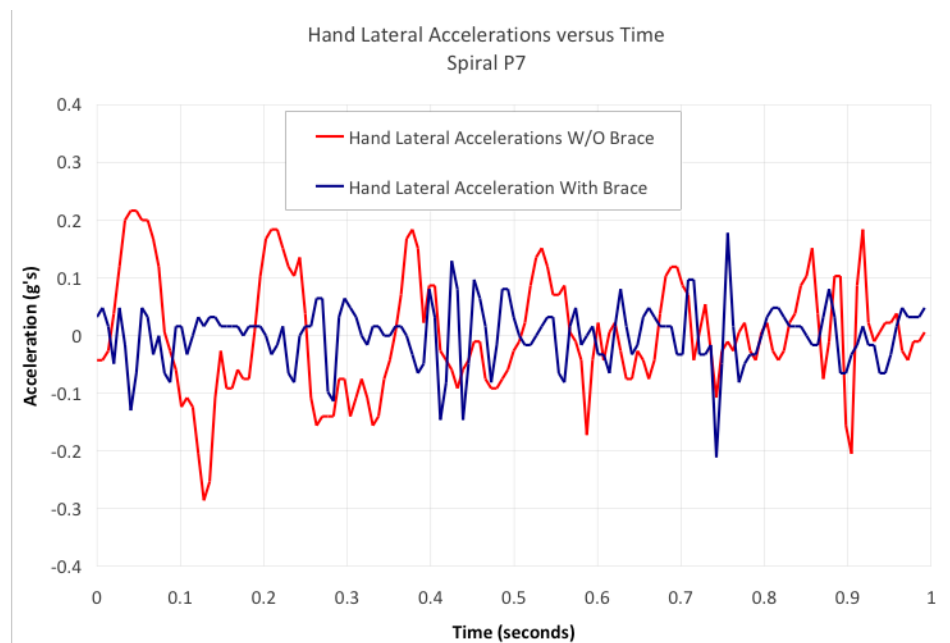


Figure 10. Lateral (Z) direction accelerations of the hand for subject number 7 while drawing a spiral.

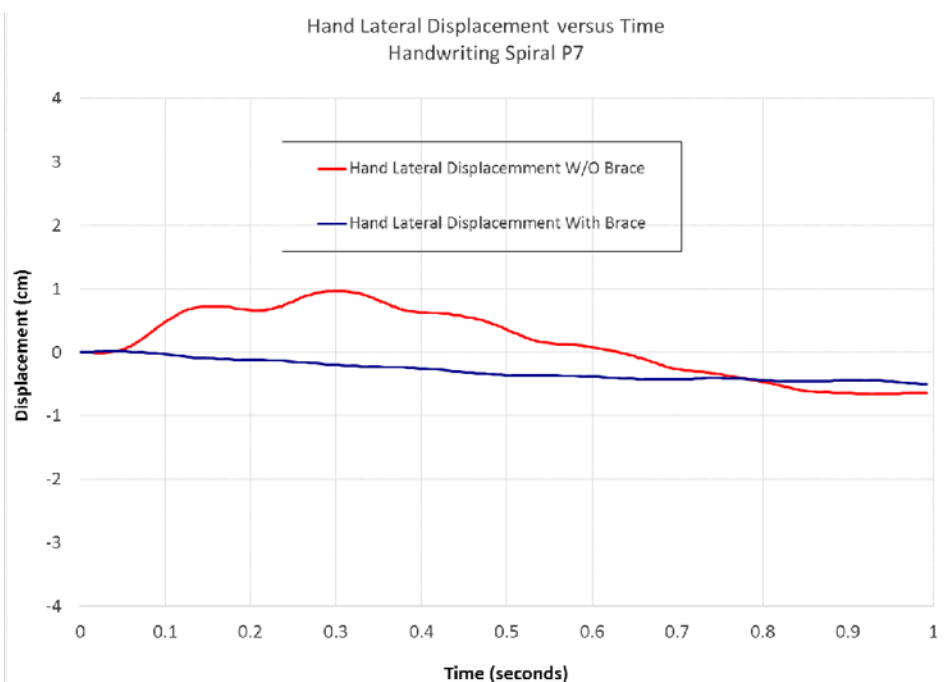


Figure 11. Lateral (Z) direction displacement of the hand for subject number 7 while drawing a spiral.

Figure 11 shows the displacement of the hand in the lateral direction vs time. Figure 12 shows the extent of the drawing represented by the graph. The frequency of the tremor is seen in the lateral displacements without the brace. The tremor movement was reduced by over 90%. The 1-second duration of the acceleration and displacement plots represents only a small portion of the approximate 12 seconds it took to draw the spiral. One second of drawing is shown in the red box in figure 12. Figure 13 is a graph of Frequency in Hz of the tremor vs amplitude in g's. This is a Fast Fourier Transform (FFT)

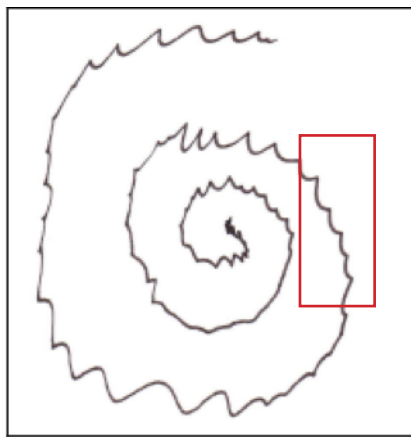


Figure 12. Spiral drawn by subject 7 showing approximately 1 second of drawing inside the red box.

of the acceleration data. A correlation is seen between the reduction of the predominant frequency in the FFT and the graph of accelerations. This graph validates the previous statement that the brace greatly reduced the predominant frequency. Figure 14 is a graph of the EMG of the bicep muscle. It shows that when wearing the brace the number of muscle fibers contracting was reduced while drawing the spiral. This is the only muscle where this reduction was observed for subject 7. A more dramatic reduction of bicep muscle activity for subject 7 is shown in Appendix B. A reduction of bicep muscle activity occurred in all six subjects that showed improvement in writing when the brace was worn. Figure 15 is a graph of the EMG of the tricep muscle. This graph shows when wearing the brace the overall effect to the muscle is inconclusive while drawing the spiral. This was the case for every muscle but the bicep and was consistent with the results from the six subjects that showed improvement in writing when the brace was worn.

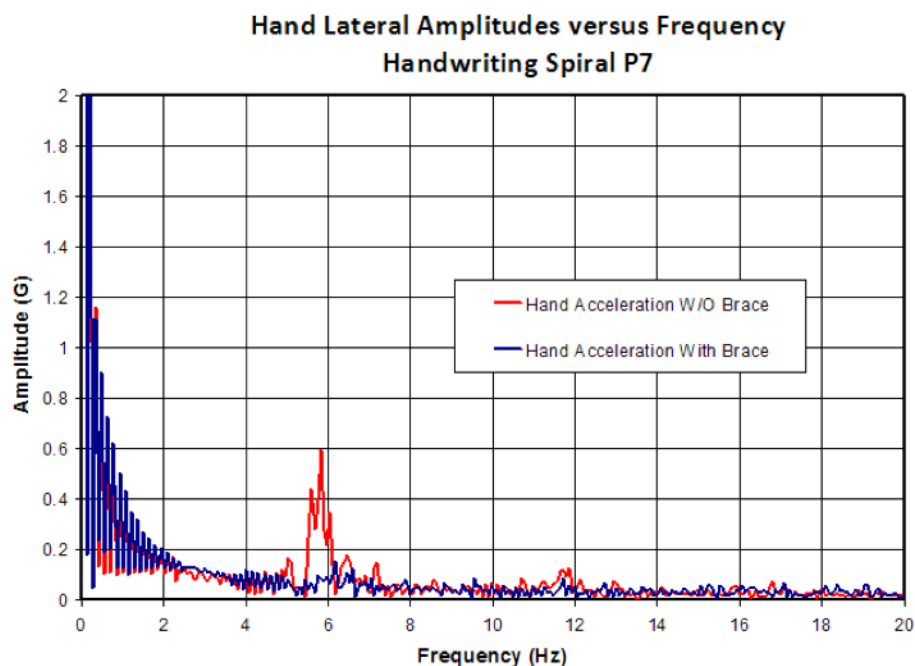


Figure 13. Fast Fourier Transform of the acceleration versus time data for subject 7 drawing the spiral.

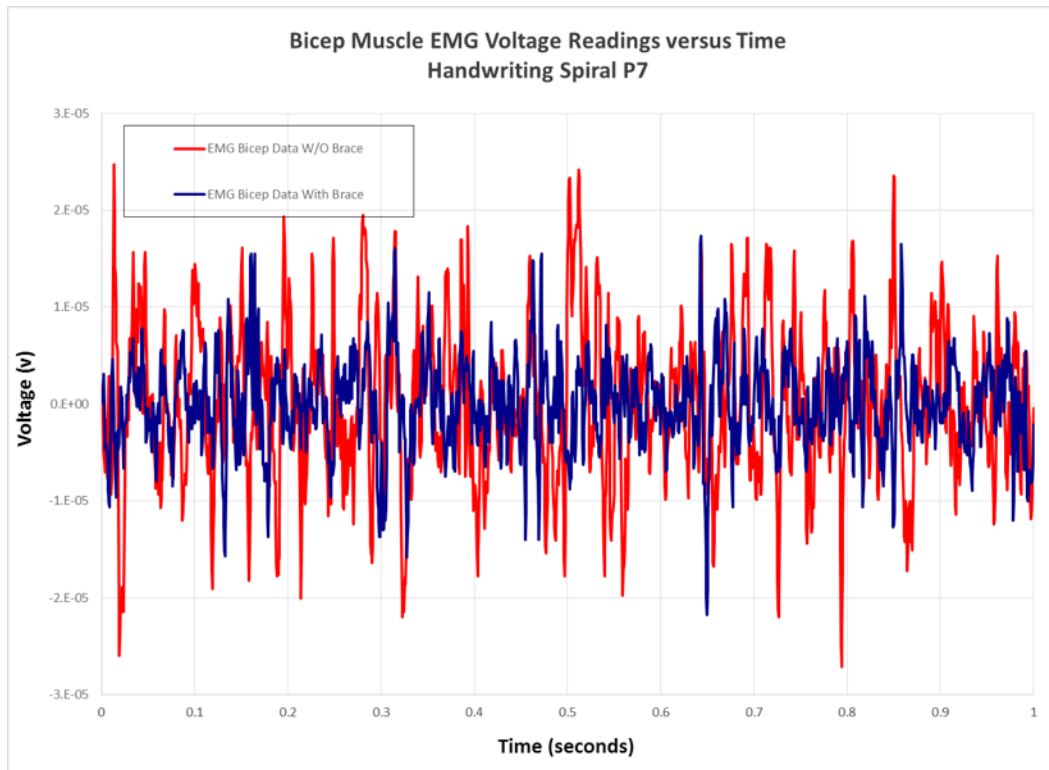


Figure 14. EMG voltage output of the bicep muscle.

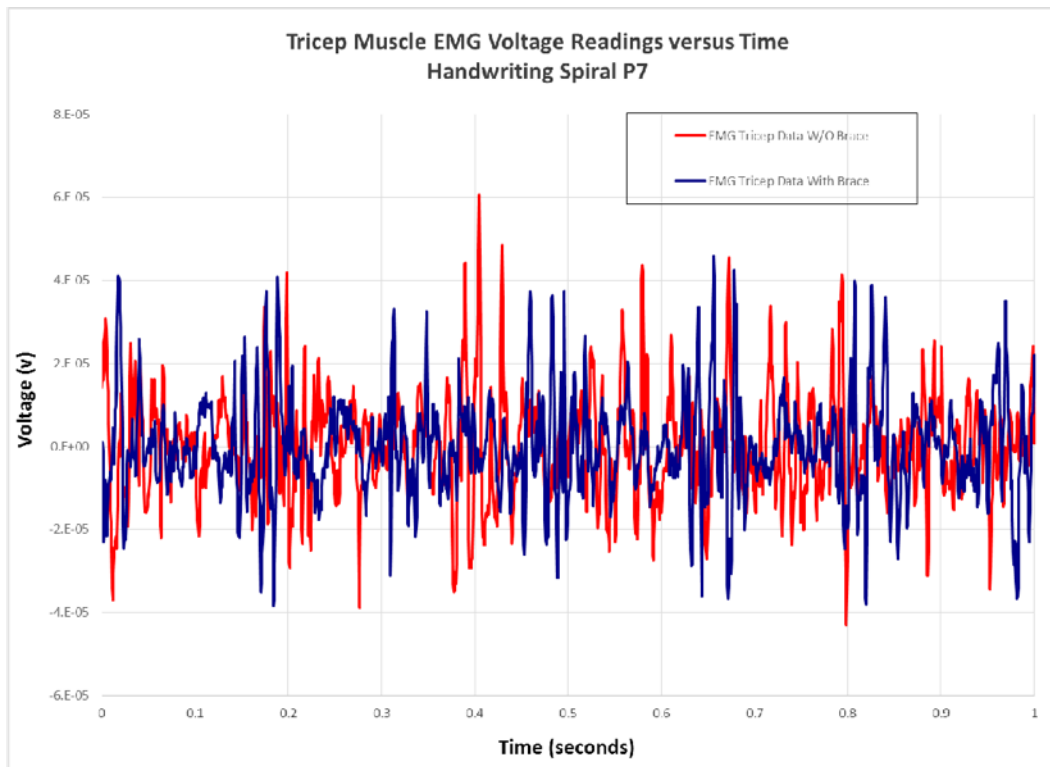


Figure 15. EMG voltage output of the tricep muscle.

DISCUSSION

The brace was beneficial for 6 out of 8 test subjects. The initial hypothesis was supported as there was a correlation seen between the brace, tremor reduction, and muscular activity. For subject seven the visual appearances of the test results show significant improvement, corroborated by the reduction/damping of the accelerations, displacements, and frequencies. The lateral acceleration of the hand displayed both an overall reduction and near elimination of the primary frequency when wearing the brace. This was confirmed by the results from the FFTs that show that the frequencies between four and six Hz were reduced in amplitude by about 83% at the greatest peak. The bicep showed a reduction in voltage activity when wearing the brace. This means that less muscle fibers were contracting during the activity. The other muscles showed inconclusive changes when wearing the brace. This occurred with every subject that found improvement when wearing the brace. Although the hand showed the most significant reduction in accelerations and displacement there were reductions of movement in other areas of the body. These included the forearm, bicep and shoulder area. The brace, although primarily acting on the hand and wrist area, shows some systemic effects that are prevalent in the arm and shoulder.

The reason for the reduction in the voltage of the bicep is unknown. Through discussion with several physical therapists, it was hypothesized that the tremor affects the tricep causing the arm to move away from the body, extending the elbow. In order to write or to do any task your hand would need to return back to the point of origin. To achieve this, the subject would have to use their bicep to bring the arm back. Because the brace is holding the arm in one place there is no need to engage the muscle to bring the arm back to its starting point. This would account for the reduction of voltages and the remaining activity could be attributed to the activity of drawing a spiral.

The results from the FFTs show that the foam used in the brace damped out frequencies between four and seven Hz. Different foams could be chosen that would be better suited for different frequency tremors. This would allow the brace to be customized to a particular individual.

The results presented herein are based on the analysis of a relatively small percentage of the electronic data collected during this test series. Much more remains to be analyzed. Also, the eight test subjects are a small sample space

representing the millions of tremor sufferers. Thus, while these results are only suggestive of the potential benefits of using the brace, they strongly support the conclusion that further research is warranted into a simple motion damping brace to help people with tremors regain the ability to perform fine motor activities such as writing. Further research should include a larger clinical trial, a harder look at tremor frequencies and investigation into different foam types.

ACKNOWLEDGEMENTS

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AUTHOR INFORMATION

Rusty Ludwigsen
Early College Academy
807 Mountain Rd NE
Albuquerque, NM 87102
rustyludwigsen@gmail.com

APPENDIX A

Appendix A shows the spiral and hello tests for all subjects. The top spiral and hello are without the brace and the bottom spiral and hello are with the brace in each figure.

	#1	#2	#3
	Hello		Hello
	Hello		Hello
	Hello		Hello
	Coded Identifier: #1	Coded Identifier: #2	Coded Identifier: #3

	#4	#7	#5
	Hello		Hello
	Hello		Hello
	Hello		Hello
	Coded Identifier: #4	Coded Identifier: #7	Coded Identifier: #5

	#6	#8	
	Hello		Hello
	Hello		Hello
	Hello		Hello
	Coded Identifier: #6	Coded Identifier: #8	

APPENDIX B

The EMG muscle voltage for subject number 7 shows how the tricep muscle remains active with or without the brace when hovering the hand over the table as shown in figure B1. However the tricep muscle from the same tests shows a significant reduction in muscle activity with the brace being worn as shown in figure B2.

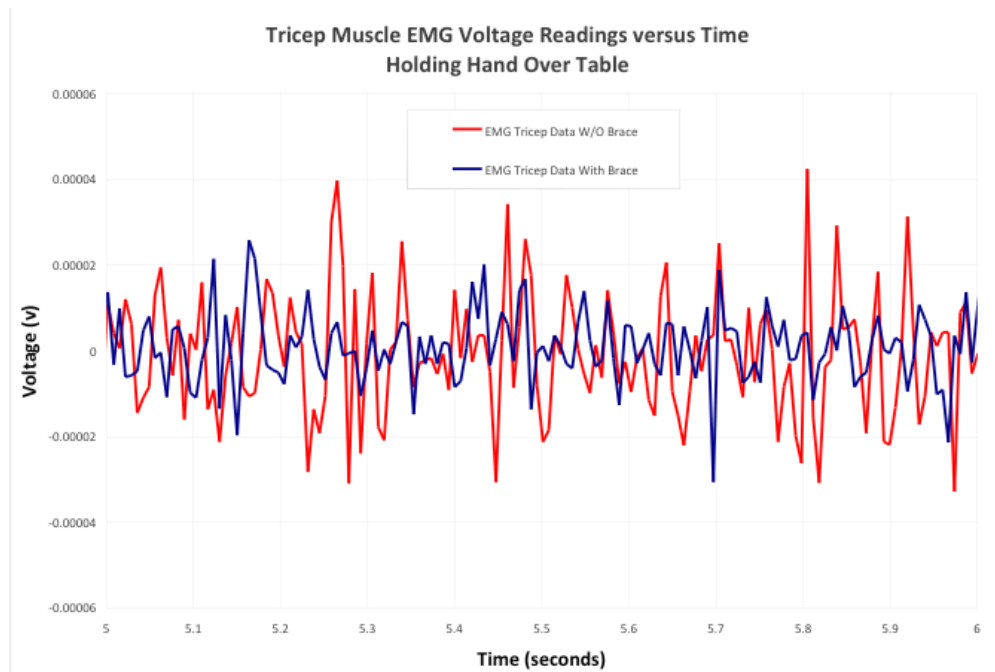


Figure B1. Tricep EMG voltage reading for subject 7 while holding hand over table.

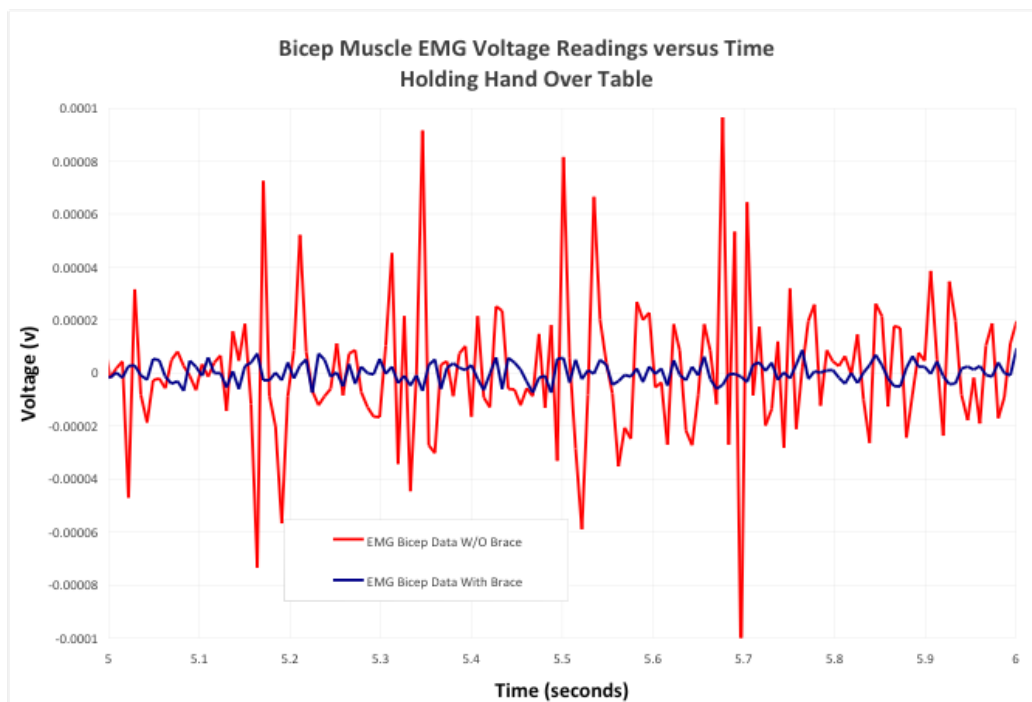


Figure B2. Bicep EMG voltage reading for subject 7 while holding hand over table.

Oil and Bacteria: Slip Sliding Away

Karishma Patel, Grants High School

Antibiotic resistance has become a critical health issue with increased use of antibiotics. Methicillin Resistant *Staphylococcus aureus* is an example of a disease causing microbe that is common in many hospitals and prisons. The purpose of this project is to determine if essential oils (Tea Tree, Sage, Rosemary, and Basil) will inhibit or reduce the growth of antibiotic resistant bacteria. It is believed the hydrophobic oils will penetrate the cell walls of the bacteria disrupting normal growth and function. Plates were made using various bacteria, *Streptococcus salivarius*, *Streptococcus mutans*, *Staphylococcus epidermidis*, *Serratia marcescens*, and *E. coli*. Nutrient agar was used as the growth medium and selected antibiotics such as Tetracycline and Erythromycin. The inhibition zones of the bacteria from the antibiotics and essential oils were compared. Thin Layer Chromatography was used to separate and isolate fractions in the oils, and isolated to identify which might have antimicrobial properties. Silica gel powder with the fractions were collected, extracted with ethyl alcohol, then plated with the bacteria to check for inhibition. Over time the zones of inhibition of Tetracycline decreased from 20 mm-18 mm, indicating bacteria were becoming tolerant. Basil zones of inhibition increased from 16 mm - 20 mm and more effectively reduced the growth of the bacteria than Tetracycline, the most effective antibiotic. The TLC plates revealed that some of the fractions isolated from the oils demonstrated antimicrobial properties. However, high concentrations of each component will be needed to show more significant results. The synergistic effect of the oils and antibiotics were potent against the bacteria, drastically slowing their ability to reproduce.

INTRODUCTION

The accidental discovery made by Alexander Fleming in 1928 has drastically changed medical care forever. One day in his laboratory Fleming noticed the presence of little green mold spores that had prevented the growth of the disease causing bacteria he was working with. After doing research he had identified the first chemical compound with antibiotic properties; penicillin. In 1940 the first antibiotic was used, dramatically reducing illness and death caused by infections. Antibiotics were first known as natural compounds produced by a fungus or microorganism that could kill pathogenic bacteria. Some common types of antibiotics are amoxicillin, doxycycline, penicillin, methicillin, tetracycline, erythromycin, clindamycin, and many more. These antibiotics are very complex and are classified by specific mechanisms of action: interference with cell wall biosynthesis (beta-lactams and glycopeptides), inhibition of bacterial synthesis (macrolides and tetracyclines), interference with nucleic acid synthesis (fluroquinolones and rifampin), inhibition of metabolic pathway (trimethoprim-sulfamethoxazole), disruption of bacterial membrane structure, and disruption of protein synthesis (Streptomycin). (Moore 2015).

Over the years, the use of antibiotics has saved millions of lives, but have we become far too dependent upon

these drugs? Yes, we are becoming more dependent on antibiotics and evidence now shows more and more bacteria are becoming resistant. Bacteria become resistant when antibiotics kill the sensitive bacteria, but resistant germs are left behind; these germs then begin to grow and multiply in the host producing microbes that are more resistant to the selected antibiotic. The improper use of the drug: when patients are given antibiotics they are told to finish the complete dose. How many people actually listen? Many do not, when they begin to feel better they stop taking the medication. By doing this the bacteria are able to survive because they were not completely eradicated by the antibiotics. The last cause of resistance is the widespread use of the drug including the use of antibiotics in animal feeds and developments; in some cases, a person may be sick so they are given antibiotics. However, they may have a viral infection which antibiotics do not treat. Therefore, by having more constant exposure to antibiotics in your body the harmful bacteria survive; if they are resistant and pass this trait to their offspring each generation often producing multidrug resistant strains. Bacteria protects itself by altering target sites such as 30s ribosome, which is an inhibition site for antibiotics. Other bacteria alter their membranes to prevent the antibiotic from penetrating through the membrane (Univ. of Maryland, 2000).

When bacteria are constantly exposed to antibiotics they begin to change their chemical makeup which reduces and eventually eliminates the effectiveness of the drug/chemical to prevent infections and disease. Some bacteria are very complex and can resist the antibiotic by neutralizing the antibiotic before it can cause harm to the cell, others can rapidly pump the drug out of the system, and lastly bacteria can change the attack site of the antibiotic so that it does not affect the bacteria. Resistance is also caused by genetic mutation of the bacteria when DNA codes that carry resistant properties are easily transferable and only require one piece of DNA to change. Bacteria also have the ability to decrease the amount of channels in their membrane for antibiotics to diffuse through. Finally, some bacteria have the ability to create an enzyme called beta-lactamase that digests penicillin. (Bush, 2009)

As more bacteria become resistant a replacement for the antibiotics that treat these bacteria is needed, which leads to the purpose of the project; Can Essential Oils reduce or inhibit the growth of antibiotic resistant bacteria? The null hypothesis is there will be no difference in the growth of the bacteria exposed to antibiotics and essential oils. It is believed that the oils will be able to reduce or inhibit the growth because oils are hydrophobic or water repelling which enables them to partition the lipids of the bacterial cell membrane and mitochondria disturbing the cell structures, thus, making them more permeable (Jayakumar, 2006). As the cell wall becomes more permeable the cell begins to leak, extensive leakage can lead to the loss of critical molecules and ions resulting in death. Many oils contain polyphenols that have strong bonds to different molecular structures such as proteins or glycoproteins, due to their high lipophilicity, or the ability to dissolve fats, can permeate through the cell walls also leading to leakage. The independent variable is the oils that will be used in this experiment, which are Sage, Rosemary, Basil, and Tea Tree.

Sage oil (*Salvia officinalis*) found in southern Europe, is commonly used for digestive problems, fungal infections and skin problems. It contains 1,8-cineole, α -thujone and camphor which are present in antimicrobials, and may have an effect when dealing with antibiotic resistant bacteria. Rosemary oil (*Rosemarinus officinalis*) found in the Mediterranean is commonly used to improve

memory, relieve pain, and support the circulatory and nervous system. Rosemary oil can affect the cell wall, distorting the cells shape causing cytoplasm leakage. Basil oil (*Ocimum basilicum*) found in Europe, Central Asia, India, and Southern Asia, is commonly used to improve blood circulation, pain relief, vomiting/ nausea, and infections. Tea tree oil (*Melaleuca oil*) is taken from the leaves of the *Melaleuca alternifolia*, which is native to Southeast Queensland and the Northeast coast of New South Wales, Australia. Tea tree oil acts to increase membrane permeability, leading to the loss of chemiosmotic control, (the ability of ions to move across the selectively permeable membrane down the electrochemical gradient to generate ATP) in gram negative and gram positive bacteria (Yep 2014). These oils will be tested against a mix of gram negative and gram positive bacteria that are all resistant to an antibiotic.

The gram negative bacteria being tested are *E. coli* (resistant to fluoroquinolones) and *Serratia marcescens* (resistant to ampicillin, tetracycline and cephalotin). The gram positive bacteria being tested are *Staphylococcus epidermidis* (resistant to penicillin, rifamycin, fluoroquinolones, gentamicin, tetracycline, chloramphenicol, erythromycin, clindamycin, and sulfonamides), *Streptococcus salivarius* (resistant to ceftriaxone, and penicillin), *Streptococcus mutans* (bacitracin), and *Staphylococcus aureus*. *Staphylococcus aureus* is a major problem in hospitals and other areas where people are found in large numbers (prisons etc.). It causes approximately 100,000 cases of infection in hospitals per year and is known to be resistant to: methicillin. (CDC.gov, 2012)

To test the hypothesis, the bacteria will be plated on Mueller-Hinton agar (a microbiological growth medium used for antibiotic susceptibility testing) with antibiotics using the Kirby-Bauer Disk Diffusion Method to determine resistance. Next, the bacteria will be plated with essential oils soaked into sterile paper disks to determine growth effects on bacteria. Zones of inhibition, or the area around the antibiotic disk or oil where bacterial growth has seized, will be observed and recorded. The size of this zone demonstrates how effective the antibiotic or oil is at stopping the growth of the bacteria. From these results the bacteria will be serially diluted and placed into test tubes with growth medium and different concentrations of the oils to check growth using

the spectrophotometer. This process will be followed for gram negative and gram positive bacteria. Thin Layer Chromatography can also be used to separate, identify and collect different fractions or molecules separated from the oils to determine their impact on bacterial growth using a variety of organic solvents.

MATERIALS

- Rosemary Oil
- Sage Oil
- Tea Tree Oil
- Basil Oil
- TLC Silica Gel 60F Plates
- Nutrient/Tryptic
- Nutrient broth
- *Staphylococcus epidermidis*
- *Streptococcus salivarius*
- *Streptococcus mutans*
- *E. Coli*
- *Staphylococcus aureus* (only used in hospital)
- Penicillin
- Ampicillin
- Erythromycin
- Streptomycin
- Tetracyclin

METHODS

1. Plate bacteria on Nutrient Agar (*Staphylococcus epidermidis*, *Streptococcus salivarius*, *Streptococcus mutans*, *E. coli*, *Serratia marcescens*) with antibiotics using disk diffusion method to determine resistance.
2. Plate bacteria on Nutrient Agar with essential oils soaked into sterile paper disks to determine growth effect on bacteria.
3. Bacteria Solution Plates
 - a. Put five mL of Nutrient Broth into each of the 4 test tubes.
 - b. Put one loop of each bacterium into the tube and mix with vortex mixer.
 - c. Let bacteria grow in solution overnight.
 - d. Put one mL of bacteria solution on plate until the whole surface is covered. Pour off excess bacteria.
 - e. Repeat step d for the remaining bacteria
 - f. Plate antibiotics and sterile disk dipped in oils on bacteria.
 - g. Place in incubator for 24 hours, and record zones

of inhibition.

4. Chromatography
 - a. Draw a line 1.5 cm from the bottom of the plate creating the origin, and score a line three cm from the top to ensure compounds do not exceed that line.
 - b. Evenly space Tea Tree and Basil Oil on origin line.
 - c. Place one drop of the oil on the marked spot.
 - d. Let oil dry and repeat three more times.
 - e. Place plate in beaker filled with 50 ml of toluene for 55 minutes.
 - f. Remove plate. Trace solvent front.
 - g. Observe plate under UV light to identify fraction separations.
 - h. Spray plates with 5% sulfuric acid, and observe for additional compound separations.
 - i. Repeat steps a-h for the second plate containing Rosemary and Sage oil.
 - j. Repeat steps a-i using ethyl alcohol and acetic acid combination as the solvent.
5. Plates using Chromatography fractions
 - a. Scrape powder from fraction and place in tube.
 - b. Put a few drops of acetone into tube to isolate compounds from silica gel.
 - c. Repeat steps a-b for the remaining oils.
 - d. Divide plates into four sections and plate bacteria.
 - e. Dip sterile disk into fraction solution and place on plate.
 - f. Dip sterile disk into alcohol and place in center of plate for a control.
 - g. Repeat steps d-f for the remaining bacteria.
 - h. Let plates grow over night and check for areas of inhibition.
6. Test tube solutions
 - a. Put five ml of nutrient broth into each of the four tubes.
 - b. Put five drops of the oil into the first tube (master).
 - c. Perform serial dilution. Take 0.5 ml from the tube and place into the second tube. Take 0.5 ml from the second tube and place in the third tube and so on.
 - d. Check absorbance in spectrophotometer at 495 nm.
 - e. Check after one hour. Check at various increments.
7. Oils and antibiotic combination plates

- Plate bacteria.
- Place different antibiotics in each quadrant.
- Put 10 microliters of Basil on each disk using a micropipette.
- Repeat steps a-c for the remaining oils.
- Repeat steps a-d but reduce concentration of oil to 5 microliters.
- Repeat steps a-d but reduce concentration of oil to 2.5 microliters.

RESULTS & DISCUSSION

As discussed in the procedure, initially, plates were made by dipping sterile disks into the different oils (tea tree, basil, sage, and rosemary) and were plated on the different bacterial growth plates with (*Streptococcus mutans*, *Streptococcus salivarius*, *Serratia marcescens*, *Escherichia*

coli, *Staphylococcus epidermidis*). Discs of the antibiotics were also plated along with the different bacteria to compare areas of growth inhibition with the essential oils. The areas of inhibition represent the bacteria's sensitivity to the antibiotic or the drug, the greater the zone the greater the sensitivity. Results for Test 1 presented in Tables 1 and 2 show all the essential oils were able to inhibit the growth of the bacteria, Basil being the greatest having an average inhibition zone of 19 mm. Sage and Rosemary showed no zones against *S. marcescens*. The antibiotics in the first test all inhibited the growth of the bacteria, Tetracycline having the greatest average inhibition zone of 20 mm. Vancomycin, Penicillin, and Erythromycin showed no zones against *S. marcescens*. All the bacteria were resistant to Penicillin.

Table 1: Essential Oil Areas of Inhibition (mm)- 12/8/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tea Tree	11	12	11	15
Sage	10	14	11	0
Rosemary	11	11	12	0
Basil	15	17	16	17

Table 2: Antibiotics Areas of Inhibition (mm)- 12/8/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tetra	25	23	20	13
Vanco	16	18	15	0
Peni	0	0	0	0
Erythro	15	12	15	0

For Test 2 Penicillin was replaced with Ampicillin to see if its effects were similar to Penicillin. Results from Test 2 presented in Tables 3 and 4, show the essential oils have similar results to Test 1. Basil still had a high average zone of inhibition about 15 mm, along with Tea Tree that had an increase in the inhibition zone to about 14 mm.

The antibiotics also showed similar results, Tetracycline maintaining an average of about 20 mm zones of inhibition, except for the Ampicillin which was only able to partially inhibit the growth of the *S. marcescens*, with an inhibition zone of 7 mm which means that *S. marcescens* was resistant to Ampicillin.

Table 3: Essential Oils Areas of Inhibition (mm)- 12/9/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tea Tree	15	15	13	15
Sage	15	11	17	9
Rosemary	15	15	11	8
Basil	19	14	15	13

Table 4: Antibiotics Areas of Inhibition (mm)- 12/9/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tetra	21	21	24	13
Vanco	16	19	21	0
Amphil	0	0	0	7
Erythro	14	13	12	0

After two tests the two essential oils having the greatest effect on the bacteria were Tea Tree (avg. zone 13 mm) and Basil (16 mm) with the lowest being Rosemary. The antibiotic that had the greatest effect was tetracycline (avg. zone 20 mm), penicillin and ampicillin had the lowest. In the first two tests it was hard to determine which bacteria the Basil oil effected the most because the zones were the same size. In Test 3 ampicillin was replaced by gentamycin to see the effects it has on the

bacteria. Results from Test 3 presented in Tables 5 and 6 showed that all the antibiotics and essential oils were able to inhibit the growth of the bacteria except the *S. marcescens* which had zero bacterial growth on the plate after the first day. The reason for this could be a chemical or chemicals in the oils were diffusing into the agar and disrupting the bacteria's metabolic pathways or changing its form, such as its cell wall.

Table 5: Essentail Oils Areas of Inhibition (mm)- 12/11/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tea Tree	15	25	18	0
Sage	13	27	26	0
Rosemary	5	15	17	0
Basil	17	30	27	0

Table 6: Antibioitcs Areas of Inhibition (mm)- 12/11/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tetra	16	16	18	0
Vanco	15	15	15	0
Genta	20	20	18	0
Erythro	15	14	14	0

Results from Test 4 are presented in Tables 7 and 8 the results are similar to Test 3; however, the plate with *S. mutans* began to show resistance to the vancomycin with isolated colonies inside the inhibition zone. This is similar

to what happens to bacteria in your body, once they are exposed to a certain drug for a period of time, bacteria develop or express genes that enable them to tolerate the chemicals allowing resistant bacteria to thrive.

Table 7: Essentail Oils Areas of Inhibition (mm)- 12/15/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tea Tree	16	15	23	0
Sage	15	20	21	0
Rosemary	20	18	17	0
Basil	30	27	30	0

Table 8: Antibioitcs Areas of Inhibition (mm)- 12/15/2015				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tetra	16	17	18	0
Vanco	15	15	14	0
Genta	20	16	16	0
Erythro	15	16	14	0

After looking at the results from Tests 3 and 4 the bacteria seem to be less affected by the tetracycline, this is seen by the zones of inhibition throughout the tests, in Tests 1 and 2 Tetracycline averaged about a 20 mm zone and in Tests 3 and 4 it averaged about 13 mm. This is evidence that bacteria are very complex and have the ability to easily adapt to their environment. The opposite happened with the essential oils, as more tests were conducted the zones appeared to increase, especially with the Basil oil. The average zone size from Tests 1 and 2 was ~ 16 mm and for Tests 3 and 4 it was ~ 19 mm. This suggests bacteria did not develop resistance to these oils, because they are more complex and are harder for the bacteria to break down, or the bacteria lack enzymes or pathways to degrade the oils. The increase in the size of the zones may have also been greater due to the amount of oil soaked into the disks compared to the first two tests.

Another test was conducted, by growing the various bacteria in test tubes and diluted amounts of basil oil. Basil oil was the only one used in this test because it

was the oil that had the greatest effect on the bacterial growth. However, after conducting this experiment twice the results came back inconclusive, because the spectrophotometer was unable to read through the oily cloud or bubbles that formed in the tubes.

The following tests used Tetracycline, Ampicillin, Erythromycin, and Streptomycin. Test 6 showed similar results as the previous experiments, the Tea Tree and the Basil had the greatest zones of inhibition followed by Sage and Rosemary. Results are shown in Appendix A Tables 9 and 10. In the next experiment the bacteria were diluted into a solution of nutrient broth and 1.0 ml of the solution was plated, excess liquid was poured into bleach. Results from Test 7 presented in Tables 11 and 12 showed all the essential oils were able to inhibit the growth of all the bacteria. The average zones of inhibition for the Tea Tree (20mm) and Basil (27mm) oils also increased, this may be due to the dilution of the bacteria. Since the bacteria were diluted it grew at a slower pace allowing the oils to greatly reduce or inhibit its growth.

Table 11: Essentail Oils Areas of Inhibition (mm)- 1/22/2016				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tea Tree	29	31	20	0
Sage	11	23	0	0
Rosemary	25	17	29	0
Basil	28	29	29	20

Table 12: Antibioitcs Areas of Inhibition (mm)- 1/22/2016				
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>
Tetra	24	23	26	10
Ampi	0	0	15	0
Erythro	15	15	16	0
Strepto	19	21	21	0

In Test 8, *E. coli* was added to the types of bacteria being treated with the essential oils because it is a Gram negative bacteria that is found in the intestinal tract of humans and animals. Results from Test 8 presented in Tables 13 and 14 show that all the bacteria were able to tolerate the Sage oil because there were no clear zones around the disk. However, in this test the *S. marcescens* showed no growth on the plate containing the oils, but grew on the plate with the antibiotics, the bacteria were plated using the same culture. After letting the *S.*

marcescens grow for a few days there was still no visible growth, it is possible that this is a result of the oil having diffused into the agar, restricting the growth of the bacteria. One thing that is interesting is how the oils, if it is the oil, stops the growth of the bacteria for many days? It is said that the oils have a rapid evaporation rate, so they must have left a chemical in the agar after the rest of the oil evaporated, that restricts the growth of the bacteria for a longer period of time.

Table 13: Essential Oils Zones of Inhibition (mm)- 1/26/2016					
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>	<i>E. coli</i>
Tea Tree	20	15	30	0	28
Sage	0	0	0	0	24
Rosemary	11	13	13	0	12
Basil	21	23	25	0	30

Table 14: Antibiotics Areas of Inhibition (mm)- 1/26/2016					
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>	<i>E. coli</i>
Tetra	21	20	23	25	19
Ampi	0	0	15	24	0
Erythro	12	13	13	0	26
Strepto	18	19	21	18	18

Next, Thin Layer Chromatography (TLC) was performed to separate the different compounds in the oils. Once the compounds were separated using chromatography the largest fractions were scraped out and placed in a tube mixed with a solution (acetone or ethyl alcohol) to extract/ isolate the compounds from the silica gel. Sterile disks were then dipped into the solution and plated on the bacteria to see if that compound had any antimicrobial properties. The fractions extracted from the first Chromatography had no effect on the bacteria. The fractions

most likely did not have an effect because the concentration of each separated compound was not high enough; in the second chromatography four drops of the oils were placed instead of two, hoping to increase the concentration of each of the separated compounds. The biggest fractions were scraped from each plate; Tea Tree was not used because its fractions were too small to obtain a significant amount of the compound. When plated Basil, Sage, and Rosemary had an effect on the *E. coli*, the area of the zones of inhibition are presented in Table 15.

Table 15: Chromatography Fraction Zones (E. coli)- 2/2		
Basil	Sage	Rosemary
19	10	11

Another chromatography was conducted prepared using 50% ethyl alcohol, 30%acetic acid, and 20% water as the solvent for the mobile phase instead of toluene, because oils are more soluble in alcohol. The fraction that moved the most was scraped from each plate because it was the largest separation and appeared the most concentrated. The results presented in Table 16 showed that all the fractions produced zones of inhibition on each bacteria, Basil having the greatest effect with an average zone area of approximately 12 mm. Rf Values of the three TLCs are shown in Appendix A Tables 17-19. Below are the averages of the essentials oils and antibiotics on the different

bacteria, these averages will give a rough idea of which antimicrobial product is having the greatest effect on the bacteria. (see Table 20 and 21) Comparing the two tables it is believed the Basil oil has the greatest effect on the bacteria overall when combining the essential oils and the antibiotics. Basil has a high concentration of a chemical or group of chemicals, which may have the ability to disrupt the function of the cell better than the other products, or it may be more soluble in the agar lasting longer. This is shown in Tables 15 and 16 containing the results from the plates made with the chromatography fractions.

Table 16: Chromatography Fraction Zones- 2/8					
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>	<i>E. coli</i>
Tea Tree	10	13	8	12	12
Sage	12	11	7	9	12
Rosemary	10	12	7	11	13
Basil	14	14	8	11	14

Table 20: Average of Essential Oils Area of Inhibition					
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>	<i>E.coli</i>
Tea Tree	18	19	19	4	14
Sage	12	16	13	1	12
Rosemary	14	15	16	1	6
Basil	21	23	25	7	26

Table 21: Average of Antibiotics Area of Inhibition					
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>	<i>S. marcescens</i>	<i>E.coli</i>
Tetracycline	21	20	22	6	20
Erythromycin	15	14	14	0	26
Vancomycin	16	17	17	0	0
Ampicillin	0	0	9	9	0
Streptomycin	18	20	21	6	17
Gentamycin	18	17	16	0	0
Penicillin	0	0	0	0	0

Next, an experiment was conducted where the oils and the antibiotics were combined to determine if they would have a synergistic effect. The plates were made similar to before; the only difference being 10µl of oil was pipetted on top of each antibiotic disk. In this experiment it is believed the concentration of the oils was too high causing the bacteria to not grow on the

plate in the first 24 hours. The plates treated with Basil showed minimal growth with the *S. salivarius*, *S. mutans*, and *E. coli*, leading to the inability to measure zones of inhibition. After waiting three days the zones were large enough or had faint bacterial growth, with enough to determine the zones. In past experiments it looked as if the bacteria were resistant to the ampicillin, this may be

because the bacteria may have picked up a plasmid when being sub cultured. When combined with an oil the bacteria were not able to tolerate the antibiotic as well. The oils and the antibiotics may have had a synergistic effect because greater zones of inhibition were shown on most plates. In the next experiment the concentration of the oil was reduced to five μL to produce more measurable zones of inhibition, ampicillin was replaced with penicillin at this time. All plates had visible zones of inhibition except Staph. epidermidis on the plates with Rosemary and Sage, the one with Sage had resistant colonies around the edge showing the bacteria could tolerate the combination of the oils and the antibiotics. The zones of the bacteria were recorded after 24 and 48 hours. Results showed that the synergistic effect of the oil and bacteria greatly slowed the growth rate of the bacteria. The zones only decreased by three to five millimeters, (exact amount for each test is shown in Tables 28 and 29 in Appendix A) however, when the bacteria began growing three days later it was very thin showing only slight regrowth, but the initial zones of the inhibition were still visible. Throughout both test the *Serratia marcescens* did not grow, this may

be because it is a very sensitive and requires the proper temperature to grow, another reason could be the combination of the oils and the antibiotic was very potent. After three days the only growth recorded on those plates was around the control disk containing saline solution. In the third experiment with the plates made with 2.5 μL the *Staphylococcus epidermidis* was having a harder time growing, defined zones, were not visible until after 48 hours. In this experiment the *S. marcescens* was able to grow after 24 hours, this may be because the bacteria were able to break down the oil or obtain nutrients from the agar when a lower concentration of the oil was present. Overall, the zones were not as big as those in the past two experiments, but when compared to the average of the zones by themselves the plates with 2.5 μL still had greater zones of inhibition. The comparison of the zones of inhibition for the three tests are shown in the tables below. The plates with the combination of oils and tetracycline showed the greatest effect overall (shown in Tables 22-25). By looking at the oils individually the Sage with 5.0 μL and 2.5 μL showed the greatest zones of inhibition, results are shown in Table 25.

Table 22: Antibiotics Area of Inhibition Combined with Basil (mm)

Bacteria	10 μL oil/24hrs				5 μL oil/24hrs				5 μL oil/48hrs				2.5 μL oil/24hrs				2.5 μL oil/48hrs			
	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E
<i>S. salivarius</i>	0	0	0	0	28	18	21	17	22	13	19	17	22	11	18	16	20	10	18	15
<i>S. mutans</i>	0	0	0	0	25	16	27	18	22	13	22	16	24	15	23	18	23	14	23	17
<i>S. epidermis</i>	33	23	33	25	30	19	24	22	26	16	22	19	-	-	-	-	-	-	-	-
<i>E. coli</i>	0	0	0	0	27	16	25	29	24	12	25	23	20	11	20	26	19	11	20	26
<i>S. marcescens</i>	0	0	0	0	0	0	0	0	0	0	0	0	16	9	19	12	16	7	18	9

Table 23: Antibiotics Area of Inhibition Combined with Tea Tree (mm)

Bacteria	10 μL oil/24hrs				5 μL oil/24hrs				5 μL oil/48hrs				2.5 μL oil/24hrs				2.5 μL oil/48hrs			
	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E
<i>S. salivarius</i>	28	26	26	24	25	11	25	19	21	11	22	16	21	-	20	15	19	-	20	14
<i>S. mutans</i>	30	26	25	30	22	11	22	18	20	11	21	16	22	-	21	17	21	-	20	16
<i>S. epidermis</i>	33	22	32	26	27	12	25	19	25	12	22	18	30	25	28	26	30	25	28	22
<i>E. coli</i>	30	10	30	26	29	12	25	31	21	11	22	24	20	-	19	23	19	-	19	23
<i>S. marcescens</i>	0	0	0	0	0	0	0	0	0	0	0	0	18	-	19	11	18	-	19	9

Table 24: Antibiotics Area of Inhibition Combined with Rosemary (mm)																				
Bacteria	10µl oil/24hrs				5µl oil/24hrs				5µl oil/48hrs				2.5µl oil/24hrs				2.5µl oil/48hrs			
	T	P	S	E	T	P	S	E	T	P	P	E	T	P	S	E	T	P	S	E
<i>S. salivarius</i>	33	0	0	35	24	10	26	18	21	9	23	16	20	-	22	10	19	-	21	9
<i>S. mutans</i>	30	16	25	35	21	9	19	18	19	9	20	15	26	-	22	21	26	-	22	20
<i>S. epidermis</i>	35	18	32	25	24	0	23	19	24	0	22	16	19	15	28	23	13	9	28	22
<i>E. coli</i>	0	17	0	0	28	9	24	30	21	8	21	24	18	-	20	24	18	-	18	24
<i>S. marcescens</i>	0	0	0	0	0	0	0	0	0	0	0	0	14	-	16	-	14	-	16	-

Table 25: Antibiotics Area of Inhibition Combined with Sage (mm)																				
Bacteria	10µl oil/24hrs				5µl oil/24hrs				5µl oil/48hrs				2.5µl oil/24hrs				2.5µl oil/48hrs			
	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E	T	P	S	E
<i>S. salivarius</i>	18	0	30	30	30	12	35	25	21	11	27	20	29	-	37	29	28	-	35	24
<i>S. mutans</i>	15	0	25	35	30	19	31	22	25	10	31	18	30	-	32	20	27	-	32	19
<i>S. epidermis</i>	0	0	0	0	30	0	25	21	24	0	22	20	23	-	-	-	23	17	-	25
<i>E. coli</i>	0	16	0	0	28	14	27	30	24	12	24	28	-	12	25	28	21	11	25	28
<i>S. marcescens</i>	0	0	0	0	0	0	0	0	0	0	0	0	15	-	18	-	15	-	18	-

CONCLUSION

Based on the results of the bacteria growth when exposed to the various essential oils (Tea Tree, Basil, Sage, and Rosemary), Basil oil was most effectively able to reduce the growth of the bacteria compared to the tetracycline which was the most effective antibiotic. At the beginning of the experiment the Basil oil had an average inhibition zone of about 16 mm and Tea Tree had zones of 15 mm. Towards the end of the experiment Basil oil had zones of 20 mm and Tea Tree had zones of 19 mm. The bacteria that were most affected by the Basil oil were Staph. epidermidis, and *E. coli*. The *S. mutans*, *S. salivarius*, and Staph. epidermidis were most affected by the Tea Tree oil. Antibiotic experiments showed that the inhibition zones of the various antibiotics began to decrease, for example, Tetracycline started the experiment having zones of inhibition at 20 mm and ended with 18 mm. Staph epidermidis was the bacteria that was most affected by the antibiotic. Indicating the bacteria were developing tolerance to them. Essential oils inhibited the growth because they have the ability to easily penetrate through the cell walls of many bacteria. The chemical makeup of the essential oils also makes it harder for the bacteria to decompose it because they may not have the proper enzymes or metabolic pathways to break it down, causing the oils to enter the cell and disrupt normal function. The oil, a lipid, is able to

enter the cell easily because cell walls are composed of a phospholipid bilayer, allowing the oil to slip through the tiny cell wall pores. The oils may be working better because three of the bacteria utilized in the experiments are gram positive bacteria, whose cell wall allows hydrophobic molecules such as oils to penetrate the cell allowing them to damage the cell wall and cytoplasm. Many essential oils contain terpenes which are hydrocarbons synthesized in the cytoplasm of plant cells that penetrates the cell wall through altering the membrane, increasing the permeability of the wall which can lead to lysis of the cell causing the bacteria to die.

Thin Layer Chromatography (TLC) was utilized to separate the different fractions in the oils to isolate the components in them that are showing antimicrobial properties. Results from the TLC fractions showed there is a component acting as an antimicrobial, however, obtaining a high enough concentration of the component is needed to show significant results.

Results from the experiment with the combination of oils and antibiotics showed that the synergistic effect of the oils and the antibiotics proved to be more potent against the bacteria. Although, the combination of oils and antibiotics was not able to completely inhibit the growth of the bacteria it was able to drastically reduce its ability to reproduce. This can be beneficial in cases where doctors cannot identify the bacteria right away;

this method could buy them time to figure out the cause of the infection. The null hypothesis for this project was rejected because the oils were able to show significant zones of inhibition compared to the antibiotics, thus proving the hypothesis correct.

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AUTHOR INFORMATION

Karishma Patel
Grants High School
500 Mountain Rd.
Grants, NM 87020
09.kspatel@gmail.com

APPENDIX A

Data tables.

Table 9: Essential Oils Areas of Inhibition (mm)- 1/19/2016			
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>
Tea Tree	22	21	22
Sage	23	21	11
Rosemary	16	13	13
Basil	23	22	35

Table 10: Antibiotics Areas of Inhibition (mm)- 1/19/2016			
	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph epidermidis</i>
Tetra	24	22	25
Ampi	0	0	5
Erythro	16	13	15
Strepto	18	19	21

Table 17: Rf Value from 1st Chromatography				
Fraction	Tea Tree	Basil	Sage	Rosemary
1	0.81	0.08	0.05	0.03
2	0.98	0.31	0.09	0.83
3	0	0.8	0.7	0
4	0	0.81	0.82	0
5	0	0.84	0.98	0
6	0	0.93	0	0

Table 18: Rf Value from 2nd Chromatography				
Fraction	Tea Tree	Basil	Sage	Rosemary
1	0.59	0.07	0.06	0.03
2	0.95	0.18	0.2	0.18
3	0.97	0.61	0.64	0.87
4	0	0.84	0.85	0.97
5	0	0.94	0	0

Table 19: Rf Value from 3rd Chromatography				
Fraction	Tea Tree	Basil	Sage	Rosemary
1	0.09	0.11	0.16	0.24
2	0.62	0.34	0.22	0.6
3	0.85	0.42	0.37	0
4	0	0.57	0.7	0
5	0	0.64	0.92	0
6	0	0.7	0	0
7	0	0.81	0	0

Table 28: Change of Zones of Inhibition (mm) 5 mL oil- 2/25					
Basil Plates	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph. epidermidis</i>	<i>E. coli</i>	<i>S. marcescens</i>
Tetracycline	6	3	4	3	-
Penicillin	5	3	3	4	-
Streptomycin	2	5	2	0	-
Erythromycin	0	2	3	6	-
Tea Tree	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph. epidermidis</i>	<i>E. coli</i>	<i>S. marcescens</i>
Tetracycline	4	2	2	8	-
Penicillin	0	0	0	1	-
Streptomycin	3	1	3	3	-
Erythromycin	3	2	1	7	-
Sage	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph. epidermidis</i>	<i>E. coli</i>	<i>S. marcescens</i>
Tetracycline	9	5	6	4	-
Penicillin	1	9	0	2	-
Streptomycin	8	0	3	3	-
Erythromycin	5	4	1	2	-
Rosemary	<i>S. salivarius</i>	<i>S. mutans</i>	<i>Staph. epidermidis</i>	<i>E. coli</i>	<i>S. marcescens</i>
Tetracycline	3	2	0	7	-
Penicillin	1	0	-	1	-
Streptomycin	3	0	1	3	-
Erythromycin	2	3	3	6	-

Detecting Climate Change through Means and Extremes

Lillian Peterson, Los Alamos Middle School

This study investigates how the climate is changing at individual weather stations around the world by measuring means and extremes. Extensive python code was written to read in the daily data from thousands of stations and compute average yearly temperature, precipitation, and extremes such as heat waves, cold spells, very wet and dry periods. A best-fit line and goodness-of-fit statistic were computed for each statistic at each station. All these linear trends were collected into histograms and geographic distribution plots. It was found that the earth is undergoing significant changes: 97% of all stations are increasing in temperature since 1950, averaging 4° F per century. All measures of extreme heat are increasing, and all measures of extreme cold are decreasing. Almost all stations are recording significant increases in the number of warm days (days above a reference 90th percentile) and heat waves (three consecutive warm days) and the warmest day of the year is getting hotter. There are fewer cold nights and cold spells. The number of frost nights is significantly decreasing, averaging 25 fewer frost nights per year over a century. Changes in precipitation vary by geography: some regions are drier while others are wetter. For example, precipitation changes are strongly varied in both the U.S. and Australia. This study confirms that the earth's climate is rapidly changing in both means and extremes. To help the public better understand climate change, this data is presented in an online map for interactive exploration at <http://lillianpetersen.github.io>.

INTRODUCTION

There are often events on the news reporting extreme weather events such as droughts, floods, and heat waves. People remember these extreme events and they want to know how climate change is affecting them. Whenever there is a massive heat wave, people think, “that must be caused by climate change!”, but when there are snowstorms people wonder, “maybe our climate isn’t changing after all.” This paper presents answers to how the extreme events are changing.

Climate change is hotly debated by politicians and in

the media, even though leading scientists have reached a consensus (IPCC 2013). The goal of this project is to test whether climate change can be documented using the simplest data set and methods possible.

The global annual average of land-surface air temperature has warmed about 1.5 °C (2.7° F) since 1850 (figure 1 and figure 2). Note that there is natural variability from year to year, but there is a definite upward trend. Since 1970 the trend has significantly increased. The earth is also getting either wetter or drier based on geographic location (figure 3).

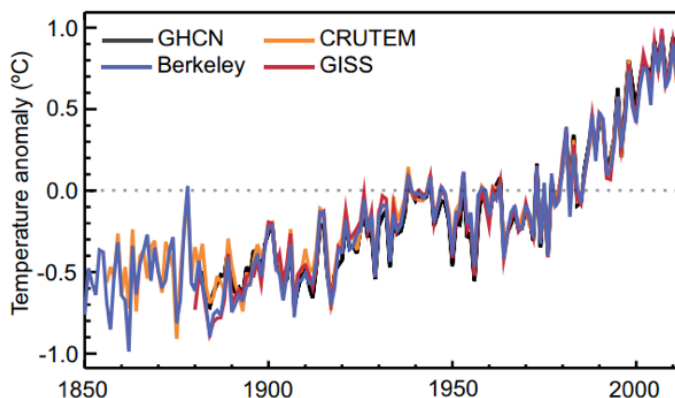


Figure 1. The global annual average of land-surface air temperature anomaly from 1850 to 2015. (Hartmann et al. 2013, ch. 2 pg. 29 fig. 2.14)

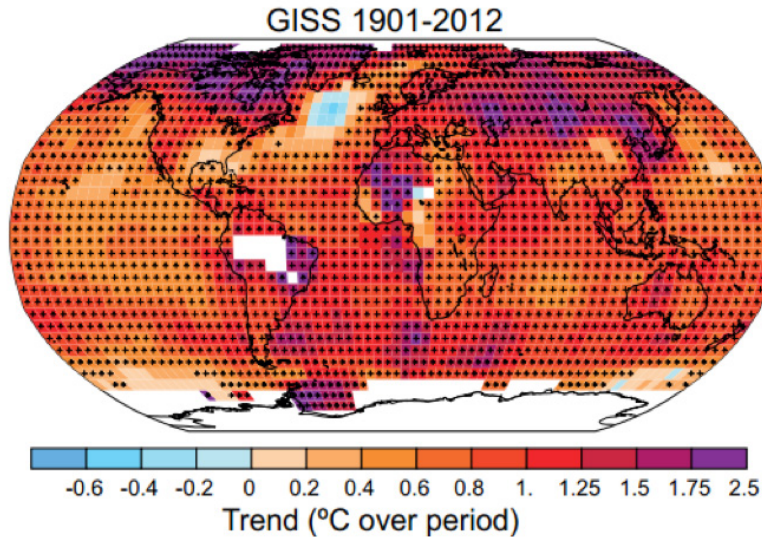


Figure 2. Global trends in surface temperature. The plus sign indicates a significant trend (i.e., a trend of zero lies outside the 90% confidence level). White areas mean that data in those places is missing. These trends were created with a combination of observed temperatures and a model to fill in the gaps. (Hartmann et al. 2013, ch. 2 pg. 193 fig. 2.21)

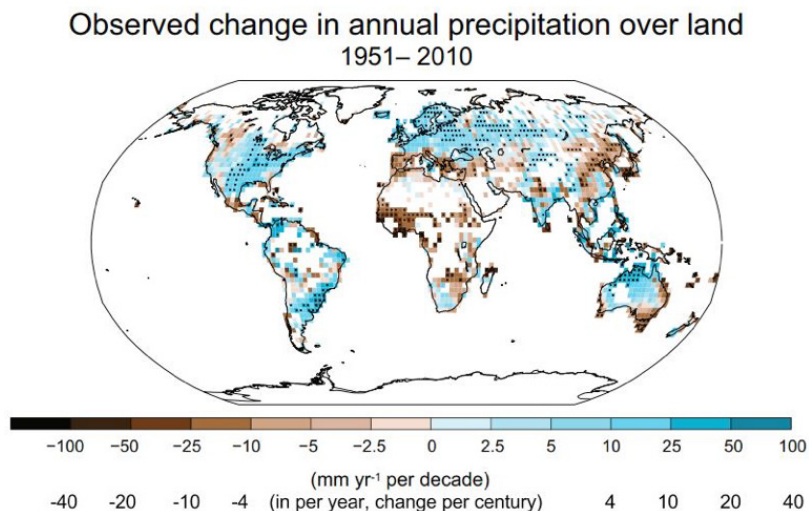


Figure 3. (IPCC 2013, pg. 6 fig. SPM.2)

METHODS

Python code was written to read in data, find averages and extremes, and plot the results. First, daily data from the Daily Global Historical Climatology Network (Menne et al. 2012a, 2012b) was read in. Four thousand cities around the world had records with daily data going back before 1950. The daily data included the maximum and minimum daily temperature, and daily precipitation (table 1).

Cities with too much bad data had to be removed. Some

cities had many -9999 values, meaning the data was not recorded that day. Other cities were missing longer chunks of data. For example Podor, Senegal, had a few years of data starting in 1857, then skipped about 8 decades and started recording again in 1945. Several steps were used to sort through all of this bad data. First, single bad data days were not included in the monthly average. If at least one day in all 12 months was good, the year was kept. If even one month in the year was completely bad, the whole year was thrown out. Finally,

station	year	month	variable																
RQC00664702	1901	01	TMAX	294	0	294	0	294	0	294	0	300	0	300	0	294	0	283	0
289	0	278	0	300	0	283	0	289	0	289	0	294	0	300	0	306	0	306	0
300	0	283	0	283	0	294	0	300	0	294	0	289	0	272	0	294	0	294	0
RQC00664702	1901	01	TMIN	206	0	206	0	206	0	200	0	194	0	194	0	189	0	178	0
206	0	194	0	189	0	189	0	189	0	183	0	178	0	183	0	189	0	189	0
189	0	183	0	194	0	189	0	189	0	189	0	161	0	183	0	183	0	189	0
RQC00664702	1901	01	PRCP	0	0	0	0	0	0	0	0	0	0	0	0	64	0	13	0
0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
660	0	0	0	0	0	132	0	0	0	0	0	0	0	0	0	0	0	0	0
RQC00664702	1901	02	TMAX	300	0	300	0	300	0	300	0	300	0	300	0	283	0	289	0
300	0	300	0	300	0	294	0	294	0	344	0	339	0	294	0	294	0	294	0
328	0	317	0	311	0	294	0	311	0	311	0	311	0	311	0	306	0	-9999	-9999
RQC00664702	1901	02	TMIN	189	0	189	0	189	0	194	0	194	0	206	0	211	0	206	0
211	0	194	0	194	0	194	0	172	0	156	0	183	0	183	0	178	0	183	0
183	0	183	0	183	0	183	0	178	0	178	0	178	0	178	0	172	0	-9999	-9999
RQC00664702	1901	02	PRCP	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	107	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-9999	-9999		
RQC00664702	1901	03	TMAX	311	0	311	0	311	0	311	0	300	0	300	0	294	0	283	0
294	0	294	0	300	0	300	0	300	0	300	0	306	0	294	0	283	0	261	0
289	0	289	0	294	0	294	0	300	0	300	0	311	0	317	0	294	0	300	0

Table 1. The raw data. Downloaded from Daily Global Historical Climatology Network (Menne et al. 2012b).

cities were thrown out completely if 15% or more of the years were bad.

This project consists of two parts: finding climate change through means and through extremes (Table 2). Means include yearly averages of daily highs and lows and yearly sums of precipitation (figure 4).

Many of the extremes (figures 5-7) were calculated using percentiles. Percentiles were found by putting the daily data from 1961 to 1990 in order. Once the 90th and 10th percentiles for temperature and the 95th percentile for precipitation was found for every city, extremes could be computed.

RESULTS

Results are presented for a single weather station (Atlantic City, NJ, figures 4-7) as explanation and then for all stations with data since 1950 (figures 8-19).

The plots for Atlantic City, NJ were made for every mean and extreme. Atlantic City was chosen as an example because it has the longest record of good data in the U.S. A best fit line was fitted to the each plot. R2 was then computed. R2 shows how much of the variance can be explained by the linear trend.

In Atlantic City, the mean temperature of daily highs (figure 4a) has warmed by 2.6 °F in the past century. The R2 value for that plot is 0.46, so 46 percent of the

variance can be explained by the best fit line. On the yearly average of daily lows (figure 4b), the R2 value is higher at 0.62, because the data has a tighter fit to the line.

For Atlantic City, the slopes of the best fit lines of the heat extremes (figure 5) are increasing and all of the slopes of the cold extremes (figure 6) are decreasing. Precipitation is not changing uniformly in either the means (figure 4c) or extremes (figure 7).

The slope and R2 value was recorded in a text data file for every mean and extreme, for every weather station with data since 1950. This included 1243 stations for temperature and 4534 for precipitation. Another python code read in these numbers and made plots of the aggregated data. It made a histogram of the slopes of the best fit lines for every mean and extreme. Then it plotted the location of the stations on a world map and colored the points based on how much each station is warming.

The average over all stations of the mean temperatures is warming by about 4oF per century (figures 8, 9). Of the 1,500 cities going back before 1950, about 97% of the stations are showing an increase in temperature and only 3% are cooling. Although almost everywhere is warming, the most intense warming varies by geography. Europe and Asia are warming more than the U.S (figures 8b, 17, 18). Extremes give even more insight on how our

MEANS

Descriptive name	Definition	Units	Figures
Yearly Average of Daily High Temperature	Average of all the daily maximum temperatures each year	°F	4a 8
Yearly Average of Daily Low Temperature	Average of all the daily minimum temperatures each year	°F	4b 9
Total Yearly Precipitation	Sum of all the precipitation in a year	inches	4c 14

TEMPERATURE EXTREMES

Descriptive name	Definition	Units	Figures
WARM DAYS	Number of days with daily high temperature >90th percentile	days per year	5a 10a 11a
HEAT WAVES	Frequency of 3 days in a row >90th percentile	number per year	5b 10b 11b
WARMEST DAY	Annual maximum value of daily high temperature	°F	5c 10c 11c
COLD NIGHTS	Number of days with daily low temperature <10th percentile	days per year	6a 12a 13a
COLD SPELLS	Frequency of 3 days in a row <10th percentile	number per year	6b 12b 13b
FROST NIGHTS	Number of days with daily low temperature <32 °F (0 °C)	days per year	6c 12c 13c

PRECIPITATION EXTREMES

Descriptive name	Definition	Units	Figures
WETTEST DAYS	Amount of precipitation from days with precipitation >95th percentile	inches	7a 15a 16a
WET SPELLS	Maximum of consecutive 5-day precipitation	inches	7b 15b 16b
DRY SPELLS	Number of days with precipitation <1mm	days per year	7c 15c 16c

EXTREMES COMPUTED BUT NOT SHOWN due to space & time restrictions

Descriptive name	Definition	Units
COLDEST DAY	Annual minimum value of daily temperature, computed for highs and lows	°F
TROPICAL NIGHTS	Number of days with daily low temperature >68°F (20°C)	days per year
WETTEST DAY	Maximum one-day precipitation	inches
WARMEST NIGHT	Annual maximum value of daily low temperature	°F
COLD DAYS	Number of days with daily high temperature <10th percentile	days per year
WARM NIGHTS	Number of days with daily low temperature >90th percentile	days per year

Table 2. Definitions of means and extremes. These are standard definitions from the Intergovernmental Panel on Climate Change (IPCC). (Hartmann et al. 2013, Box 2.4 pg. 221)

climate is changing. All measures of extreme heat are increasing (figures 10, 11), and all measures of extreme cold are decreasing (figures 12, 13). This confirms that climate change strongly affects average temperatures and has a pronounced influence on extreme temperatures.

The R2 value can be used to tell how significant a trend is. On the geographic distribution plots of R2 (figures 8c, 9c), all points that are red means that there is less than one-in-one thousand chance that the increase in slope happened by a random process. All points that are blue means that there is less than one-in-one million chance that the increase in slope happened by a random process. This was computed using a significance of correlation coefficient calculator (Lowry 2015) with number of samples N=65 years and correlation coefficient, R, where R2 is the R2 value.

More heat extremes and fewer cold extremes affect agriculture and are bad for crops. In extreme heat, many seeds cannot germinate so plants cannot reproduce. Fruits have more trouble maturing and in many cases fall off the tree before they are ripe. Many plants die as they are more susceptible to diseases and pest infestations. While fewer frost nights make for a longer growing season thus making it possible to grow plants further north, it will also increase pests and bring on more severe heat stress that will kill of crops.

Precipitation results are more varied (figures 14-16). While most places are changing, how they change varies by geography. There is high spatial correlation amongst stations that are getting wetter and those that are getting drier. For example, the eastern and western coasts of Australia are significantly drying, by about 17 inches per year over a century. Just inland is about neutral, and northern Australia is getting wetter (figure 19).

Because this project uses raw data straight from stations, places that didn't record data are underrepresented. For example, there are only a few stations in South America, Africa, and the southern half of Asia. Because of this, the data is biased towards the places that are most strongly represented. However, where there are stations in these places, those stations are warming too.

CONCLUSIONS

This project investigates changes in climate using data from individual weather stations. The history of means

and extremes in both temperature and precipitation are evaluated. The world is getting warmer, there are more heat extremes, fewer cold extremes, and the change in precipitation varies by geography. The results clearly show that climate change is real because it can be seen at almost every single station around the world. It also shows that extremes are changing along with the means. In conclusion, this project proved that climate change is evident using the simplest data set and mathematical methods possible: conclusive evidence was found by using daily weather records, yearly averages, percentiles, and the slope of a best fit line.

One of the biggest challenges in working in the climate change field is helping the public better understand the risks of climate change. To accomplish this goal, an interactive map of the world was created that shows how each individual station is changing in the means and the extremes. It is more convincing when people can see how their home town is changing. The author is currently working with museum specialists to put this educational tool in an interactive exhibit that will travel to museums around the country (see <http://lillianpetersen.github.io>).

ACKNOWLEDGMENTS

Thanks goes out to Mark Petersen, Phillip Wolfram, and Francesca Samsel. Mark Petersen taught me how to write python code and pointed me to weather data sets and references. Phillip Wolfram of Los Alamos National Laboratory and Francesca Samsel of the University of Texas at Austin listened to my talk before I presented it and gave me ideas on how to improve it. Ms. Samsel develops museum exhibits and has advised me on how to display my data in an interactive map.

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Menne, M.J., I. Durre, B. Korzeniewski, S. McNeal, K. Thomas, X. Yin, S. Anthony, R. Ray, R.S. Vose, B.E. Gleason, and T.G. Houston, 2012b: *Global Historical Climatology Network - Daily* (GHCN-Daily), Version 3. NOAA National Climatic Data Center. <http://doi.org/10.7289/V5D21VHZ> [June 2015].

Lowry, Richard. 2015. *Significance of a Correlation Coefficient*. <http://vassarstats.net/rsig.html>

DATA

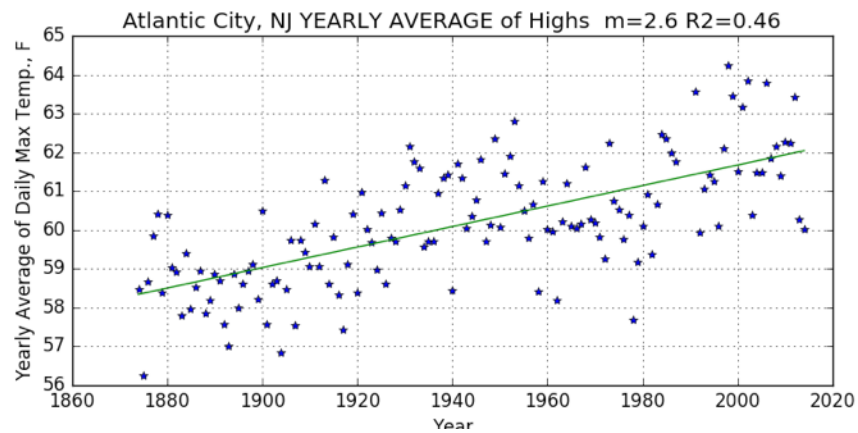
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AUTHOR INFORMATION

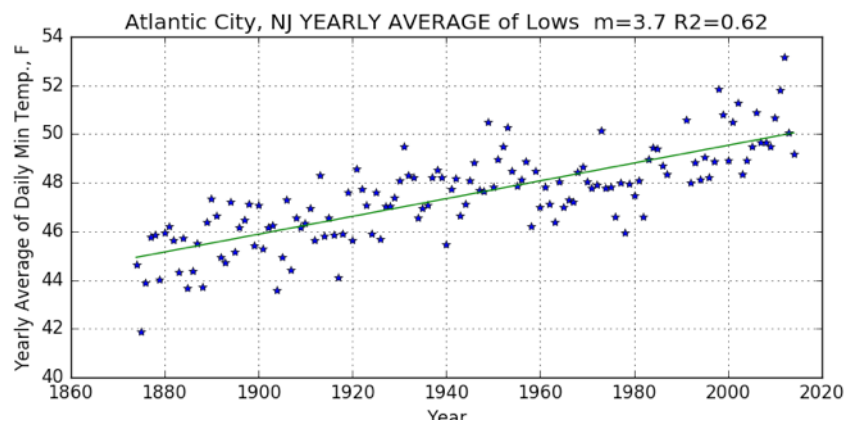
Lillian Petersen
Los Alamos Middle School
2101 Cumbres Dr.
Los Alamos, NM 87544
lilliank.la@gmail.com

MEANS

a.) Daily Highs



b.) Daily Lows



c.) Precipitation

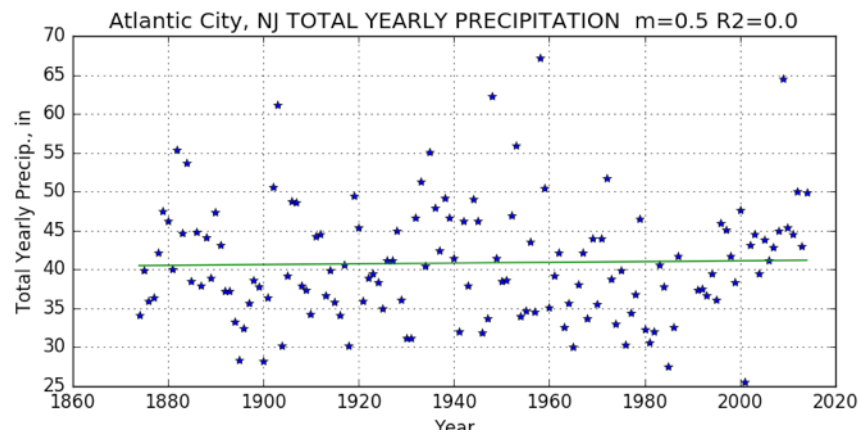
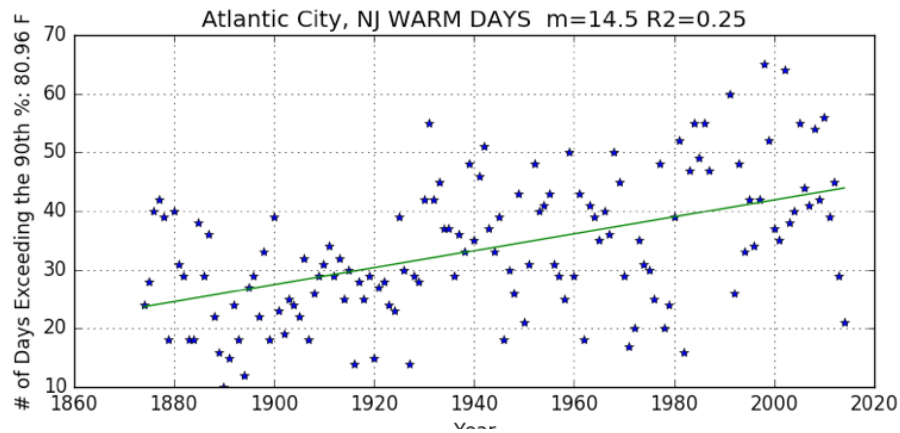


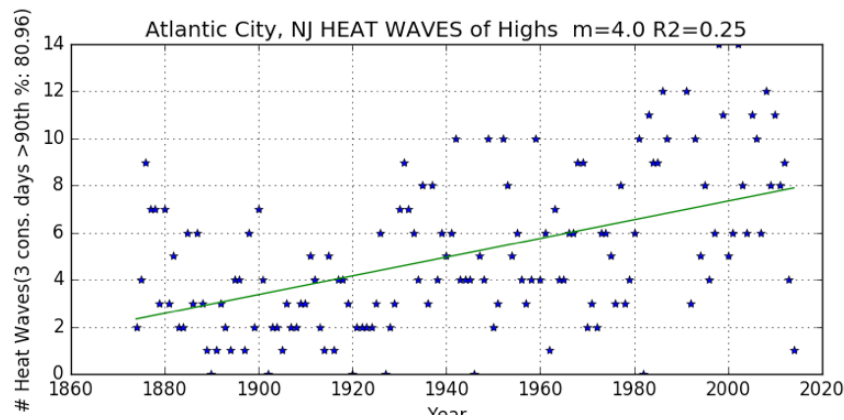
Figure 4. Data from Daily Global Historical Climatology Network (Menne et al. 2012). Each point represents the yearly average of daily highs (a), yearly average of daily lows (b), and yearly sum of precipitation (c). The green line is the best fit line and has a slope, m in title, of change per century. R^2 (in title) is goodness of fit. All plots created by author.

HEAT EXTREMES: ATLANTIC CITY, NJ

a.) Warm Days: More



b.) Heat Waves: More



c.) Warmest Day: Warmer

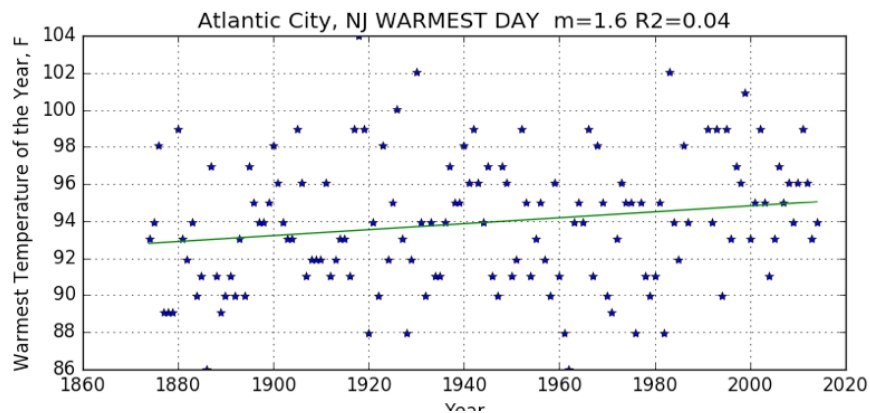
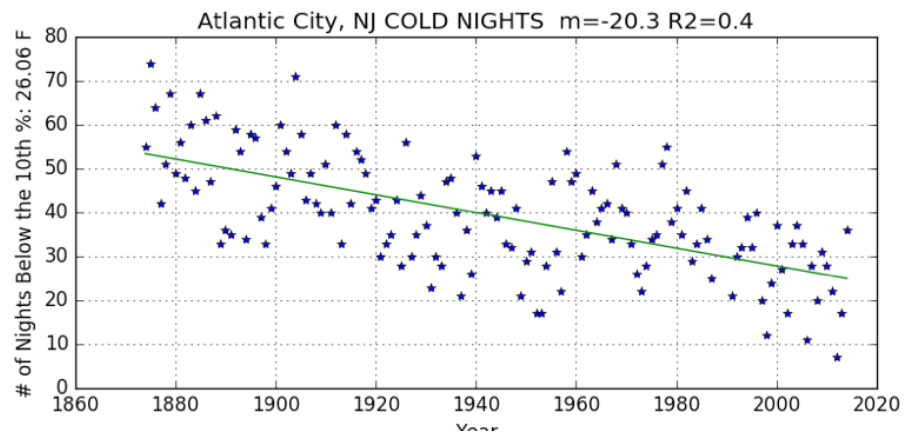


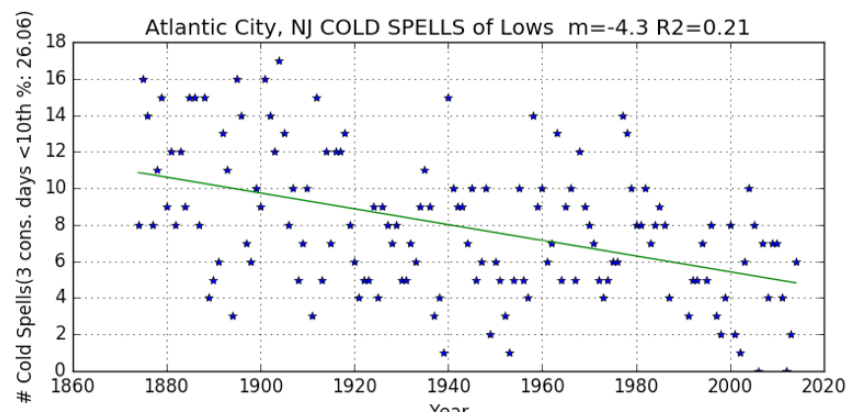
Figure 5. Same as figure 4, but for heat extremes.

COLD EXTREMES: ATLANTIC CITY, NJ

a.) Cold Nights: Fewer



b.) Cold Spells: Fewer



c.) Frost Nights: Fewer

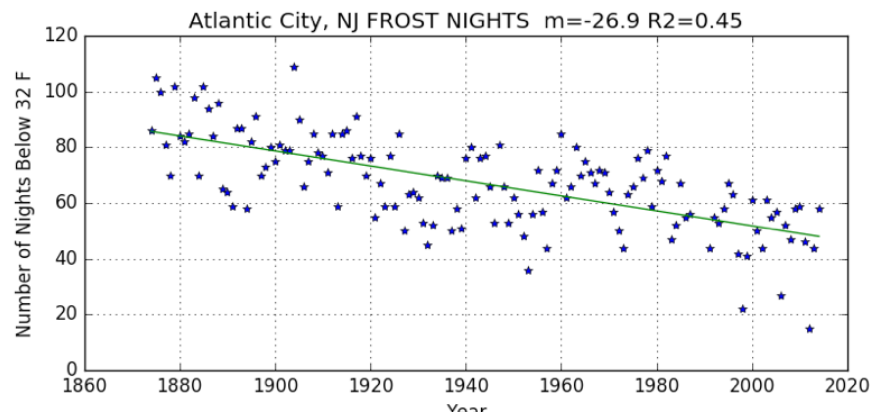
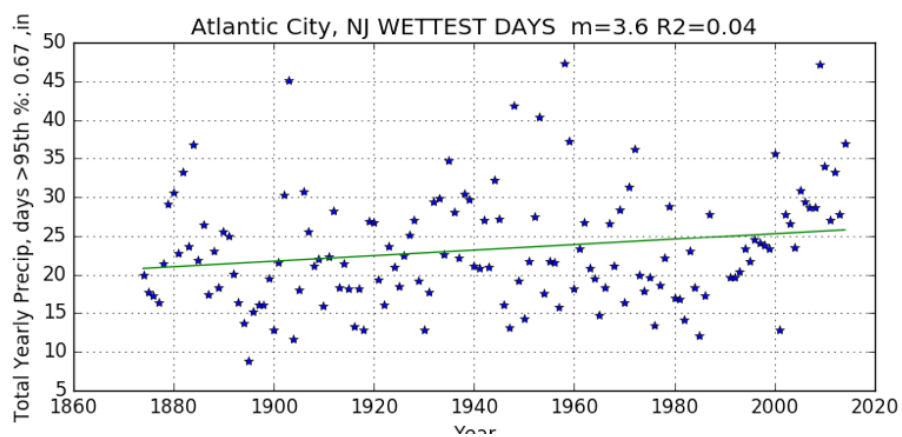


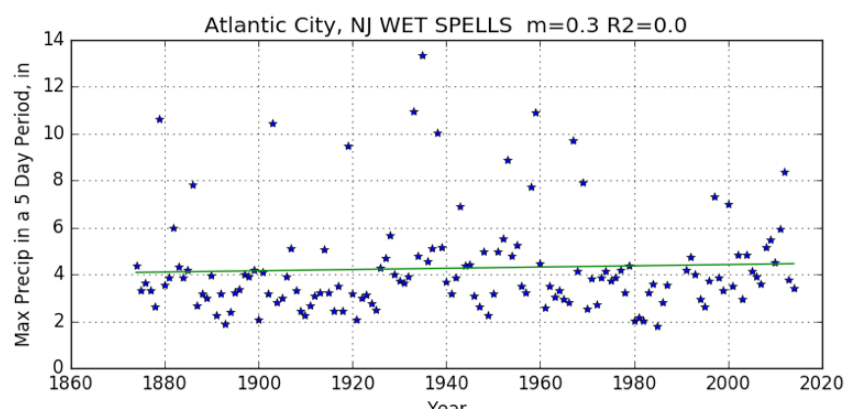
Figure 6. Same as figure 4, but for cold extremes.

PRECIPITATION EXTREMES: ATLANTIC CITY, NJ

a.) Wettest Days



b.) Wet Spells



c.) Dry Spells

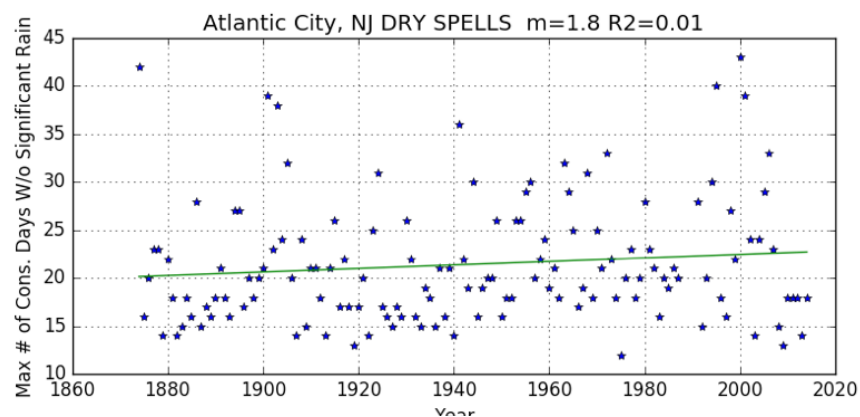
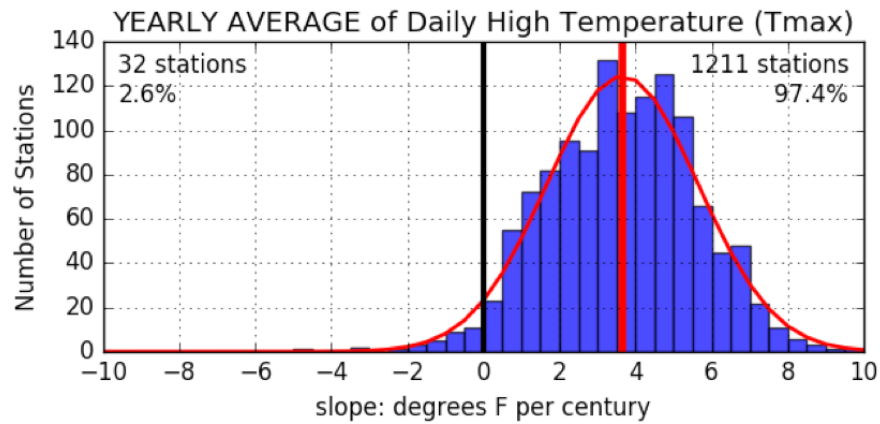


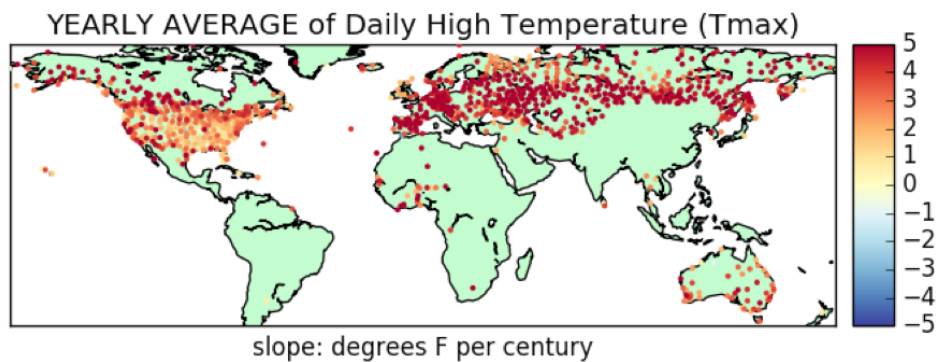
Figure 7. Same as figure 4, but for precipitation extremes.

MEANS OF DAILY HIGH TEMPERATURE

a.) Yearly Average of Daily High Temperature (Tmax)



b.) Yearly Average of Daily High Temperature (Tmax)



c.) R2 of Yearly Average of Daily High Temperature

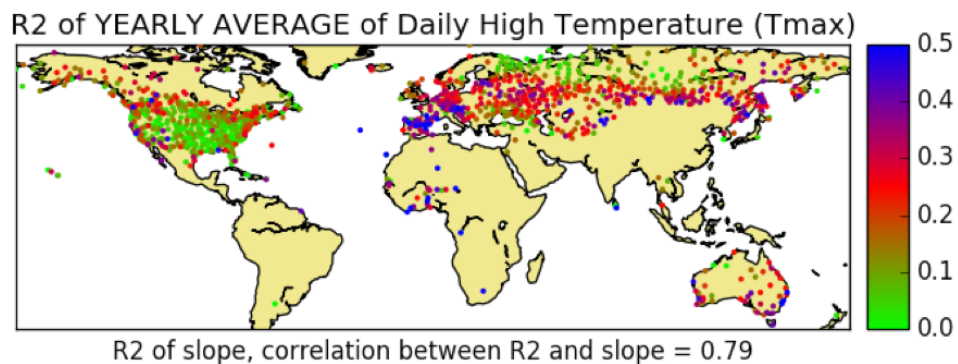
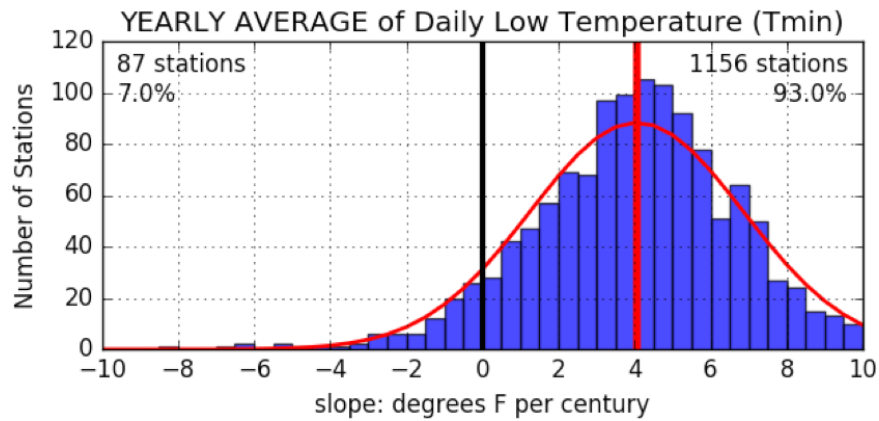


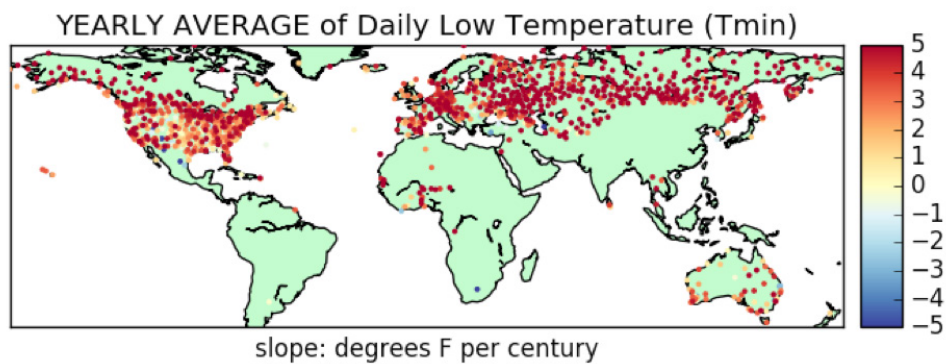
Figure 8. The histogram (a) and geographic distribution plot (b) of the slopes of the best fit lines and the geographic distribution plot of R2 (c) for all cities with data since 1950. On the histogram, the straight red line is the average, the curved red line is the best fit normal distribution, and the black line is zero. All plots by author.

MEANS OF DAILY LOW TEMPERATURE

a.) Yearly Average of Daily Low Temperature (Tmin)



b.) Yearly Average of Daily Low Temperature (Tmin)



c.) R2 of Yearly Average of Daily Low Temperature

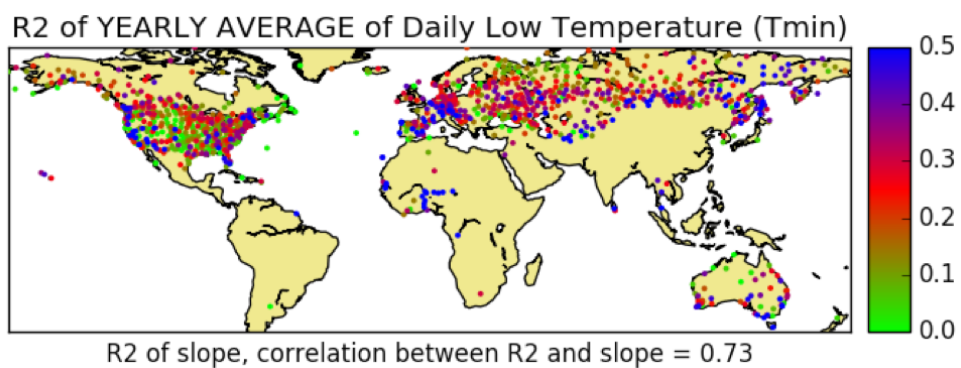
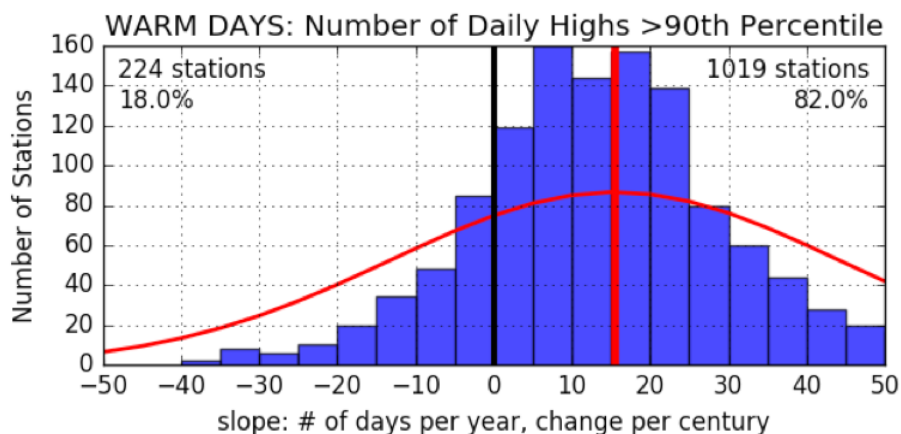


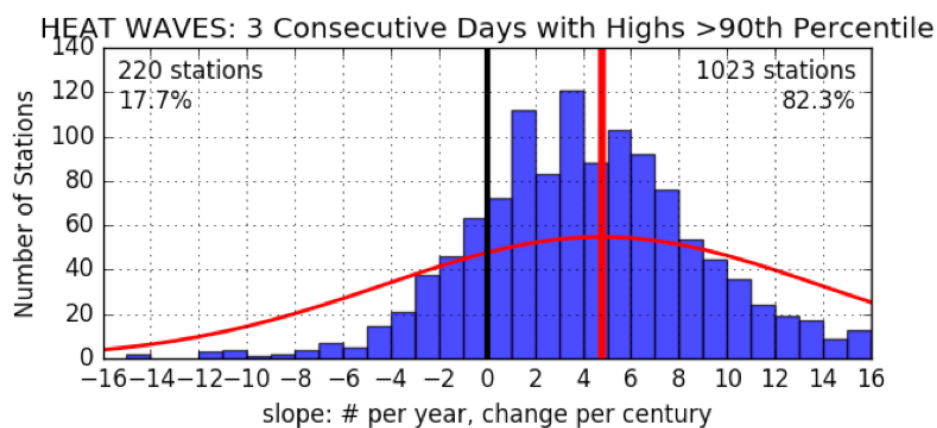
Figure 9. See previous figure for description.

HEAT EXTREMES: HISTOGRAMS

a.) Warm Days: More



b.) Heat Waves: More



c.) Warmest Day: Warmer

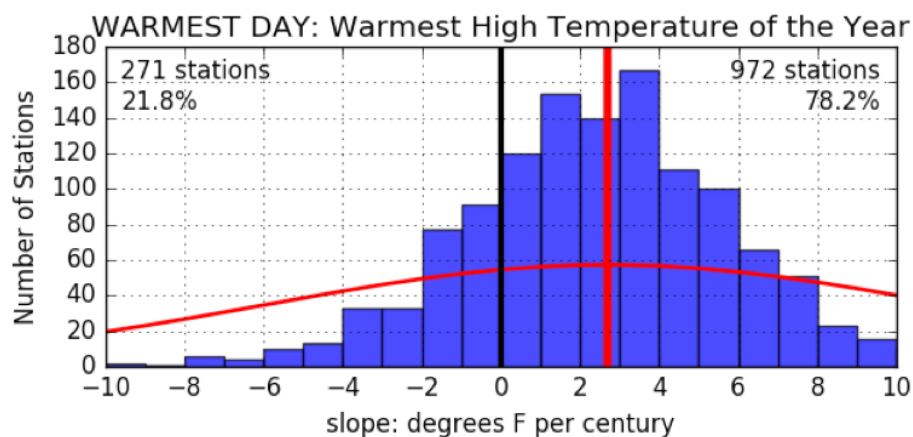
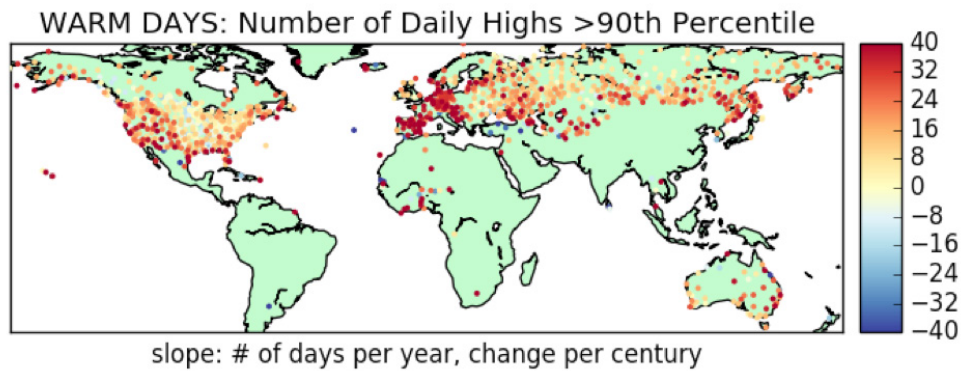


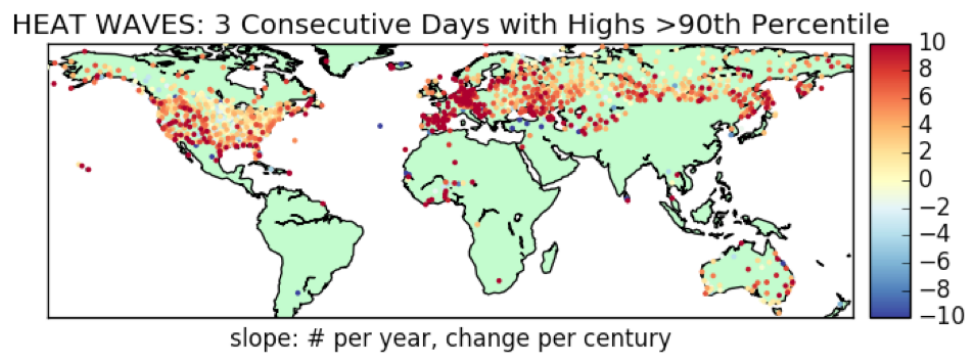
Figure 10. Histograms, slopes of best fit line of all stations, 1950-2015. Vertical red line is mean. All plots by author.

COLD EXTREMES: MAPS

a.) Warm Days: More



b.) Heat Waves: More



c.) Warmest Day: Warmer

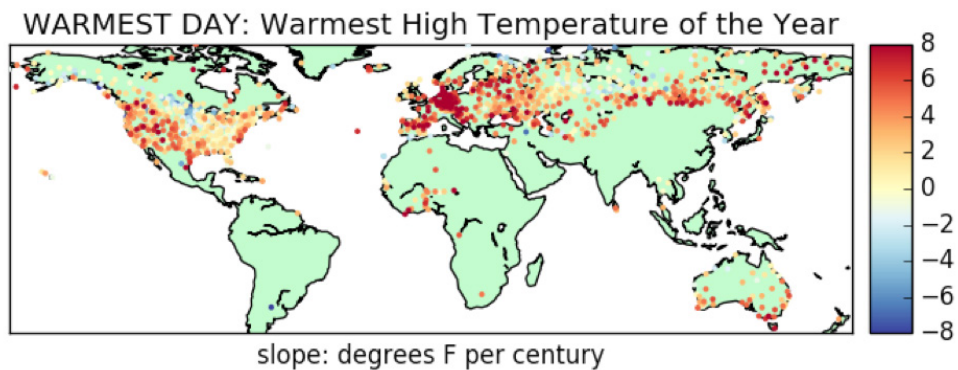
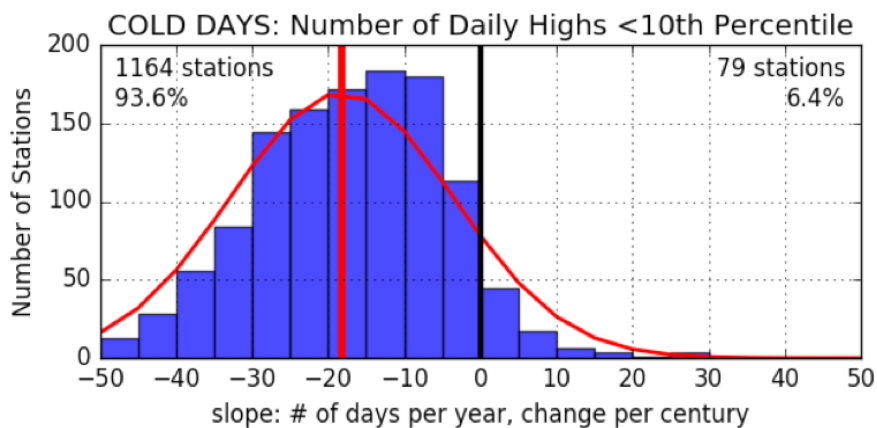


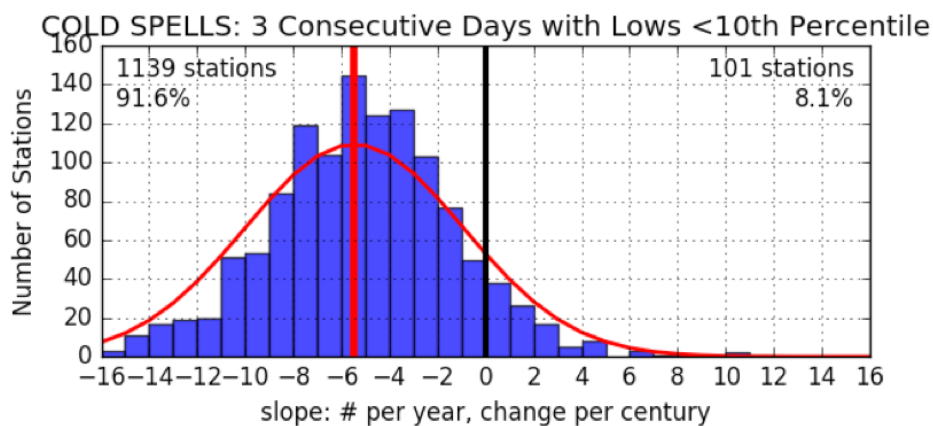
Figure 11. The change in different heat extremes by geographic location. All plots by author.

COLD EXTREMES: HISTOGRAMS

a.) Cold Days: Fewer



b.) Cold Spells: Fewer



c.) Frost Nights: Fewer

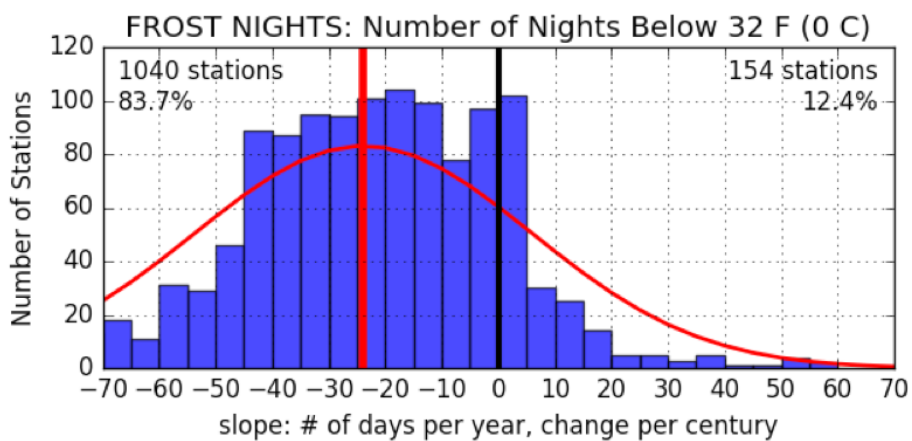
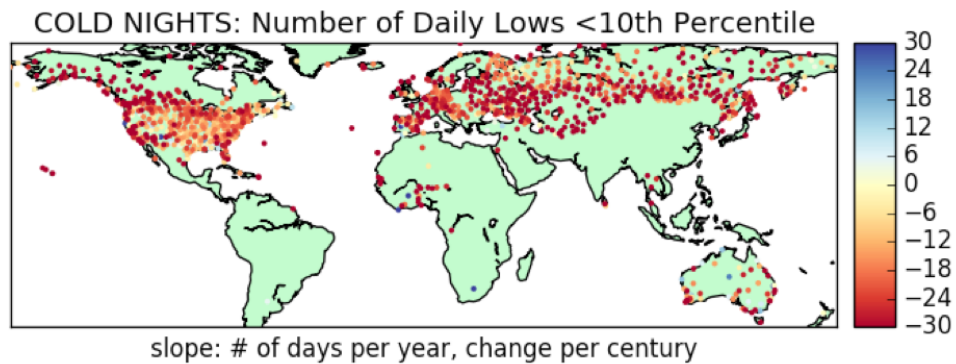


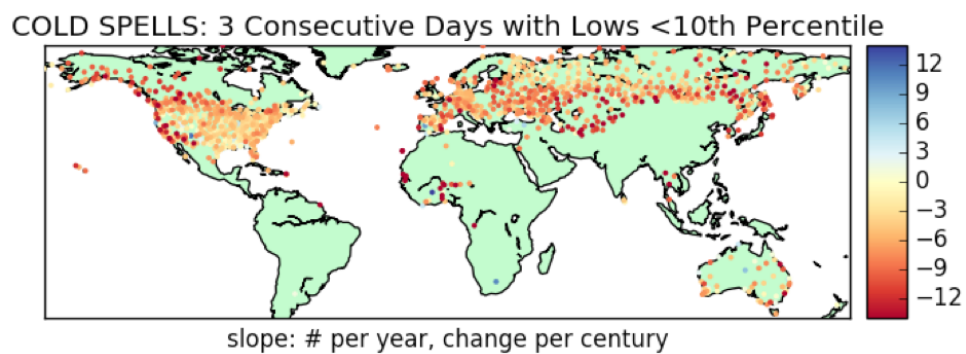
Figure 12. Same as figure 10 but for cold extremes.

COLD EXTREMES: MAPS

a.) Warm Days: More



b.) Heat Waves: More



c.) Warmest Day: Warmer

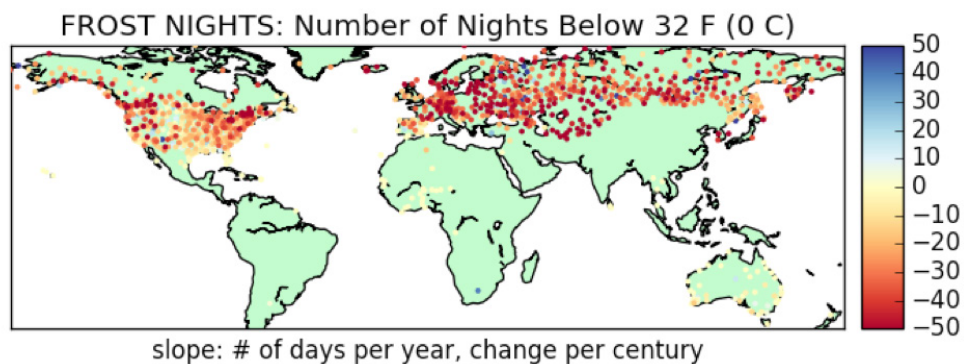
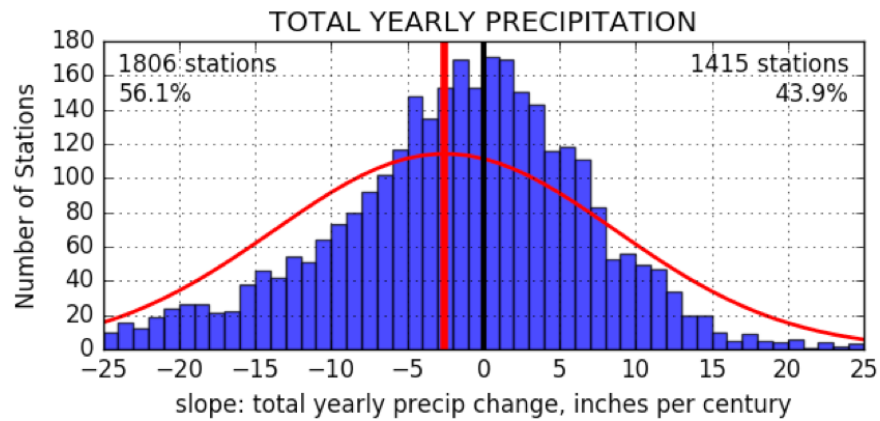


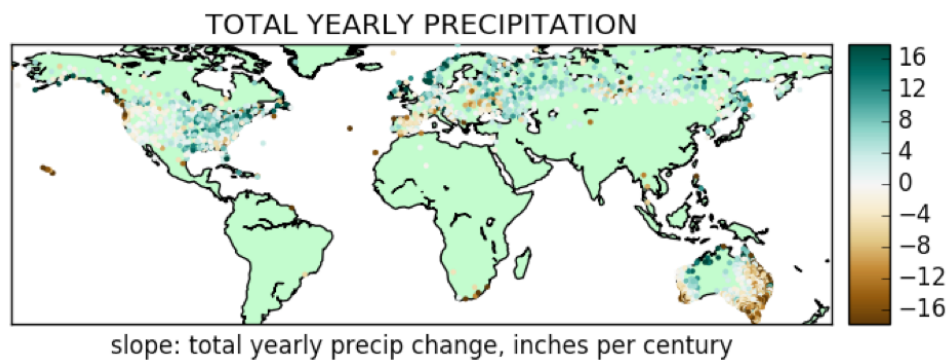
Figure 13. Same as figure 11 but for cold extremes.

PRECIPITATION MEANS

a.) Total Yearly Precipitation



b.) Total Yearly Precipitation



c.) R2 of Total Yearly Precipitation

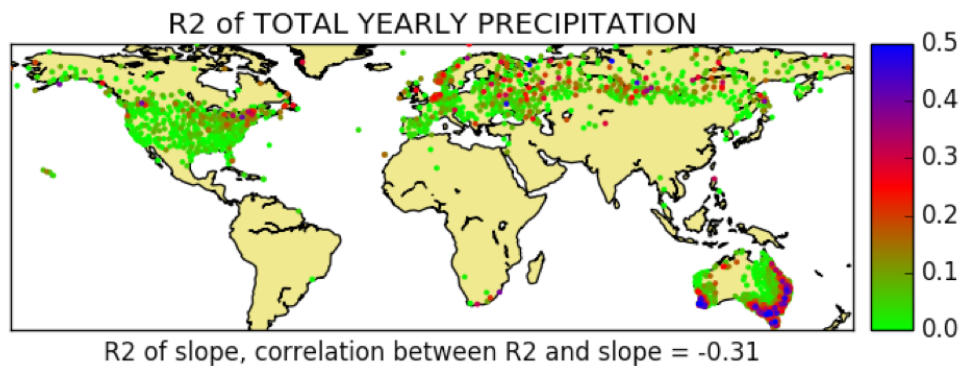
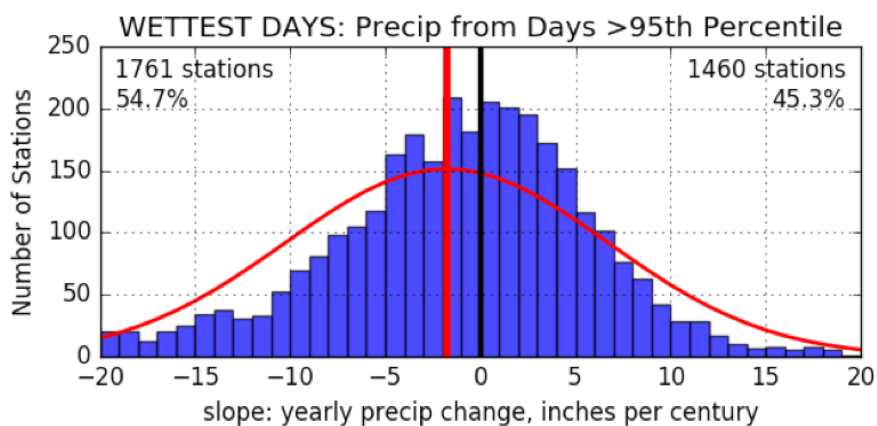


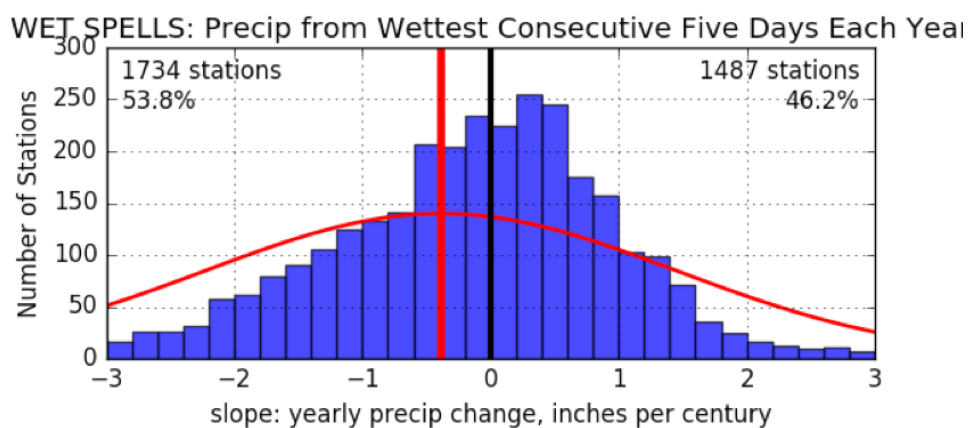
Figure 14. Same as figure 8 but for precipitation.

PRECIPITATION EXTREMES: HISTOGRAMS

a.) Wettest Days: Varied



b.) Wettest Spells: Varied



c.) Dry Spells: Varied

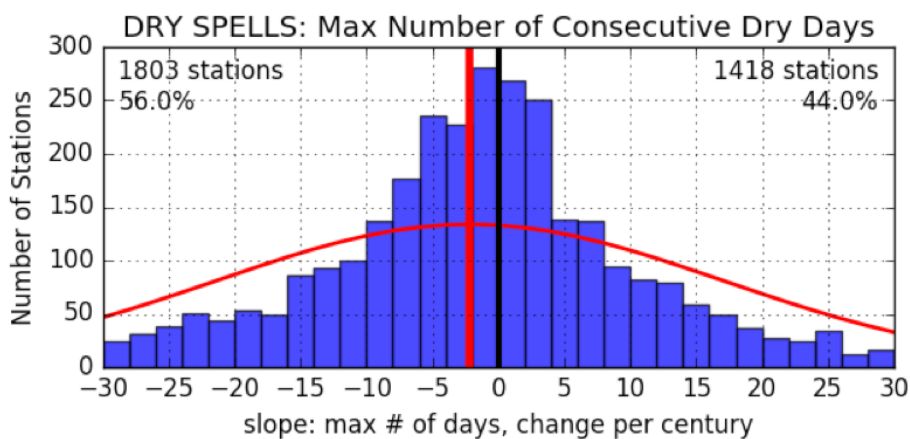
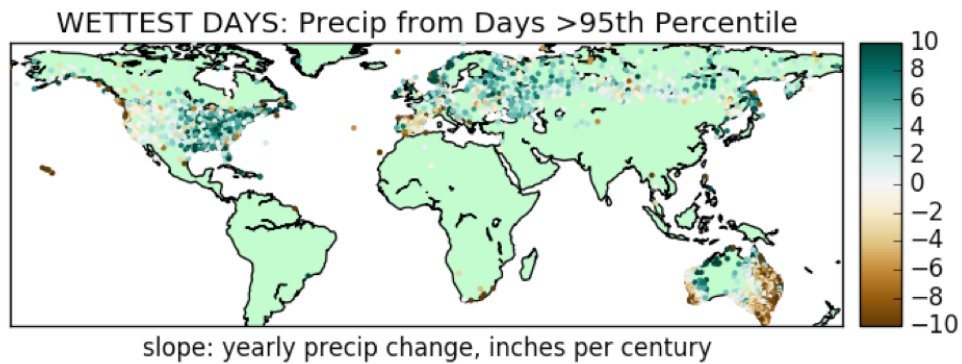


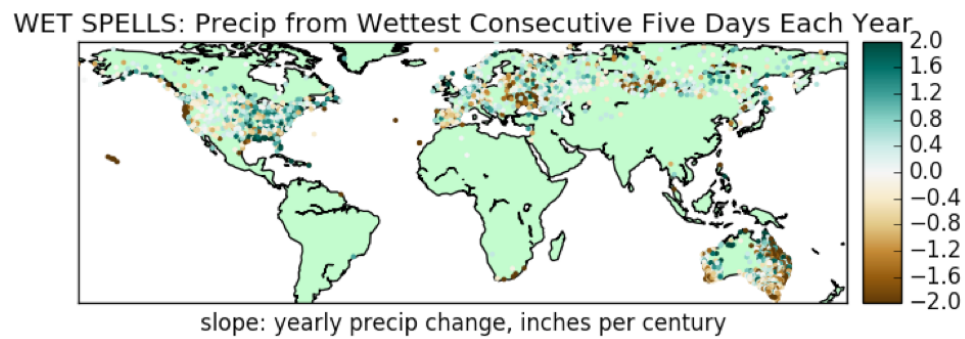
Figure 15. Same as figure 10 but for precipitation extremes.

PRECIPITATION EXTREMES: MAPS

a.) Wettest Days: Varied



b.) Wettest Spells: Varied



c.) Dry Spells: Varied

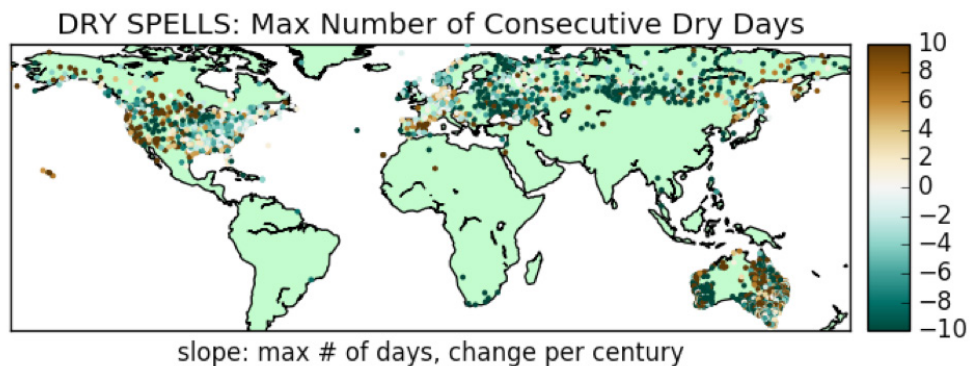


Figure 16. Same as figure 11 but for precipitation extremes.

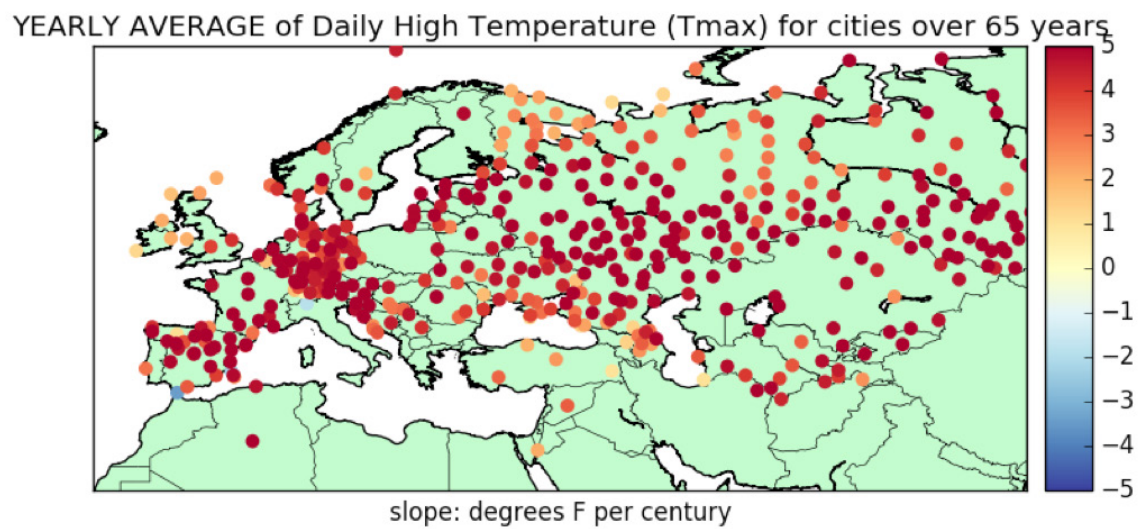


Figure 17. The change in yearly high temperature in Europe

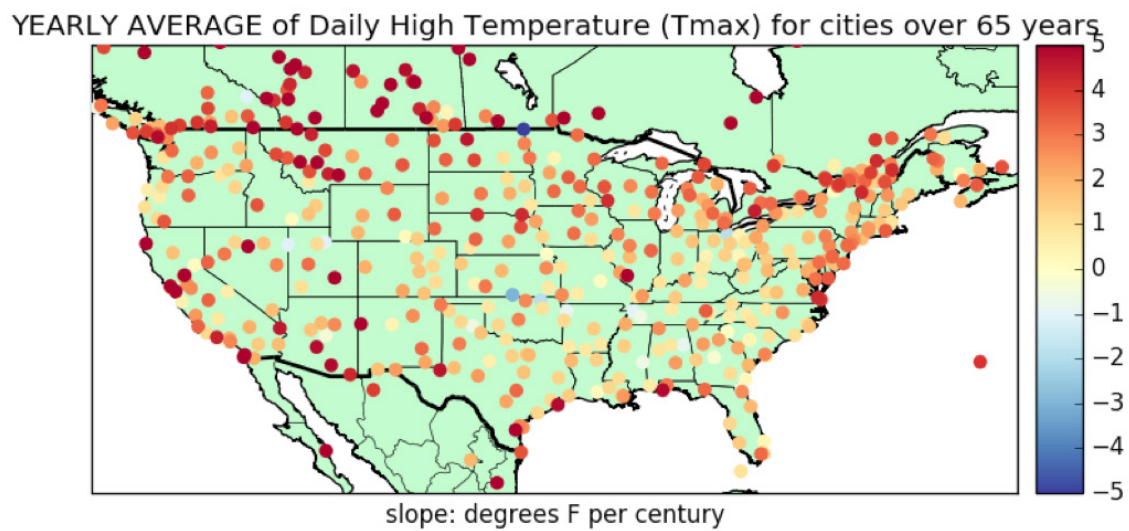


Figure 18. The change in yearly high temperature in the U.S.

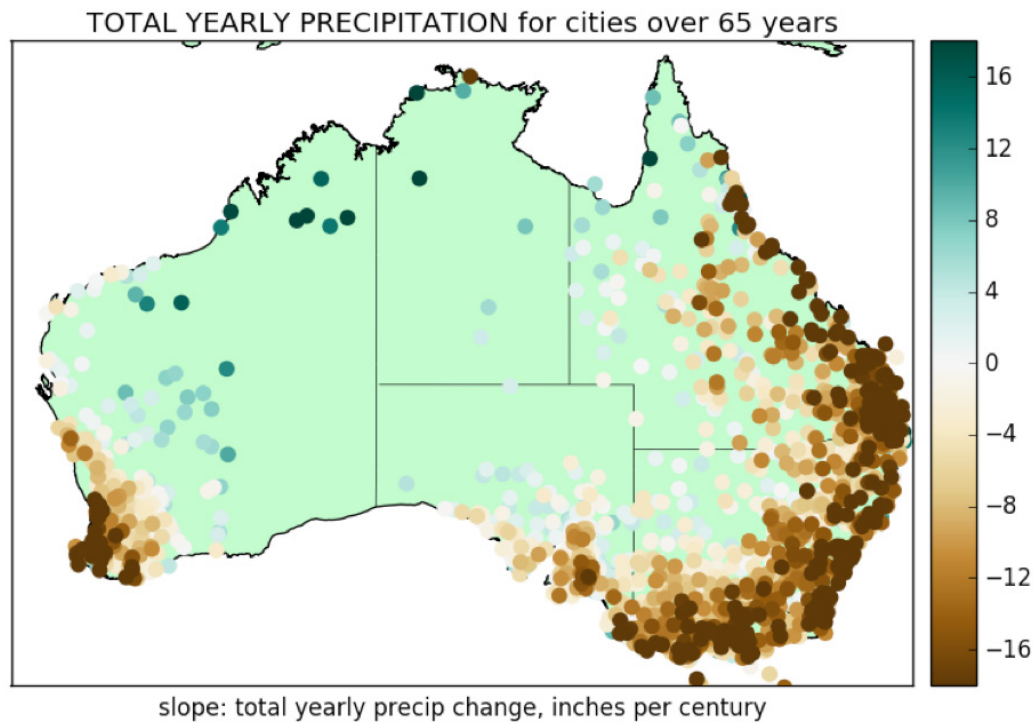


Figure 19. The change in yearly high temperature in the Australia

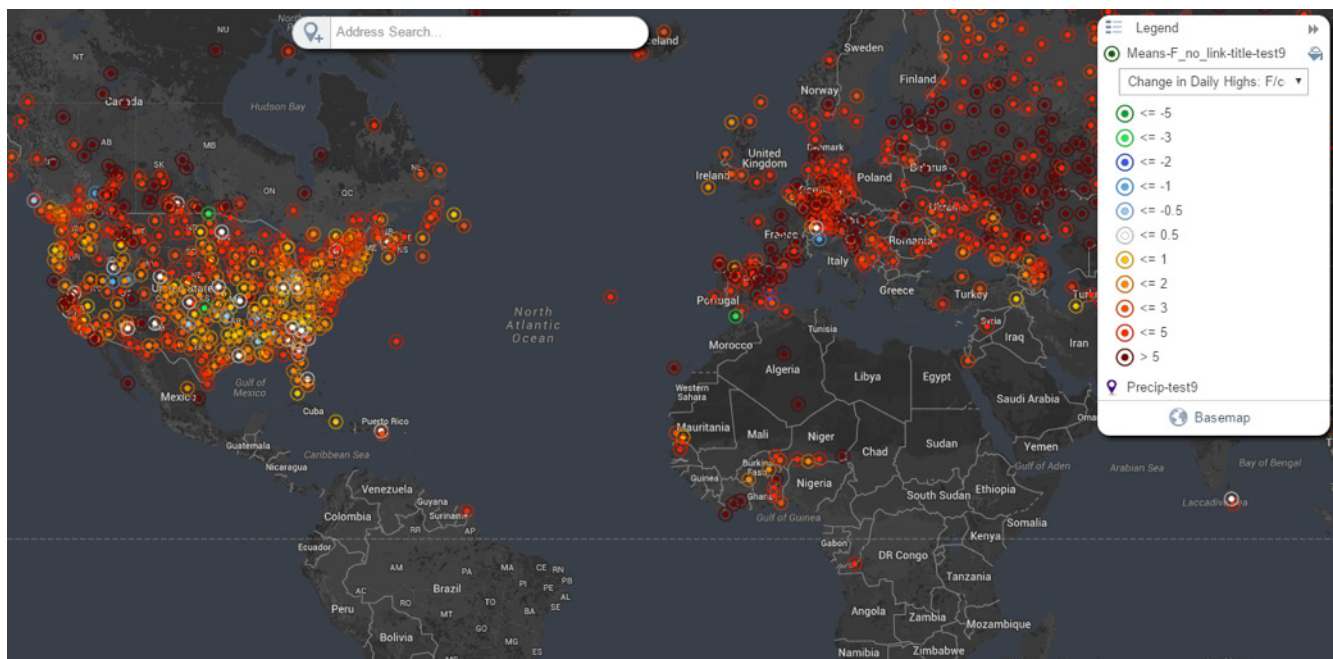


Figure 20. Online interactive map, planned for use as a museum display. See <http://lillianpetersen.github.io>

Effect Of Natural Antibiotics on the Antibiotic Resistance of *E. coli* k12

Alex Silverhart, Albuquerque Institute of Math & Science

The constant use of synthetic antibiotics has led pathogenic bacteria, such as *E. coli*, to develop a resistance against these antibiotics. Natural antibiotics may be able to inhibit the antibiotic resistance of pathogenic bacteria. The researcher hypothesized that natural antibiotics would be able to inhibit antibiotic resistance better than synthetic antibiotics. The Kirby-Bauer disk diffusion method was used to analyze the antibiotic resistance of *E. coli* k12 against cinnamon, oregano, clove, and ampicillin. The results showed that ampicillin created an average inhibition zone of 30-millimeters while the natural antibiotics created a 21-millimeter average inhibition zone in the first week, showing the antibiotics' effectiveness. By week five, the ampicillin inhibition zone had decreased by 22-millimeters while the natural antibiotics' inhibition zones had decreased by 5-millimeters on average. This information shows that natural antibiotics cause the bacteria to develop resistance over a longer period, indicating that the hypothesis was correct. The bacteria had a greater resistance against the more effective antibiotics than it did against the less effective antibiotics. Future research could be conducted by using a wider variety of antibiotics as well as pathogenic strands of bacteria, allowing there to be a further confirmation of the hypothesis.

INTRODUCTION

Escherichia coli are a variety of bacteria found in the intestines of warm-blooded animals. Although most of the *E. coli* present on earth are harmless and are important to the human intestinal tract, certain strains of pathogenic *E. coli*, such as *E. coli* O157, cause diarrhea, urinary tract infections, respiratory illness, and pneumonia. Pathogenic *E. coli* are transmitted to humans through ingesting contaminated water, undercooked meat, and raw vegetables that have been exposed to the bacteria. (CDC, 2015). *E. coli* can pose a major risk to human health. A number of methods are used to lessen this risk, including antibiotics.

Antibiotics are medications that can either destroy or inhibit the growth of bacteria. Antibiotics have two main different purposes: to kill bacteria (called bactericides) and inhibit the multiplying of bacteria (called bacteriostatic) (Nordqvist, 2015). Antibiotics can be divided into two groups based on the way they are produced: synthetic and natural. Natural antibiotics develop from nature. Cinnamon, oregano, and clove can be considered natural antibiotics due to the antibiotic properties they contain. Synthetic antibiotics are antibiotics that are chemically created by humans to kill specific bacteria. Most synthetic antibiotics tend to work faster and more efficient than natural antibiotics. Synthetic antibiotics are extremely effective, sometimes to a point where

they occasionally kill the harmful bacteria as well as the needed bacteria.

Natural antibiotics kill the pathogenic bacteria and enhance "the body's natural capacity to fight off such bacterial infections in the future" (Chan, 2011). This experiment's results will show the difference between synthetic and natural antibiotics in the way they affect antibiotic resistance.

Antibiotic resistance is the outcome of bacteria developing a resistance against a certain antibiotic, causing the bacteria to be less effected by the antibiotic (General Background: About Antibiotic Resistance, 2014).

Antibiotic resistance is observed through using the Kirby-Bauer disk diffusion susceptibility test. This test consists of applying antibiotic infused filter paper disks onto a bacterial surface, allowing the antibiotic to diffuse throughout the bacteria. This forms an inhibition zone, or a zone of no bacterial growth (Hudzicki, 2009). A study was formed to observe if *E. coli* k12 could develop antibiotic resistance against natural antibiotics and if so, how does this data compare to the development of resistance in *E. coli* against synthetic antibiotics.

METHODS

The controlled variables included the strain of bacteria used, the type of agar used, the temperature of the

incubator, the intervals between the measurements of the inhibition zones, and the type of filter paper used to create the saturated filter paper disks. The changed variable was the antibiotic that was used in each culture. The independent variables were the bacteria, antibiotics, incubator, conditions of the bacteria, the agar, and the filter paper. The dependent variable was the inhibition zone left by the bacteria as a result of the antibiotics. The data was measured in the unit of millimeters and represented the measurement of the inhibition zone diameter of each disk. The bacteria were cultured in a 37°C incubator where temperature, sunlight, and other outside contact did not disrupt the outcomes of the experiment. The Kirby-Bauer disk diffusion method was used in testing antibiotic effectiveness and antibiotic resistance.

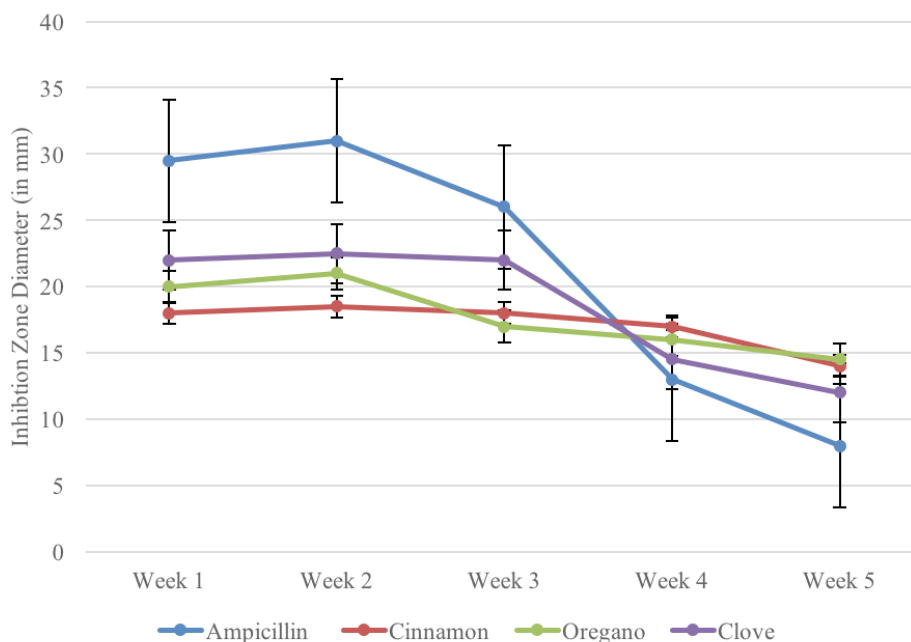
LB agar was used as the nutrients to sustain the *E. coli* k12. *E. coli* k12 was then swabbed onto the agar plates in three different directions to ensure that the plate was fully covered with bacteria using a sterilized cotton swab. This was done to five different plates, and they were then labeled “Control,” “Cinnamon,” “Oregano,” “Clove,” and “Ampicillin.” The agar petri dishes were incubated at 37 °C for three days.

One gram of cinnamon, oregano, and clove were separately mixed with 50 milliliters of distilled water in beakers. The solutions were mixed until the water had dissolved the spices. Nine five-millimeter sterilized filter

paper disks were made using the hole puncher. Then, three filter disks were dipped into separate solutions using the forceps. Next, the filter disks were placed onto the agar plate that had the name that corresponded with the antibiotic that the disk was saturated in. The three disks were placed in the center of the plate. The disks did not touch each other but were very close together. Three prepared ampicillin disks were placed in the middle of the “Ampicillin” labeled plate. The agar plates were then placed in the incubator at 37°C for one week.

Another agar plate was prepared with plain filter disks dipped in distilled water, acting as a control group. This was done to confirm that the filter paper disks and the distilled water had no antibiotic properties themselves.

Every week for five weeks, the inhibition zone was measured in millimeters using a ruler. The inhibition zone was measured from one side of the inhibition zone to the opposite boundary under a microscope. The data was recorded in a scientific journal. The process above was repeated every week for five weeks. Every week, the bacteria surrounding the inhibition zone’s border was swabbed using a sterilized cotton swab submerged in water. This bacterium was used as the suspension bacteria. For example, the bacteria surrounding the inhibition zone of the cinnamon was swabbed and put into a new petri dish that was labeled. This entire process was repeated three times, resulting in three complete trials.



Graph 1. Shows the average inhibition zones for trial one.

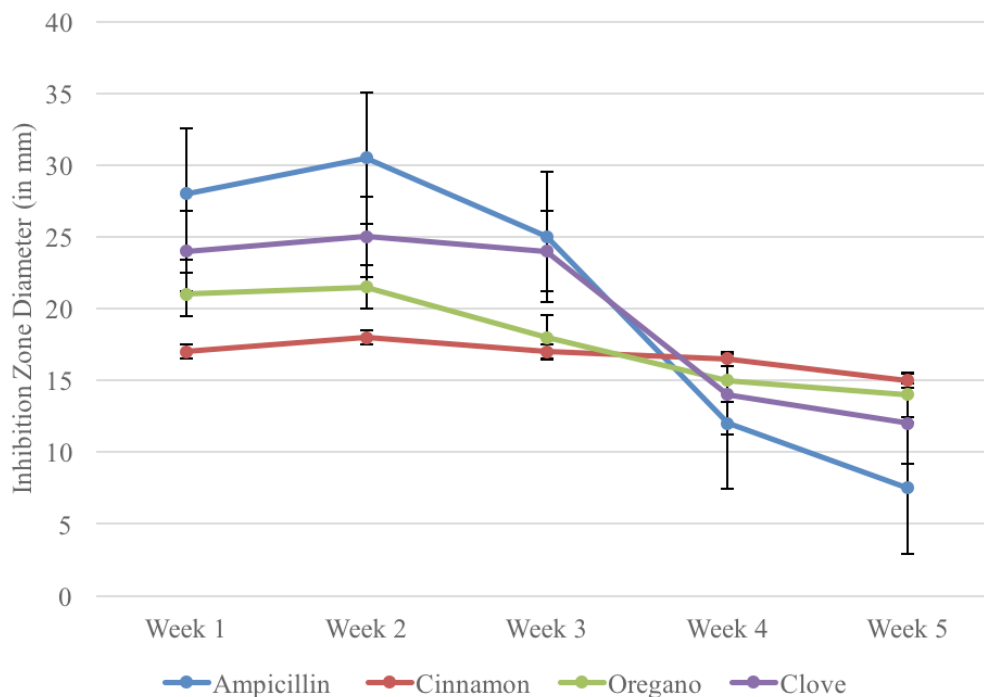
RESULTS

Graph 1 displays the decreasing inhibition zone diameters over a five-week period. The decrease in the inhibition zone represents the decreasing effect of the antibiotic and the increase amount of bacterial resistance. In week one, ampicillin created the largest inhibition zone diameter. During week two, the inhibition zone diameter increased by 0.5 to 2 millimeters for every culture, showing no antibiotic resistance. In week three, the bacteria began to develop antibiotic resistance. In weeks four and five, ampicillin decreased to 8mm while the natural antibiotics inhibition diameters decreased by 4 to 10 millimeters. As shown by the standard deviation lines, there is room for human error. This can be caused by falsely measuring the inhibition zone by adding or deducting millimeters, unequally swabbing the bacteria across the four plates, or other human errors. For the data for ampicillin in week four, the data point is outside the barriers of the standard deviation, showing that human error was present.

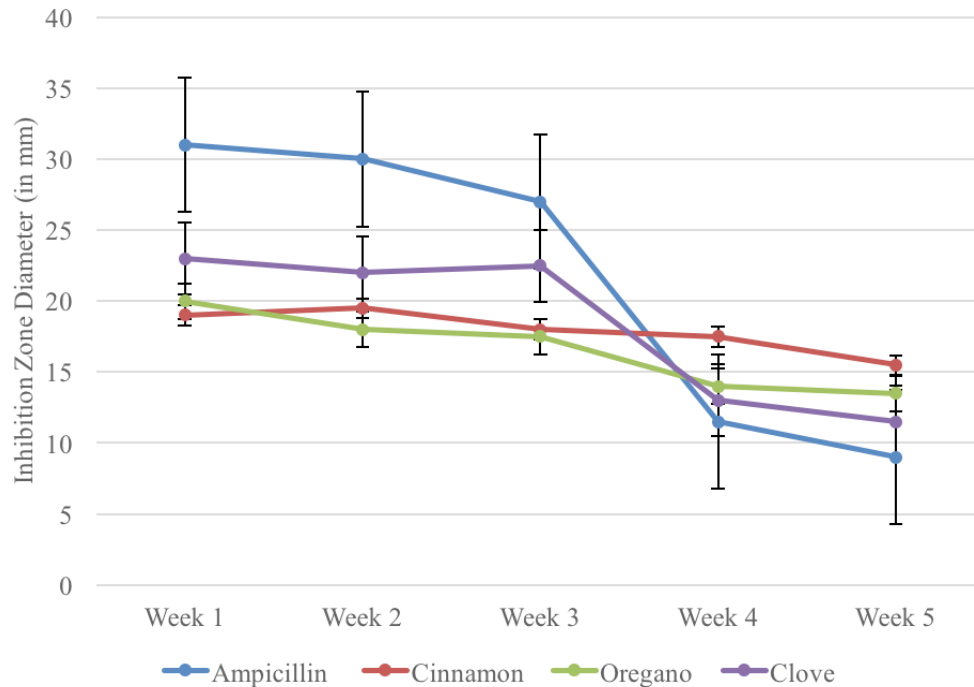
Week one and week two show a small increase in the inhibition zones, representing little to no antibiotic

resistance. As shown, there is a decrease in week three, representing antibiotic resistance. By week five, ampicillin had decreased to less than half of its length in week one while cinnamon and oregano decreased by a five-millimeter average. In this graph in particular, the error bars are constantly overlapping one another, showing that the data in trial two is less reliable than trial one's data. This is so because the standard deviation shows the range of possible numbers for one data point due to human error. When these standard deviations overlap, it is stating that due to human error, the data is not very reliable. For example in the first three weeks of trial two, the standard deviation lines of ampicillin and clove overlap stating that clove could possibly have a higher inhibition zone diameter than ampicillin if no human error occurred.

Ampicillin created the largest inhibition zone, while the inhibition zones of the natural antibiotics were 10 millimeters less in week one. In week two, most of the bacteria was already resisting the antibiotics. In ampicillin, oregano, and clove, the inhibition zones decreased, while cinnamon's zone increased by 0.5 millimeters.



Graph 2. Displays the average inhibition zones for trial two.



Graph 3. Shows the average of the inhibition zones for trial three.

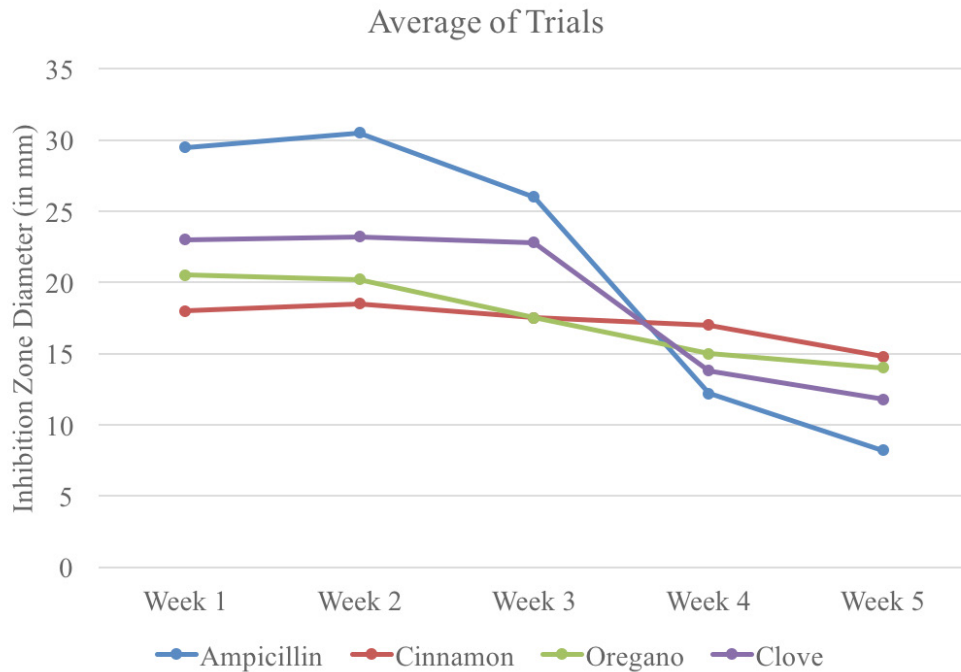
Week three showed a greater decrease in the inhibition zone for every antibiotic. Ampicillin's inhibition zone decreased by 16 millimeters while the natural antibiotics had decreased by less than 10 millimeters. By week five, ampicillin and clove had inhibition zone diameters under 12 millimeters, while oregano and cinnamon's inhibition zones had decreased less. Each graph has small differences in data measurements and overlaps between standard deviation lines. In trial three, the oregano's inhibition zone diameter had dropped below the measurements of cinnamon by week two, but few extravagant outliers or overlaps were observed.

All of the inhibition zones had decreased between a range of 3-25 millimeters. The smaller the difference between the first week's inhibition zone and the fifth week's inhibition zone, the smaller the antibiotic resistance. Ampicillin had created the largest inhibition zone in the first weeks and decreased the most by week five. Cinnamon created the smallest inhibition zone in the first weeks and decreased the least by week five. Oregano and clove had created a somewhat large inhibition zone in-between 20 and 25 millimeters and decreased by about 7 millimeters over the five-week period. Both ampicillin and clove had an inhibition zone diameter less than 13 millimeters by the end of the five-week period,

showing antibiotic resistance. Due to human error, this data cannot be solely relied on, yet it creates foundationally knowledge on the study of natural versus synthetic antibiotic resistance created by *E. coli* k12.

DISCUSSION

The researcher hypothesized that natural antibiotics would inhibit the antibiotic resistance of *E. coli* k12 greater than synthetic antibiotics would because they create a resistance against bacteria while killing the bacteria as well. The hypothesis was supported through the data received. The natural antibiotics of cinnamon, clove, and oregano inhibited the bacteria's resistance greater than the synthetic antibiotic of ampicillin. Ampicillin and clove had both had inhibition zones under 13 millimeters by the end of the five week period, showing antibiotic resistance. Cinnamon inhibited the bacteria's antibiotic resistance the most, while oregano inhibited the resistance as well. One reason for this is natural antibiotics enhance the capability to fight off bacteria. This means that natural antibiotics make it more difficult for the bacteria to gain resistance. Another possible reason is that the natural antibiotics were less effective than ampicillin. The bacteria may have a greater chance



Graph 4. Shows the average of the inhibition zones over the three trials.

of gaining resistance towards stronger antibiotics rather than weaker antibiotics. The natural antibacterial agents in these natural antibiotics also could have caused the bacteria to gain resistance over a longer period. Errors were made in the experimentation. When applying the strands of bacteria, it was very difficult to swab precisely around the inhibition zone. During week four, the supply of agar dishes had ran out. Agar was ordered online, delaying the data collection. The incubator in which the experiment took place was being accessed by multiple other people, possibly resulting in a mistake in the data.

Many suggestions can be made to improve the experimental idea of this project. Different strands of pathogenic bacteria, such as salmonella and other strands of *E. coli* could be used to see the difference in antibiotic resistance between different strands of bacteria. Different methods could be used to test the antibiotic resistance rather than using the Kirby-Bauer disk diffusion method. Different antibiotics could be used as well and the experimentation could go longer than five weeks. Changing these things would enhance the amount of detail in the results and increase the variety of data. Using more professional equipment, such as a certified lab with real pathogenic *E. coli*, would cause the data to be more

exact and relatable to the occurrences of bacteria in consumables.

The knowledge gained from this experiment can be applied to daily life in many ways. In the past months, pathogenic bacteria have been found in spinach, cucumbers, ground beef, celery, etc. This information can be used by food cleaning facilities so they can use the antibiotic that inhibits antibiotic resistance the most. This information can also aid doctors in creating medicines that inhibit antibiotic resistance as well as killing the pathogenic bacteria. Although not all antibiotic treatments last for five weeks, the experiment showed the different stages of antibiotic resistance, acting as a representation of antibiotic treatments, either long or short, in general. This experimentation can lead to further research and trials on improving the antibiotic properties of cinnamon, oregano, and clove without decreasing their ability to inhibit bacterial resistance. If these natural antibiotics could be as operational as synthetic antibiotics, they would be effective and could inhibit bacterial resistance. Future research could also be done on the correlation between the effectiveness of the bacteria and the bacteria's ability to gain resistance towards the certain antibiotic.

ACKNOWLEDGMENTS

I would like to thank many people for helping me during the process of this experimentation. Michael Harris, a ninth grade biology teacher, helped with swabbing the bacteria, supervising the experimentation, and measuring the inhibition zones. Scott Wilcox and Linda Fey also aided in revising the paper and supervising the experiment. Reginald Tyler allowed me to use the school's incubator. My parents and friends are also thanked for helping gather the materials and preparing the experiment.

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AUTHOR INFORMATION

Alex Silverhart
Colorado Early Colleges Parker
7319 Rochester Ct
Castle Pines, Colorado 80108
amsilverhart99@gmail.com
(505) 515-4340

New Mexico Academy of Science 2016 Awards for Outstanding Science Teaching

Kevin Sebastian

El Camino Real Academy, Santa Fe

Kevin Sebastian is currently a 3rd grade dual-language teacher at El Camino Real Academy, Santa Fe Public Schools, Santa Fe, NM. He is an adamant believer in the power of inquiry science instruction in both English and Spanish to nurture his students to become the scientists they naturally are. He broadens his students' perspectives as he guides them through the scientific practices of data collection, discovery, argumentation, and discussion.

Mr. Sebastian earned an M.Sc. degree in Agronomy from Oregon State. Prior to becoming a teacher he worked for seven years on different agricultural projects in several countries in Latin America. He received his teaching certificate through the Santa Fe Community College Teacher Academy.

For the past eight years he has been the science fair coordinator for El Camino Real Academy. He says "I like the science fair process, as it allows our students to have direct contact with scientists (the judges) and enables students to share their ideas with a wider audience. I think science truly allows students to think outside the box. I never tire of watching their delight upon making new discoveries and their eagerness to share with others their newfound knowledge."

Jodie Guillen

Moriarty Middle School, Moriarty

Jodie Guillen is currently a science teacher for 6th and 7th grades at Moriarty Middle School in Moriarty, NM. She is committed to providing her students with authentic, hands-on, learning experiences for the 21st Century, including the daily use of technology. She is pursuing a master's degree in Curriculum and Instruction from Grand Canyon University, and was one of a limited number of educators selected from around the planet to attend Space Camp this past summer in Huntsville, Alabama.

In 2015 and 2016, Ms. Guillen was selected to participate in the Research Experience for Teachers (RET) at the University of New Mexico where she worked in engineering labs with professors and students and developed project-based learning units which have been approved for publication on Teach Engineering, a national database for teachers. She credits the RET program with introducing her to grant writing. She has used her skills to gain funds for an after-school STEM program, a 3D printer, and special programs including planetarium presentations, Solar Outreach, the Google Expeditions Program, and the Sally Ride EarthKAM program (as well as badly needed basic supplies) for her Title 1, minority-majority, rural school.

She is also one of five teachers recently selected as a Jacob's Educator for the 2016-2017 school year. This prestigious award recognizes preK-12 teachers from throughout the U.S. who use technology to support inquiry-based teaching in their classrooms. During her tenure as a Jacob's Educator she will be working with the School of Education at Indiana University Bloomington to create research-to-practice briefs that will provide outreach to other teachers on research with technology.

New Mexico Academy of Science Research Symposium

SYMPOSIUM WELCOME FROM 2016 NMAS PRESIDENT

On behalf of the New Mexico Academy of Science, I would like to welcome each of you to the 2016 Research Symposium! NMAS is pleased to partner with New Mexico EPSCoR and sponsor this annual conference to promote science and science education in our community. Our keynote speaker, Sandra K. Begay is a Principal Member of Technical Staff at Sandia National Laboratories, and has been a UNM Regent, a UNM Foundation Board Member, and Executive Director for the American Indian Science & Engineering Society. Join us for her lunchtime presentation, a day of interesting and engaging presentations by students and professors, and finally for the poster awards as well as the NMAS Outstanding Teacher awards in our state.

Shanalyn A. Kemme
NMAS President

ABOUT THE RESEARCH SYMPOSIUM

The 2016 New Mexico Academy of Science Research Symposium was held in Albuquerque on 05 November 2016. The Symposium was sponsored by the New Mexico Academy of Science (NMAS), the New Mexico Experimental Program to Stimulate Competitive Research (NM EPSCoR), and the University of New Mexico Center for Water and the Environment. The Symposium schedule included 32 oral presentations and 52 poster offerings from the students and faculty of New Mexico's universities and colleges. Sandra Begay of Sandia National Laboratories provided the luncheon keynote address. Abstracts of these presentations are included in this annual volume of the NMAS *New Mexico Journal of Science*. The Symposium closed with the presentation of awards for what were judged to be the best undergraduate posters, and with the New Mexico Academy of Science's two annual awards for Outstanding Science Teaching.

KEYNOTE SPEAKER: SANDRA BEGAY

As Native woman engineering, I have had unique career opportunities from managing facility projects to supporting Executive strategic plans to leading a national non-profit. Today, I am working to "save the planet" by supporting Native American tribes with their renewable energy projects. I was taught as a Navajo woman that I should "Walking in Beauty—Navajo way of life" no matter the situation. Join me as I share my journey along an ever-changing path.

A former regent of the University of New Mexico, Ms. Begay joined Sandia National Laboratories in 1992 and is now a Principal Member of its Technical Staff. She heads Sandia's technical efforts in the Renewable Energy Program to assist Native American tribes with renewable energy development. Ms. Begay is a former Executive Director of the American Indian Science and Engineering Society (AISES), former chair of the AISES Board of Directors, and the recipient of the AISES Lifetime Achievement Award. Ms. Begay recently received the Alumni Circle Award from the National Action Council for Minorities in Engineering (NACME) for her lifetime contributions to the advancement of Native American students in science, technology, engineering and math (STEM) education and careers.

ABOUT THE SYMPOSIUM SPONSORS



New Mexico Academy of Science

Founded in 1902, the New Mexico Academy of Science has been in continuous existence since 1915. The Academy is a member of the National Association of Academies of Science (NAAS) and an affiliate of the American Association for the Advancement of Science (AAAS). The New Mexico Academy of Science works with teachers, state agencies, and the legislature to establish appropriate standards for the teaching of the sciences. The Academy can also act as a resource center, providing scientific advice and expertise to these groups and others. The Academy goals are to foster scientific research and scientific cooperation, increase public awareness of the role of science in human progress and human welfare, and promote science education in New Mexico. Visit www.nmas.org to learn more.



UNM Center for Water & the Environment

The mission of the Center for Water and the Environment at the University of New Mexico (UNM) is to increase the participation of underrepresented minorities (URM) in science, technology, engineering and math (STEM) professions while conducting cutting-edge research into technological and engineering-based solutions to problems with water and the environment, in a framework that considers the social, economic, policy, regulatory, and legal implications. Practical solutions to problems related to water availability in arid environments and in times of drought, and problems associated with energy generation and consumption are particularly relevant, in light of the criticality of these issues to the state of New Mexico, the southwestern United States, and their global importance. Learn more at cwe.unm.edu.



New Mexico EPSCoR

The New Mexico Established Program to Stimulate Competitive Research (NM EPSCoR) is funded by the National Science Foundation (NSF) to build the state's capacity to conduct scientific research. The infrastructure and activities of Energize New Mexico are designed to support shared-use equipment, engage new research and community college faculty, and support the STEM pipeline by training teachers, undergraduate and graduate students, and post-doctoral fellows. Research findings are communicated broadly through partnerships with New Mexico's museum network, a citizen-centric web portal, and vibrant, experiential programs targeting K-12 students. Visit www.nmepscor.org to learn more about NM EPSCoR, and visit www.nsf.gov/epscor to learn more about the NSF EPSCoR initiative and other jurisdictions.

CONCURRENT SESSION PRESENTATION ABSTRACTS

SESSION A: ENERGY & ECONOMICS

Modeled impacts of economics and policy on historic uranium mining operations in the Grants Mineral Belt, New Mexico

KATIE ZEMLICK, UNIVERSITY OF NEW MEXICO

The Grants Mineral Belt in Northwestern New Mexico was at the forefront of the nuclear age, producing more uranium than any other mining district in the U.S. for more than three decades until the early 1980s. This region is also unique because these historic activities have been studied and quantified over the last three decades, providing a unique opportunity for evaluating the factors that influenced past mining operations. The objective of this study was to improve understanding of the role that economic and policy factors played in the operation of mines in the Grants region using a system dynamics modeling framework. Mines operating from 1948 to 1980 were grouped by size and type and optimal price and competition values were quantified over four policy environments resulting from federal legislation and policies associated with U markets. The results of this work found that as the industry evolved over time, the influence of these factors changed and that they did not impact all mining operations equally. Changes in price and competition from larger mines influenced open and closure and varied in response to national U and nuclear policy. Perhaps because small mines operated only in the nascent stages of U policy development, results for medium and large mines were more accurately represented historic data than did small mines. Perhaps more significant than the modeled results was the development of a modeling framework to understanding the relationships between price and policy on U mining operations that have been widely discussed but never quantified. This approach has utility in understanding the dynamic relationships between natural resource development and economics subject to changing policy and regulatory environments.

Keywords: uranium mining, economics, policy, systems modeling

The impact of air pollution on emergency room visits for respiratory diseases in New Mexico

NA LU, UNIVERSITY OF NEW MEXICO

Though the impact of air pollution on health has been addressed in existing literature, little research has been conducted in areas with moderate levels of air pollution. Air pollution in New Mexico mainly comes from coal-fired power plants in Northwest, oil and gas production in San Juan and Permian Basin, transportation and energy consumption in the middle Rio Grande Area. As Clean Power Plan proposed, reducing coal-fired power plants will also lower the air pollution level, which will reduce total health cost in New Mexico. This paper utilizes a fixed effect panel model to estimate the impact of three major air pollutants on emergency room visits for respiratory diseases in New Mexico. Employing a dataset covering five counties in New Mexico from 2010-2014, we find that ozone has a significant impact on respiratory emergency room visits. The result indicates that 1 ppb (2% of current level) decrease in monthly average ozone level will on average decrease 1.887 emergency room visits per 100,000 people per month for respiratory diseases. Using San Juan County as an example, if we reduce 5 ppb of monthly average ozone level by implementing Clean Power Plan, there will be about 12 less ER visits for respiratory diseases per month. In separate analysis on different age groups, the effect of ozone on respiratory emergency room visits is significantly positive for children age 1-14 and adults age below 45 which might be caused by more exposure to air pollution than other age groups.

Keywords: air pollution, ozone, emergency room visits, New Mexico

Willingness to pay to meet clean power plan requirements: Evaluation of New Mexico's options to meet requirements

KARA WALTER, UNIVERSITY OF NEW MEXICO

New Mexico (NM) is a top US fossil-fuel producer and energy contributes to the state's budget—over 30% of the General Fund in 2013. A push towards renewables through the renewable portfolio standards and the Clean Power Plan (CPP) to reduce emissions could impact this. While the CPP lets each state choose their own path for reductions, suggested methods are to improve coal efficiency or increasing natural gas use and/or renewables. Specifically, NM's reduction requirement is 36% from 2012 levels (EPA 2015). The state's energy plan argues for an "all of the above approach" (NM EMNRD 2016). The extant literature primarily focuses on comparing preferences for characteristics and tradeoffs between different renewable energies. We contribute to this literature by considering the tradeoffs between energy sources themselves, that is fossil fuels and renewables, when policy requires a change in the energy mix. To evaluate NM's response to the CPP, we employ a choice experiment and evaluate each of NM's options to meet the requirements. Utilizing multinomial logit and random parameter models we find observable differences in preferences (living in fossil fuel producing county, climate change opinion, and political leanings) and unobservable heterogeneity. The difficulty in developing policy under these conditions is evident if we consider the largest electricity provider in the state's plan to increase electricity from nuclear power. We find significant variation in preferences; some are highly supportive of nuclear while others are highly opposed. These outcomes suggest challenges in energy policy development, but also directions residents will support.

Keywords: energy preferences, choice experiment, carbon emission reduction

State and local potential socioeconomic and environmental impacts from proposed renewable energy projects: A case study of New Mexico

JAMAL MAMKHEZRI, UNIVERSITY OF NEW MEXICO

Recent federal legislation, such as Clean Power Plan, is motivating the move away from coal-fired electricity generation to increase renewable resources. This provides a mechanism that can result in reduced Greenhouse Gas emissions and saving water, but may also impact economic growth and jobs in the state. The goal of this research is to assess the trade-offs of increasing renewable energy at the county and plant level in terms of jobs and economics, as well as greenhouse gas emissions and water. An analysis of these twelve potential renewable energy projects, constituting nearly 1,202 MW of power capacity, are estimated to result in close to 4,753 job-years during construction period from 2015 to 2019 in New Mexico. Over the operations period beyond construction, we demonstrate that statewide projects are estimated to result in 131 onsite jobs and 183 total jobs annually over the life of the plants. These projects are mainly located in the eastern part of New Mexico, which is a potential boom for economic development of the area. The expected amount of electricity that could be generated from these 12 renewable energy plants and replacing equivalent amount of coal-fired electricity would result in saving 44,000 million gallon of water, along with avoiding 81 million tons of greenhouse gases.

Keywords: renewable energy, economic impacts, environmental impacts

Waste or resource? Understanding the trade-offs between produced water management strategies in New Mexico

KATIE ZEMBLICK, UNIVERSITY OF NEW MEXICO

Hydraulic fracturing (fracking) has revolutionized the fossil fuel industry by enabling oil and gas production from low-porosity shale reserves. However, fracking itself requires large volumes of water and subsequent oil and gas production generates large volumes of produced water which has historically been considered a waste product requiring disposal. However, in arid regions such as New Mexico, produced water reuse is increasingly being considered as a

resource that may reduce demand for limited freshwater supplies, diminish costs associated with transportation and deep well disposal, and reduce the risks for injection induced seismicity. The objective of this study is to quantify the spatial variation in energy demands and costs associated with produced water management strategies using a spatially-based system dynamics model. Management strategies include procurement and transportation of fresh water for fracking, treatment and reuse of produced water for fracking, and transportation and disposal of produced water via deep well injection. Results indicate that conventional disposal is in many cases less energy intensive than treatment and reuse, but fresh water acquisition can exceed energy requirements for produced water disposal in some regions of the state. In addition, the costs and energy requirements associated with produced water management vary dynamically, where changes in oil and gas production impact both fresh water availability and deep well disposal capacity. This approach highlights the spatial and temporal variation in energy requirements and tradeoffs between produced water management choices, energy, costs, and impacts on critical freshwater resources.

Keywords: produced water, hydraulic fracturing, systems modeling

SESSION B: SYNTHESIS & CATALYSTS

Reactive transport of U and V from abandoned mine waste sites

SUMANT AVASARALA, UNIVERSITY OF NEW MEXICO

In this study, we investigate the reactive transport of uranium (U) and vanadium (V) from abandoned mine wastes collected from Blue Gap/Tachee, AZ by integrating flow through column experiments, reactive transport modelling (PFLOTRAN), and electron microscopy. Transmission electron microscopy (TEM) integrated with selected area electron diffraction (SAED) and electron dispersive spectroscopy (EDS) was used to identify amorphous and crystalline U-V phases in unreacted mine waste sediments. The sediments were sequentially reacted with 18MΩ water (pH 5.4), 10mM HCO₃Ω (pH 7.9) and 10mM CH₃COOH (pH 3.4) to simulate relevant oxidizing conditions encountered at the Blue Gap/Tachee mine site and investigate the reactive transport of U and V. Reactive transport simulations of mine wastes reaction with 10mM HCO₃Ω and CH₃COOH suggest dissolution of U-V bearing mineral phases as a key process controlling transport of U and V, attributing difference in their release to different U and V phases, possibly to the identified multi-crystalline U-V phases. Therefore, this study provides insights of interfacial processes affecting the transport U and V in water resources adjacent to mine wastes.

Keywords: uranium, vanadium, mine wastes, transport modeling

Utilizing negative electron affinity semiconductors in photocatalyzed reduction of nitrogen to ammonia

MICHAEL HEAGY, NEW MEXICO TECH

Since the discovery of the Haber-Bosch process for the production of ammonia from nitrogen, a few milestones have advanced this technological challenge. Beginning with dinitrogen cleavage coupled to Mo-Mo triple bond formation and other methods will be discussed. More recently in 1983, the solar-driven catalytic conversion of nitrogen to ammonia over semiconductor materials was reported at UCSD. This study indicated that sands from various geographic locations reduce N₂ from the air to NH₃ and traces of N₂H₄ on exposure to sunlight. From this standpoint, our team seeks to focus the sun's energy using the latest developments in semiconductor and hole-transport catalysis and theory. More recently, attention has centered on semiconductors with a large band gap and a conduction band edge that lies above the vacuum level. This special property, initially reported with diamond, is termed negative electron affinity (NEA).

Keywords: photocatalysts, negative electron affinity, nitrogen

Semiconductor-based photocatalysis for the production of solar fuels: Photoreduction of bicarbonate to formate via zinc oxide photocatalyst

VICTORIA RISLEY, NEW MEXICO TECH

Over the years, there has been a growing interest in solar fuels, which utilizes CO₂ and sunlight as a sustainable energy source. In this study, micron- and nano-sized zinc oxide (ZnO) particles, as well as ZnO nanorods, were used as photocatalysts for the reduction of bicarbonate to formate. ZnO was chosen because of its comparable band gap energy to TiO₂, a well-known photocatalyst that has proven to be efficient in bicarbonate reduction. ZnO is also non-toxic, earth-abundant, and can be synthesized easily and at low cost. The photocatalysts were tested in a bicarbonate buffer solution using two different hole scavengers (isopropyl alcohol and glycerol) using a solar simulator with air mass coefficient 1.5 (AM 1.5) to mimic natural sunlight. Formate production was quantified using ion chromatography, and productivity reached 35.4 mM Formate/g cat-hr. Glycerol was found to be a superior hole scavenger than isopropyl alcohol. Solar energy is an important renewable form of energy, and this study will help better understand the fundamentals of photophysics and catalysis processes.

Keywords: bicarbonate photoreduction, zinc oxide, formate, photocatalyst

A novel gated charge transfer complex with large ligand folding distortion

JING YANG, UNIVERSITY OF NEW MEXICO

A novel metallo-dithiolene complex, MoO(SPh)₂(ⁱPr₂Dt⁰) (where (ⁱPr₂Dt⁰ = N,N'-isopropyl-piperazine-2,3-dithione), was synthesized and examined with X-ray crystallography. This compound possesses a remarkable “envelope”-type fold angle (~70°) along the S-S vector on the ⁱPr₂Dt₀ side and bending upward toward the terminal oxo ligand. This is the largest fold angle observed for any Mo-dithiolene compound. Electronic absorption and resonance Raman spectroscopies have been used to probe the fundamental electronic structure of this system that is responsible for the large fold angle distortion. Interligand thiolate J dithione charge transfer (LLCT) leads to an intense optical transition observed at ~18 000 cm⁻¹. Combined spectroscopic studies and computational work reveal the presence of a strong orbital mixing between occupied and low-energy-lying virtual orbitals with Mo(x²-y²) orbital character. Vibronic coupling involving a very low energy total symmetric folding mode results in a strong pseudo Jahn-Teller effect, which drives the large fold-angle distortion to yield a double-well potential in the electronic ground state.

Keywords: molybdoenzymes, electron transfer, pyranopterin, rectifier

SESSION C: GEOLOGIC PROCESSES IN NEW MEXICO

Zinc, lead, copper, chromium, and arsenic accumulation associated with naturally accumulating iron-manganese oxide coatings on *in-situ* stream substrates in streams comparing geothermal and non-geothermal waters

MARGARET TURPIN, UNIVERSITY OF NEW MEXICO

Geothermal trace metals (As, Cr, Cu, Pb, Zn) can have negative health effects on humans and wildlife. Previous studies utilized *in situ* pebbles, glass, or ceramic substrates with iron-manganese oxide coatings to understand chemical cycling. Here we develop a tracing method in a distal geothermal environment (upper San Antonio river, Valles Caldera, NM) using adsorption onto substrate surfaces to better understand trace metal transport. We focus on natural oxide-hydroxide accumulation on 24mm silica bead substrates at sites near and away from geothermal inputs. Results show that adhesion of iron and manganese oxides were closely correlated at both sites and showed a positive trend of accumulation over an 8 week trial period. Manganese at the thermal vent showed a decrease at the 6 week mark potentially indicating an unknown component of reduction for that metal. The adsorption of arsenic,

chromium and lead on iron-manganese oxide coatings were significantly higher on substrates in the geothermally influenced waters than those not near the thermal input. All trace metals in the study were shown to have patterns of adsorptions and desorption over the course of the trial.

Keywords: trace metals, geothermal, water quality

Textural Analysis of Picuris-Pecos Fault Deformation: Dalton Canyon, New Mexico

WESLEY CLARY, UNIVERSITY OF NEW MEXICO

The Picuris-Pecos fault has been shown to have about 40 km of observed dextral strike slip separation due to various contributions of Laramide, Pennsylvanian, and/or Precambrian age fault slip and reactivation (e.g. Cather et al., 2000; Erslev et al., 2004; Sanders et al., 2006). Based on the regional cooling history, deformation in the Precambrian would likely be ductile while more recent deformation would be dominated by brittle features. Original field workers interpreted the main phase of deformation along the Picuris-Pecos to be Precambrian, and interpreted the observed deflection of folded units near the fault to be ductile and relatively high temperature. Other more recent studies have shown large offsets in Pennsylvanian rocks, and have proposed the main phase of dextral separation to have occurred during the Ancestral Rocky Mountain orogeny. Petrographic and structural analysis by Luther et al., 2012 proposed that ~2.5 km of observed refolding in the Hondo syncline was likely at brittle-ductile conditions and predated, or formed during, the inception of dextral shear possibly associated with Grenville age activities. In order to evaluate hypotheses proposing brittle or ductile deformation we present a pilot textural study of the Picuris-Pecos fault at Dalton Canyon based on field measurements such as foliations, and petrographic analysis of oriented thin sections collected in the area. We approach ductile deformation using a spatial analysis of foliations in the McClure quadrangle to quantify orientation near the fault, and we quantify brittle deformation by comparing grain size distributions in cataclase samples near the fault zone.

Keywords: fault, textures, deformation, spatial analysis

Influence of Laramide deformation on the Proterozoic basement in the southern Sangre de Cristo mountains, New Mexico

ZAKIYA SHIVJI, NEW MEXICO HIGHLANDS UNIVERSITY

The Las Vegas Range of the southern Sangre de Cristo Mountains is part of the southern-most subrange of the Rocky Mountains west of Las Vegas, New Mexico. Structures associated with the late Mississippian to early Permian (320-270 Ma) Ancestral Rocky Mountain orogenic event first deformed the Paleozoic cover strata that were deposited into a series of intracratonic basement uplifts. Evidence of Ancestral Rocky Mountain deformation are shown by the N-NW to S-SE striking structures throughout Colorado and New Mexico; however, many of these structures are overprinted by ones associated with the Late Cretaceous (80-55 Ma) Laramide Orogeny which resulted in broad folds, sedimentary basin development, and numerous range-frontal reverse faults. Uplift of these basement blocks and deformation of the Paleozoic-Mesozoic cover has implications for intraplate deformation, reactivation of older structures, and understanding the response of the continental lithosphere to compressive stress. The purpose of this study is to determine if, and how much, Laramide deformation affected the Proterozoic basement blocks. We hypothesize that the basement rocks were uplifted as largely intact and unrotated blocks. We further submit that Laramide deformation was accommodated in the basement by cleavage development and shearing at the Proterozoic contact - the Great Unconformity. The degree of cleavage development provides some evidence on the amount of strain the rocks have experienced. Paleomagnetic data will constrain the timing of deformation by determining the age of the magnetization (i.e. Late Paleozoic versus Late Cretaceous). To accomplish this, macrostructures (fractures, foliations, and cleavages) have been measured in the field and compared to original basement structures. Preliminary results

infer that the original basement regional structures trend NW - SE while at the Great Unconformity contact, fractures trend NE to SW and dip to the east, which supports formation during Laramide deformation.

Keywords: Laramide Deformation, Sangre de Cristos, geologic influence

Seismic and gravitational modeling of White Sands New Mexico

JASON BUTTS, UNIVERSITY OF NEW MEXICO

The purpose of this presentation will be to present further research of the region and to answer the following questions using seismic and gravitational modeling of White Sands National Monument (WSHA). WSHA is the largest gypsum dune field in the world and was formed ~7000 years ago with the retreat of Pleistocene Lake Otero: 1) What controls the location of the western dune front? The western dune front of WSHA has remained relatively fixed as shown by measurements from 1944 to 2010. This behavior is quite different from other dune fields in the region that show migration up to 35 m per year. The hypothesis is that the dune front is pinned to a now buried paleo-shoreline of Lake Otero; 2) What is the relationship between subsurface structure of the Tularosa Basin and the dune field? Fault and block geometries in our study area are currently unknown. Previous gravitational modeling has shown that the highest measurements stand in the deepest part of the basin. From this we can hypothesize that Lake Otero regressed towards the deepest part of the basin and the dune field migrates over the highest part of the basin along with the Jarilla Fault that flanks the eastern edge of the basin. Our methods include seismic and gravitational imaging and modeling that will provide a detailed image of the upper 50-100 meters and 101 km respectively. Expected outcomes, results, and conclusions of this project will provide further knowledge of the subsurface structure and the underlying basin for our study area of WSHA.

Keywords: seismic, gravity, acquisition, imaging, basin

Geothermal influences on water quality in the Jemez River

CHRIS MCGIBBON, UNIVERSITY OF NEW MEXICO

The Valles Caldera is an ideal natural laboratory for testing multi-tracer hydrochemical models of geothermal fluid outflow and mixing in distal portions of geothermal systems. Springs with an endogenic component provide evidence of the plume, while the Jemez River provides a location for mixing of different end-member fluids. The models are of relevance for exploiting geothermal potential and understanding threats to water quality. The Valles Caldera is part of a hydrothermal system which has seen extensive study with focus on assessing geothermal potential. The outflow system, the Baca Plume, flows along the fault network in San Diego Canyon. Two pathways have been suggested for the plume, one discharging at Soda Dam and the other at Jemez springs. Questions remain about the extent of the plume and distal effects of the Valles Caldera, with current research suggesting a connection to springs across the Nacimiento Mountains. Geothermal groundwater components lead to degradation of water quality in the Jemez River, a snow melt dominated system, and associated alluvial aquifer; a problem for local stakeholders. With climate change forecasts predicting reduction in snow pack, the contributions to surface water from springs takes on greater significance. Our pilot studies and historical work have used major ion and gas chemistry, and stable isotopes to define the geothermal plume and highlight mixing of different end member fluids. Preliminary geochemical mixing models show that springs at Soda Dam and Jemez Springs do not fall along a simple binary continuum. The significant differences in hydrochemistry suggest complex fault-related flow-paths.

Keywords: water quality, geothermal, jemez mountains, groundwater

NASA Swarmathon - Southwestern Indian Polytechnic Institute

EMERY SUTHERLAND, SOUTHWESTERN INDIAN POLYTECHNIC INSTITUTE

The NASA Swarmathon (nasaswarmathon.com) competition was developed by Dr. Melanie Moses and her team from the Moses Biological Computer Lab at the University of New Mexico. The first competition took place April 2016 with two more years of competitions planned. Swarmathon consisted of students automating a group of rovers (Swarmies) to collect as many April Tags as possible during a timed event (256 tags available). The Swarmies operated autonomously and can be programmed to communicate and interact as a collective swarm. There was both a physical (real world) competition and virtual (simulated) competition. The preliminary competition consisted of three rovers collecting as many april tags as possible during 30 minute heats in a 15m square arena. If teams made it to the finals the rovers increased to six, the arena increased to a 22m square and the time limit to one hour. The goal of the competition was to get students excited about STEM and thinking creatively to solve challenges. There were 12 teams nationally competing in the physical competition and 23 teams competing in the virtual competition.

Keywords: NASA, rovers, competition, simulations

Counting individual algae species from mixed population images with public domain software Ilastik and ImageJ

SARAH KINTNER, UNIVERSITY OF NEW MEXICO

Current algal research aims to determine the effects of algal communities on various analytically derived parameters such as lipid and chlorophyll concentrations. The total cell count of individual species or genera within a mixed algal culture is often desired but has not been made available except by hand. The purpose of this presentation is to provide researchers a new method for counting algae populations from mixed culture images using public domain, software Ilastik software (version 0.5, ilastik.org) and ImageJ (version ≥ 1.46 , <https://imagej.nih.gov/ij/>). In the Ilastik software, the researcher outlines separate populations on different layers and then generates .png image of each layer. Once Ilastik has trained on the first image, it can determine the individual populations for another image unsupervised. Next, the .png images are processed through an ImageJ script, which generates counts and other parameters for each layer which are saved to an Excel spreadsheet. The image data below comes from a mixed algal population, which was taken from an Olympus BX51 microscope using a hemocytometer at either 100X or 400 X magnifications using the counting method described. The average growth rate results of two 100X algae genus ($n=3$) from a mixed population nitrate-limited media study (day one to five) are: genus *Plectonema* 814,100 cells/(ml x day) and the genus *Chlorosarcinopsis* 677841 cells/(ml x day). Applying the two public domain software packages, Ilastik and ImageJ, can assist the researcher in determining algae population counts much more rapidly than by hand.

Keywords: Ilastik, ImageJ, counting algae species, algal populations

What is the best placement to maximize the effectiveness of smog reducing materials?

ROWAN CAHILL, THEODORE GOUJON, LISEL FAUST, AND RAMONA PARK, SANTA FE HIGH SCHOOL

Air pollution is a major contributor to many detrimental health and environmental issues around the world. As such, companies worldwide have been creating materials aimed at passively reducing smog concentrations in urban environments. Titanium oxide (TiO_2), a photocatalyst, is at the center of this research. The goal of this simulation was to find the most effective placement of TiO_2 bearing materials in an urban environment, from ground level infrastructure to the rooftops of high rises. Over the course of this experiment, we have researched the variables that contribute to the creation and dispersal of air pollution, as well as the materials currently in production. The model was created using NetLogo. Its primary subroutines are the diffusion of smog and the smog's interaction with

buildings along a stretch of road within a rudimentary cityscape. Full coverage application of titanium oxide bearing materials is most effective for the reduction of smog, however, it is not the most cost effective. A bottom application would be more economically feasible and the second most effective up to a point, roughly mid-day, at which time it is overcome by the smog and falls behind. We anticipate that the data acquired from our simulation could be utilized by city planners to maximize smog reduction. On a large scale and over an extended period of time this could contribute to a reduction in smog related illness and deaths, as well as global temperatures.

Keywords: pollution, reduction, smog, titanium oxide, urban

SESSION E: SPECTROSCOPY & THEORY

Ultrafast fluorescence emission decay dynamics of CdSe and CdSe/ZnS quantum dots using femtosecond time-resolved fluorescence upconversion spectroscopy

RUWINI RAJAPAKSHA, NEW MEXICO TECH

Among all synthesized colloidal quantum dots (CQDs), Cd chalcogenide (CdX; X= S, Se, Te) QDs are the most interested and widely used due to their potentials in QDs sensitized solar cells, sensing, photocatalysis and biolabeling/bioimaging for clinical diagnostics. Investigations of photophysical dynamics/kinetics of these CQDs are essential in order to use them in above applications. Our studies are focused on investigating the ultrafast fluorescence decay dynamics of various commercially available CQDs using fluorescence upconversion spectroscopy. These studies are focused on extending the studies that have been done so far in the field of CdSe core and CdSe/ZnS core shell type quantum dots using fluorescence upconversion spectroscopy. For our studies, commercial available CdSe, CdSe/ZnS and CdS samples having wide range of band gap energies were selected. During these studies we investigated the dependence of decay dynamics with core only materials and core/shell materials by selecting six samples of CdSe and CdSe/ZnS core/shell samples. Each CdSe core sample studied along with core shell sample with same absorptions and emissions. Furthermore, the study was extended to understand the effect of shell thickness on fluorescence decay dynamics. With these studies we intend to offer a better and complete insight about photoinduced ultra-fast fluorescent decay dynamics of these core/shell QDs.

Keywords: core-shell quantum dots, fluorescence upconversion spectroscopy

Molecular rectification behavior of the pyranopterin ligand of molybdoenzymes

LAURA INGERSOL, UNIVERSITY OF NEW MEXICO

Molybdenum plays an indispensable role in human metabolism, global nitrogen and sulfur cycles, the formation of greenhouse gases, bacterial detoxification pathways and anaerobic respiration, and is critical for maintaining human health and ecological balance. To become catalytically active it must be incorporated into a molecular scaffold by complexation with a singular ligand known as the pyranopterin, an arrangement commonly referred to as Moco, the nearly ubiquitous molybdenum cofactor found in molybdoenzymes. Molybdoenzymes typically catalyze the two-electron oxidation or reduction of a substrate coupled to oxygen atom transfer. The pyranopterin can adopt several distinct oxidation and tautomeric states, which we hypothesize contributes to its suspected role as an electron transfer conduit during the redox reactions catalyzed by molybdoenzymes. Our calculations reveal that the fully reduced tetrahydro pyranopterin functions as a molecular diode, and demonstrates a rectification ratio of ~ 3.4 at ± 0.4 V. The rectification behavior at ± 0.4 V is ascribed to the eigenstate containing primarily LUMO character entering the bias window at forward, but not reverse, bias. These results suggest that the tetrahydro form of the pyranopterin serves as an electron transfer conduit mediating vectorial electron transfer and favoring the dithiolene group as the electron donor. Our calculations further elucidate the nature of the transmission eigenchannels to determine how electron transfer capability is facilitated by the orbital contributions of this unique ligand.

Keywords: molybdoenzymes, electron transfer, pyranopterin, rectifier

Quantum Mechanics of Palladium Clusters

JAMES MCKEOUGH, NORTHERN NEW MEXICO COLLEGE

We study the chemisorption of different atomic and molecular species on small clusters of metallic elements, by examining the interactions of H, H₂, Li and O adsorbates with Pd_n clusters (n = 2 through 24). Such a study can reveal the effects of substrate geometry on the behavior of adsorbates. Transition-metal clusters, such as palladium clusters, are suited for the study of quantum size effects and for formation of metallic states, and are ideal candidates for catalytic processes. In this presentation, we focus on the properties clusters Pd₂ through Pd₂₄. Hybrid ab initio methods of quantum chemistry (particularly the DFT-B3LYP model) are used to derive optimal geometries for the clusters of interest. We compare calculated binding energies, bond-lengths, ionization potentials, electron affinities and HOMO-LUMO gaps for the clusters. Of particular interest are the comparisons of binding strengths at the three important types of sites: edge (E), hollow (H), on-top (T), threefold sites and fourfold sites. Effects of crystal symmetries corresponding to the bulk structures are investigated. The capacity of Pd clusters to adsorb H atoms will be considered. Admixture of Pd clusters with Ni atoms will be examined in our future work.

Keywords: palladium, clusters, computational

New insights into molecular rectification

RANJANA DANGI, UNIVERSITY OF NEW MEXICO

Metal complexes of donor-bridge-acceptor (D-B-A) biradical constitutional isomers (D: S=1/2 ortho-semiquinonate, SQ; A: S=1/2 nitronitroxide, NN) serve as constant bias analogs of molecular current rectifying devices. Biradical electronic couplings (HDA) for asymmetric bridges (B = thiophene-pyridine, T-P and pyridine-thiophene, P-T) are described in terms of McConnell's electronic coupling theory and Nitzan's correlation between electronic coupling and conductance. Magnetic exchange couplings are used to estimate a rectification ratio (RR), yielding gDTPA/gDPTA = 0.88. Analysis of molecular conformations show that changes in the intrabridge torsion angle can change the sign of the RR. The small RRs inferred from this study result from electronic coupling being mediated by a highly symmetric P-T/T-P bridge LUMO, which promotes the electronic coupling in these biradicals. We show how the biradical approach can be used to derive key structure-property relationships that allow insight into the choice of bridge fragments for molecular rectification. Transport calculations support both the exchange coupling-based calculation of the RR, the preferred conductance direction as well as the orbital nature of the eigenchannel.

Keywords: molecular rectifier, electronic coupling, donor-bridge-acceptor

SESSION F: WATER IN NEW MEXICO

The Social Construction of Water and Water Use in the CAERT Curriculum

KRISTIN WALDO, EASTERN NEW MEXICO UNIVERSITY

The CAERT Curriculum was created as a resource for agricultural and environmental educators in order to provide secondary students the necessary intellectual and practical training for sustainable agriculture. Given the critical water issues in New Mexico, our research objective was to identify cultural water discourse across a purposeful sample of the New Mexico CAERT Curriculum. We asked: Within the CAERT Curriculum, how are humans situated within the socio-ecological system and what is the relationship between human activity and water? Qualitative content analysis using first cycle domain coding and second cycle taxonomic coding revealed that the human-environment interaction within the CAERT Curriculum is largely consistent with the empty world socio-ecological regime arising during the Industrial Revolution. These findings are significant because the empty world regime is grounded in the assumption of resource abundance, an assumption that is inconsistent with resilience and adaptive responses

to critical water issues. The implication is that the cultural lag in the CAERT Curriculum may actually exacerbate system decline, contrary to its intended purpose.

Keywords: water, CAERT curriculum, socio-ecological system, sustainable agriculture

Assessment of potential impacts on water resources posed by hydraulic fracturing in San Juan County, New Mexico

JAYVION S. CHEE, NAVAJO TECHNICAL UNIVERSITY

The state of New Mexico is one of the Major extractors and producers of crude oil and natural gas production ranking 6th in national production respectively. Most of the oil and gas production happens in two counties which make 80-143 million annually; Lea and San Juan county. Including the rest of the state, there are approximately 110,000 wells in New Mexico and about 90% of these employ a technique called hydraulic fracturing which is an effective but highly controversial mining technique. Hydraulic fracking is a technique that uses thousands of gallons of water to fracture the bed rock to allow oil or natural gas to flow upwards. This process involves shooting water down mixed with a cocktail of chemicals, many if not all are dangerous. Due to a loophole in environmental laws companies are not required to clean or recycle the water. This along with improper storage and treatment has led to many incidents of spillage resulting in severe water contamination. This has become a severe concern especially in the San Juan area where fracking has recently been sourced closer to agricultural areas that depend heavily on ground water. This project was completed so residents of impacted areas could address concerns and misconceptions about hydraulic fracturing. The project was a collaboration of Jayvion Chee along with the resources of Kiksapa Consulting, LLC and Navajo Technical University.

Keywords: water resources, hydraulic fracturing, contamination assessment

Transboundary aquifer assessment program

MARÍA E. MILANÉS-MURCIA, NEW MEXICO WATER RESOURCES RESEARCH INSTITUTE

Groundwater represents the major available source of freshwater in the world. More than half the world's population depends on groundwater as a primary water source. Irrigation and domestic uses are the main sectors of the society demanding water from aquifers. Increases in population and excessive amounts withdrawn have caused a rapid depletion of groundwater level. Contamination of aquifers is another problem, which makes it very difficult to clean up groundwater; prevention, assessment and monitoring are essential to protect groundwater resources. The U.S. – Mexico Transboundary Aquifer Assessment Act (Public Law 109-448) was signed into law by the President of the United States on December 22, 2006. This Act authorizes the Secretary of the Interior, through the U.S. Geological Survey (USGS), to collaborate with the States of Arizona, New Mexico, and Texas through their Water Resources Research Institutes (WRRIs) and with the International Boundary and Water Commission (IBWC), stakeholders, and Mexican counterparts (Chihuahua and Sonora) to develop mapping, modeling of priority transboundary aquifers and hydrogeologic characterization (Public Law 109-448). Section 4 of the Act established the U.S.-Mexico transboundary aquifer assessment program (TAAP), which is a distinctive Federal agency – university – binational partnership and establishes the methodology and implementation of the Act. Current cooperation efforts with Mexico were shown in the binational meeting regarding the transboundary aquifers between the United States and Mexico hosted by IBWC last September 29th in El Paso, addressing current efforts, next steps and future objectives. This research provides conservation policies among both countries able to ensure the sustainable development in a cooperative framework.

Keywords: transboundary, groundwater, cooperation

Exploring web GIS tools for hydraulic fracturing

ELLIOT BURNS, NAVAJO TECHNICAL UNIVERSITY

This research is a continuation of Mr. Jayvion Chee's project about hydraulic fracturing in New Mexico, specifically in the Lea and San Juan County. Hydraulic fracturing is a technique that uses thousands of gallons of water to fracture the bed rock to allow oil or natural gas to flow upwards. To accomplish this research is to use a combination of online resources such as Mapbox and Leaflet along with a bit of programming to construct a fully interactive map for better analysis for online users. The purpose of this research is to understand the mobility and accessibility of common Geographic Information Systems (GIS) tools in a webpage viewed on a desktop and mobile device. When viewing interactive maps online, the common uses often foreshadow the underlying tools needed for analysis. This would give the public a better look at where exactly in New Mexico hydraulic fracturing is occurring and using web GIS tools to see how effective hydraulic fracturing is bad for our environment. Also with Mr. Jayvion Chee's previous work about hydraulic fracturing, we're going to implement his work to make into a interactive application for non-GIS users. This research will allow implementation of tools common place in GIS software in webpage for better mobility and analysis for local users.

Keywords: GIS, hydraulic fracturing, applications

SESSION G: RENEWABLE ENERGY RESOURCES

Algal research at Eastern for wastewater treatment and biofuel development

JUCHAO YAN, EASTERN NEW MEXICO UNIVERSITY

Eastern New Mexico University in Portales, New Mexico is well suited for exploring novel, sustainable technologies to turn dairy and cheese plant wastewaters into biofuels and other valuable chemicals. In this talk, I will talk about our significantly enhanced algal productivities of filamentous algae in dairy manure effluents on an outdoor pilot unit called Algal Turf Scrubber (ATS®), simply by controlling the pH of the effluents through shading the carbon recovery unit. A special emphasis will be on nutrient removal. I will also talk about our efforts in producing bioethanol through fermentation of algal biomass and in treating dairy and cheese whey wastewaters in indoor, air-lift photobioreactors. I am grateful for the financial support from NSF-EPSCoR and Eastern New Mexico University.

Keywords: wastewater treatment, filamentous algae, and biofuels

Multi-omics studies of *Nannochloropsis salina* cultivated under suboptimal temperatures

SABA GILL, NEW MEXICO STATE UNIVERSITY

American Heart Society recommends consumption of 1g Omega-3 fatty acids per day to prevent heart diseases. The oleaginous marine microalga *Nannochloropsis salina* has received attention for its high oil yield (37-60% wt.) and production of the dietary polyunsaturated fatty acids, ω -3 eicosapentaenoic acid (EPA). The incorporation of unsaturated fatty acids into membrane lipid pools is particularly important for maintaining membrane fluidity and cellular structure at suboptimal temperatures. We found that *N. salina* grown under "cold stress" ($\geq 10^\circ\text{C}$ below optimal temperature) results in increased desaturation of fatty acids. Here, we demonstrate the effects of cold stress under 16:8 hr day:night cycle on *N. salina* using four temperature regimes: 5°C , 10°C , 15°C and 25°C , where 25°C was used as control. Physiological stress was determined by measuring growth rate, chlorophyll fluorescence and dissolved oxygen measurements. Total lipids were measured using FAME analysis. Gene expression studies were carried out targeting the genes involved in Kennedy pathway for tri-acylglycerol (TAG) synthesis. We performed Fourier Transform Ion Cyclotron Resonance (FT-ICR) mass spectrometry to study the variation in different lipid classes under sub optimal temperatures. Metabolomics was carried out using GC TOF MS, and the results were analyzed for statistical significance using MetaboAnalyst V3.0

Keywords: gene expression, Kennedy pathway, cold stress, FT-ICR, metabolomics

Ten years of projects in alternative energy, renewable energy, and energy efficiency at SIPI (2007 – 2016)

NADER VADIEE, SOUTHWESTERN INDIAN POLYTECHNIC INSTITUTE

The Southwestern Indian Polytechnic Institute's (SIPI) renewable energy program seeks to establish renewable energy technology hardware on and around the campus, which will supplement and create the educational resources to teach renewable energy courses at its campus. Under the program, SIPI will design, install, operate, and maintain photovoltaic, wind and solar hot water systems to be located at the SIPI campus and educate and train Native American students in renewable energy technology. SIPI's vision is to establish a Renewable Energy Program whose goals are: to prepare students both for technical careers in renewable energy technologies and for their pursuit of advanced studies in renewable energy engineering and technology; to demonstrate and provide examples on SIPI's campus of the practical uses of renewable energy technology for its students, its faculty, and the community at large; and to employ renewable energy technologies to produce useful and environmentally benign energy on the SIPI campus, while simultaneously providing students with the opportunity for hands-on experience with these systems.

Keywords: educational projects, renewable energy, efficiency, SIPI

Optimization of lipid extraction from microalgae cultivated on dairy wastewater

TANAKA PFUPAJENA, EASTERN NEW MEXICO UNIVERSITY

The majority of the fuels we use in our vehicles and other equipment on a daily basis are nonrenewable. As a result, the world is going to eventually run out of supplies of fuels. In addition, the current fuel sources are environmentally unfriendly, releasing greenhouse gases into the atmosphere. Many alternatives to using natural reservoirs as sources of fuels have been exploited, among which, the use of algal feedstock as a source of biofuel has received enormous attention. Algal biofuel was studied for a long time, and has recently gained popularity again due to the global demand for transportation fuels, the greenhouse gas effects, and the energy security risks. Funded by the NSF, at Eastern, we are cultivating algae on an outdoor pilot unit—Algal Turf Scrubber®—in dairy manure effluent for wastewater treatment and sustainable biofuel production. Algae offer an inexhaustible source of energy, nutrients and raw materials. When microalgae are grown and harvested, the biomass obtained contains lipids, which can be converted into biodiesels through chemical transformations. One of the main difficulties in implementing the use of algae for biofuel on a wider scale, is the inefficient methods of lipid extraction, and the current methods used do not exhaustively extract all the lipids, and are costly, thereby making the wide scale production of algae not economically feasible compared to the current natural fuels being used. In this project I investigated ways to maximize the amount of lipids extracted and develop simple extraction procedures that do not require a lot of energy to successfully extract the lipids required for the production of the biofuels. I used Gas Chromatography - Mass Spectrometry to characterize the extracted lipids. In addition, I will also investigate how to utilize the remaining material after the extraction is completed.

Keywords: biofuel, lipid extraction, and wastewater treatment

SESSION H: BIOLOGY & ECOSYSTEMS

Submerged aquatic macrophytes (SAMs) in the sky: At home in high elevation streams

VIRGINIA THOMPSON, UNIVERSITY OF NEW MEXICO

Submerged aquatic macrophytes (SAMs) are key species when present in aquatic ecosystems, but are not a ubiquitous aquatic ecosystem component. When present, they perform multiple ecosystem functions including water quality enhancement, provision of habitat structure and food sources, and nutrient cycling. Normally studied in low elevation, low gradient, often highly impacted river systems, SAMs were found in multiple high elevation (2,500 m) stream

systems in the Jemez Mountains. However, little was known about SAM communities in this area. We studied physical (geomorphology: depth, width, velocity, estimated discharge, and stream gradient) and biological parameters (% cover, biomass, and plant tissue stoichiometry) of three Jemez Mountain river systems that contained SAM species in some locations to assess the SAM community. A Principal Components Analysis (PCA) and Mann-Whitney U tests showed that the physical parameters in surveyed systems differ in sites with and without macrophytes present. While there were no differences in biomass found in each system, there was a difference in the percent composition of different species in each system. Elodea average nutrient content was 35%, (C), 2.8% (N), and 0.6% (P), consistent with other reported measures. Although elevation is a common limiting factor in biogeographic ranges of other plants, these results imply that elevation alone may not be key to shaping the geographic range of these macrophyte communities.

Keywords: submerged aquatic macrophytes; aquatic ecosystems; high elevation

Using GIS and drone technologies to analyze anthropomorphic changes in the Navajo commercial forest over the past 40 years to improve management and sustainable use on the Navajo Nation

STEVEN CHISCHILLY, SR., NAVAJO TECHNICAL UNIVERSITY

Through the use of historical maps and current technology in Geographic Information Systems, Remote Sensing, and Drone Technology, Mr. Chischilly and Mr. Clyde intend to measure how anthropomorphic effects have changed the Navajo Commercial Forest over the past 50 years on the Navajo Nation. Partnerships have been forged with Navajo Nation Fish and Wildlife and Navajo Forestry in this initiative and with their guidance we map how human inhabitation, livestock grazing, road building, home site construction, and other human induced changes have affected timber resources related to timber volume, structural diversity, wildlife habitat, and riparian areas. We hope to provide this research and subsequent maps to the Navajo Nation natural resources programs for their use in management, planning, and harvesting and use of forestry products.

Keywords: GIS, drone technology, Navajo Nation, anthropomorphic changes

The effects of avian decomposition on sunflower vegetation at 20°C

SHALEEN GEARHART, EASTERN NEW MEXICO UNIVERSITY

Decomposition can affect not only the soils micro organismal communities but also the vegetation. The depth of decomposition influenced physical and chemical features of the sunflowers. Changes were noted in plant height, chlorophyll content and pH, and leaf and bud morphology. Plant height was retarded by decomposition, yet leaf breadth was increased. Chlorophyll pH decreased but overall chlorophyll content increased in the presence of decomposition. These changes may have significance in a practical sense by providing a tool to identify potential clandestine burial sites, either by direct observation or by remote sensing sensitive to differences in chlorophyll content.

Keywords: decomposition, vegetation, morphology

POSTER SESSION ABSTRACTS

Poster session participants are listed alphabetically by last name of registered presenter.

Improved algal productivity and wastewater bioremediation by pH correction in an outdoor pilot Algal Turf Scrubber®

DAVID ARELLANO, EASTERN NEW MEXICO UNIVERSITY

JUCHAO YAN, EASTERN NEW MEXICO UNIVERSITY

The Algal Turf Scrubber (ATS) Project at Eastern New Mexico University (ENMU) has had an exceptionally productive year. By changing construction and influencing certain parameters, a correction in pH has been achieved; from a daily pH cycle of approximately 9.5–11.0 to approximately 7.3–7.6 reliably. This change in pH has led to distinctive improvements to the overall project goals of algal biomass generation and bioremediation of readily available wastewater. The biomass productivity has increased nearly eight times over previous year's data, from 0.74 g AFDW m⁻² day⁻¹ in 2015 to 5.98 g AFDW m⁻² day⁻¹ in 2016, with an organic content increasing by as much as 10%. Bioremediation became quantifiable, with removal rates of ca. 0.71 mg L⁻¹ h⁻¹ for s-TKN (i.e., simplified-Total Kjeldahl Nitrogen) and 0.17 mg L⁻¹ h⁻¹ for ortho-phosphorus. With 2016's growing season coming to a close, 2017 looks to be highly productive and advancing year for the ATS Project at ENMU.

Keywords: algal productivity, bioremediation, and nutrient removal

Growing algae in dairy manure effluents for sustainable biofuel production

BIN BAI, EASTERN NEW MEXICO UNIVERSITY

JUCHAO YAN, EASTERN NEW MEXICO UNIVERSITY

The continued use of petroleum-based fuels is becoming unsustainable because of the diminishing fuel reserves worldwide. Algae, renewable biofuel feedstocks, have grown in importance as green and sustainable fuels. Filamentous algae, for example, are capable of growing rapidly under a variety of conditions and of eliminating the nutrients from an overlying water stream. We have adapted filamentous algae cultivation in dairy manure effluents on an Algal Turf Scrubber® to our local conditions. An ATS is an engineered, high-turbulent aquatic system to cultivate benthic filamentous algae for the removal of pollutants. We have closely monitored the cultivation broth, including pH, temperature, conductivity, oxidation reduction potential, and nutrients. We have used Soxhlet extraction to extract the lipids, and also used high performance liquid chromatography to separate the extracts. Our goal is to maximize the algal productivity in an outdoor setting for enhanced biofuel production and wastewater treatment.

Keywords: filamentous algae, lipid extraction, and chromatography

Seismic and gravitational modeling of White Sands New Mexico

JASON BUTTS, UNIVERSITY OF NEW MEXICO

MOUSUMI ROY, UNIVERSITY OF NEW MEXICO

LINDSAY LOWE WORTHINGTON, UNIVERSITY OF NEW MEXICO

SHARI KELLEY, NEW MEXICO BUREAU OF GEOLOGY

The purpose of this presentation will be to present further research of the region and to answer the following questions using seismic and gravitational modeling of White Sands National Monument (WSHA). WSHA is the largest gypsum dune field in the world and was formed ~7000 years ago with the retreat of Pleistocene Lake Otero: 1) What controls the location of the western dune front? The western dune front of WSHA has remained relatively fixed as shown by measurements from 1944 to 2010. This behavior is quite different from other dune fields in the region that show migration up to 35 m per year. The hypothesis is that the dune front is pinned to a now buried paleo-shoreline of Lake Otero; 2) What is the relationship between subsurface structure of the Tularosa Basin and the dune field? Fault and block geometries in our study area are currently unknown. Previous gravitational modeling has shown that the highest measurements stand in the deepest part of the basin. From this we can hypothesize that Lake Otero regressed towards the deepest part of the basin and the dune field migrates over the highest part of the basin along with the Jarilla Fault that flanks the eastern edge of the basin. Our methods include seismic and gravitational imaging and

modeling that will provide a detailed image of the upper 50-100 meters and 101 km respectively. Expected outcomes, results, and conclusions of this project will provide further knowledge of the subsurface structure and the underlying basin for our study area of WHSA.

Keywords: seismic, gravity, acquisition, imaging, basin

Assessment of potential impacts on water resources posed by hydraulic fracturing in San Juan County, New Mexico

JAYVION S. CHEE, NAVAJO TECHNICAL UNIVERSITY

RAMSEY SEWEINGYAWMA, NAVAJO TECHNICAL UNIVERSITY

The state of New Mexico is one of the Major extractors and producers of crude oil and natural gas production ranking 6th in national production respectively. Most of the oil and gas production happens in two counties which make 80-143 million annually; Lea and San Juan county. Including the rest of the state, there are approximately 110,000 wells in New Mexico and about 90% of these employ a technique called hydraulic fracturing which is an effective but highly controversial mining technique. Hydraulic fracking is a technique that uses thousands of gallons of water to fracture the bed rock to allow oil or natural gas to flow upwards. This process involves shooting water down mixed with a cocktail of chemicals, many if not all are dangerous. Due to a loophole in environmental laws companies are not required to clean or recycle the water. This along with improper storage and treatment has led to many incidents of spillage resulting in severe water contamination. This has become a severe concern especially in the San Juan area where fracking has recently been sourced closer to agricultural areas that depend heavily on ground water. This project was completed so residents of impacted areas could address concerns and misconceptions about hydraulic fracturing. The project was a collaboration of Jayvion Chee along with the resources of Kiksapa Consulting, LLC and Navajo Technical University.

Keywords: water resources, hydraulic fracturing, contamination assessment

Understanding growth behavior of alumina (Al_2O_3) and boehmite ($\text{AlO}(\text{OH})$) nanoparticles

MADDISON CASILLAS, SANDIA NATIONAL LABS

TIMOTHY BOYLE, SANDIA NATIONAL LABS

FRANCESCA FASULO, SANDIA NATIONAL LABS

LARICO TREADWELL, SANDIA NATIONAL LABS

NELSON BELL, SANDIA NATIONAL LABS

BERNADETTE HERNANDEZ-SANCHEZ, SANDIA NATIONAL LABS

Alumina (Al_2O_3 or aluminum oxide) is an important metal oxide used in variety of applications due to its chemical and thermal stability. Nanoscale powders can be useful as an integral ink material used in direct write (robocasting) processes as well as in numerous commercial products such as electronics and paints. Critical to these applications is understanding how Al_2O_3 crystals grow under various processing conditions in order to control its properties. In order to understand growth behavior of Al_2O_3 nanoparticles, the effect of precursor on nanoparticle phase and morphology was examined within solution processing routes. Solution nanoparticle processing routes (e.g., glycothermal, solvothermal, and solution precipitation) were used to lower the temperatures and/or pressures required to reach the $\alpha\text{-Al}_2\text{O}_3$. Powders were isolated and examined with X-ray Diffraction and Electron Microscopy. Depending on processing route, wires, plates, or spherical particles of boehmite or alumina were obtained. Full details on the synthesis and characterization on alumina and boehmite will be presented. This work was supported in part by Laboratory Directed Research and Development (LDRD), Department of Energy (DOE), Geothermal Technologies Office (GTO) under the Office of Energy Efficiency and Renewable Energy (EERE), and by the Sandia STAR Program. Sandia National Laboratories, a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Keywords: nanoparticles, alumina, metal oxides, microscopy, boehmite

Surfactant and rheologically varied copper N-inks

FRANCESCA FASULO, SANDIA NATIONAL LABORATORIES
NELSON BELL, SANDIA NATIONAL LABORATORIES

TIMOTHY BOYLE, SANDIA NATIONAL LABORATORIES
LARICO TREADWELL, SANDIA NATIONAL LABORATORIES

Direct write manufacturing is a method that provides precision when printing things like electronics for computer chips. Currently silver nanoinks are in demand due to silver's high conductivity; however, silver is very expensive, so we have been investigating the use of copper as an alternative. Copper has comparable conductivity but is much more cost competitive. The copper nanoparticles were synthesized using a newly developed, simple, low-temperature route that employs octylamine and hexadecylamine only! Once we verified that we had clean Cu np, formulation of the nanoinks (N-inks). Additives such as solsperser and benzotriazole were added to the inks to increase dispersion and reduce the potential oxidation of the nanoink. The viscosity of the nanoink was also varied by increasing the weight percent of copper and then measured using a rheometer. All aspects of the synthesis, formulation and properties of the inks will be presented.

Keywords: wire manufacturing, copper, nanoparticles, nanoinks

A comparison of resistivity imaging techniques using 1D, 2D and 3D MT inversions in the middle Rio Grande Rift, NM

Matthew Folsom, New Mexico tech
Jeff Pepin, New Mexico tech
Shari Kelley, New Mexico bureau of geology

Mark Person, New Mexico tech
Jared Peacock, New Mexico tech

Twelve magnetotelluric (MT) soundings were collected along a 40 km profile crossing the Rio Grande rift and a portion of the Socorro Magma Body. A comparison of 1D, 2D and 3D inverse models highlight the strengths and weaknesses of the respective methods. 2D inversion results are distorted by the 3D nature of the data at longer periods, producing conductive artifacts at depths greater than 3 km. We demonstrate through a 3D forward modelling exercise how it is possible to recreate this effect by placing large resistive and conductive features off of an otherwise perfectly 2D resistivity model. Investigators that image deep conductors using 2D inversion codes should consider the influence of off-axis 3D features. The models outline the geometry of syn-rift and pre-rift sediments at the "Socorro Constriction", the southern terminus of the Albuquerque Basin. A strong, northward trending conductor 2-3 km deep and less than 2 ohm-m is coincident with the rift, creating a reversal of induction arrow directions at this point. This is interpreted as deep basin brines, perhaps influenced by evaporates hosted in the Permian Abo and Yeso formations. It has been noted that Rio Grande salinity increases in a stepwise manner, coincident with the terminal ends of sedimentary basins. Our geophysical models suggest a possible connection between rift-bounding faults and deep sedimentary brines, which likely impact the water quality of the Rio Grande. Future work includes adding additional MT stations to better constrain off-axis features and their relationship to the Rio Grande.

Keywords: magnetotelluric, Socorro Magma Body, Rio Grande Rift, resistivity modelling

Bioremediation of high-nutrient dairy wastewater using air-lift photo bio-reactors

SHALEEN GEARHART, EASTERN NEW MEXICO UNIVERSITY

JUCHAO YAN, EASTERN NEW MEXICO UNIVERSITY

The approach uses eight Air-Lift Photo Bio-Reactors designed to increase the algal morphology for easy harvesting and dewatering, and recycling and reuse. By culturing both a polyculture, along with three pure cultures from UTEX of both fresh water and salt water species. *Skeletonema costatum* (salt water), *Dunaliella salina* (high-brackish saltwater), and *Chlorella sp.* (fresh water), by altering the concentration of the effluent, the algal processing will theoretically remove organic substances from the water that are otherwise inhibitory to the reuse prospects for the water. Our goal in the indoor cultivation in conjunction with the ENMU ATS project is to create a proof of concept case. Do the algae in fact purify the wastewater? If so what data can we collect to prove this point? The nutrients that the algae will be consuming from the wastewater set the upper limit for biomass production. The daily rate of biomass production should

be hyperbolically related to the external nutrient supply rates. We will be focusing on testing organic weight + dry ash (silt) weight, pH, concentration of nutrients/effluent, Total Dissolved Solids (PPM/PPT), Conductivity ($\mu\text{S}/\text{Ms}$), light intensity, light dark cycle, flow of air, and temperature. We will use an UV-vis spectrometer, which will give us an ideal of the optical density of the culture. All these tests and data will then come together to help support our argument that bioremediation could theoretically increase the morphology of the algae for the purposes mentioned above.

Keywords: polyculture, bioremediation, wastewater

Algal sequestration of heavy metals from mine waste effluent

ROYA GHORBANI, NEW MEXICO STATE UNIVERSITY

OMAR HOLGUIN, NEW MEXICO STATE UNIVERSITY

Heavy metal pollution is common all over the world. Of the many negative effects associated with heavy metal contamination, one concern is the impact on crops including plants irrigated with contaminated surface water and or growing on contaminated soils show a reduction in growth, performance, and yield. Subsequently soils polluted by heavy metals can also causes organ damage, cancer, and economical losses. This is why today, human beings are concerned with finding new methods for remediation of surface waters contaminated with heavy metals. In this investigation we evaluated soils for heavy metal contamination obtained from the surrounding areas impacted by the Gold King Mine spill of 2015. Air dried soils samples were microwave acid digested and heavy metals were measured using inductively coupled plasma/optical Emission spectrometry (ICP-OES). In the study, found the metals of concern in Animas River Contaminated Soils were Aluminum(AL), lead(Pb), arsenic(AS), zinc(Z), calcium(Ca), chromium(Cr) copper(Cu), manganese(Mn) and iron(Fe). Based on our analysis of the metals identified to be of concern we evaluated the potential for a microalgae *Galderia sulpharia* to effectively remove those metals in culture solution and present.

Keywords: Galderia sulpharia, heavy metal sequestration, water contamination, Gold King Mine spill

Molecular and biochemical characterization of suboptimal temperature induced responses in *Nannochloropsis salina*

SABA GILL, NEW MEXICO STATE UNIVERSITY

TANNER SCHAUB, NEW MEXICO STATE UNIVERSITY

STEPHANIE WILLATTE, NEW MEXICO STATE UNIVERSITY

ROLSTON ST. HILAIRE, NEW MEXICO STATE UNIVERSITY

BARRY DUNGAN, NEW MEXICO STATE UNIVERSITY

OMAR HOLGUIN, NEW MEXICO STATE UNIVERSITY

Oleaginous microalga *Nannochloropsis salina* is known for its potential as a source of renewable bio-fuel due to its high oil yield. In addition *N. salina* is also a source for the value added polyunsaturated fatty acids (PUFAs) with relative high level of n-3 eicosapentaenoic acid (EPA). Lipid productivity and composition of oleaginous microalgae is variable and dependent on strain selection and environmental growth conditions. When environmental conditions lead to suboptimal temperatures aka: “cold stress” one of the response of the organism is to increase PUFAs metabolism leading to an increase in membrane fluidity decrease the negative impact that near freezing temperatures have on cellular components. In this study we report on the effect of suboptimal temperatures from 20oC to 5oC on the growth, physiological measurements and fatty acid profile of *N. salina*. In addition we investigated the fatty acid composition of different lipid species, lipid gene expression and how metabolic alterations and remodeling occur in various lipid pools with specific interest in TAGs.

Keywords: lipid metabolism, RT-PCR, PUFAs, gene expression, GC/MS, FT/ICR

Non-Anthropogenic CO₂ degassing: is the Socorro Magma Body Emitting CO₂?

BRITTANY GRIEGO, UNIVERSITY OF NEW MEXICO

JARED SMITH, UNIVERSITY OF NEW MEXICO

LAURA CROSSEY,, UNIVERSITY OF NEW MEXICO

CHRIS MCGIBBON, UNIVERSITY OF NEW MEXICO

Fault networks can provide pathways for fluids (water and gas) to the surface. Magma bodies (such as the Socorro Magma body, SMB, in NM) beneath Earth's surface also release CO₂ to the surface. Recent work has provided

information on CO₂ flux and defined background, diffuse, and endogenic sources in the Albuquerque basin and Valles Caldera. Our main focus was to measure the active CO₂ flux in the Rio Grande Rift south of any previously measured CO₂ emission sites and was specifically across the margin of the Socorro Magma Body. Geological evidence, in the form of numerous travertine deposits associated with bounding rift faults co-located with the SMB, indicates persistent recent outgassing in this region. The method used was an EM-5 with a soil respiration chamber and an infrared detector to enable direct measurement of the flux of CO₂ from the ground being studied. After surveying the western part of the Socorro Magma body in the Sevilleta Wildlife Preserve, we found that there was a small amount of CO₂ being emitted by non-anthropogenic means (non-biological). To differentiate between anthropogenic and non-anthropogenic we had a minimum flux of 0.084 to 1.01 g/m²/d, which we defined as background flux to a maximum flux of 3.02 to 9.06 g/m²/d, which is substantially above background flux. Compared to previous works on the Valles Caldera, the data we collected for this project is only a small fraction compared to 170,000 g/m²/d. This preliminary work indicates that the Socorro Magma Body is emitting currently emitting diffuse CO₂.

Keywords: degassing, Socorro Magma body, fault networks, CO₂

The synthesis of metal silica based nanomaterials

FERNANDO GUERRERO, SANDIA NATIONAL LABS
JEREMIAH SEARS, SANDIA NATIONAL LABS

TIMOTHY BOYLE, SANDIA NATIONAL LABS
BERNADETTE HERNANDEZ-SANCHEZ, SANDIA NATIONAL LABS

Metal silica-based (MSiOx) materials have found use in scintillator applications due to their intense luminescent response upon exposure to radiation sources. The metals in these silicates have been reported from across the periodic table but when doped with lanthanide (Ln) cations are especially sensitive and luminescent. The production of metal silicates has been widely investigated using a variety of synthetic pathways. For routes that employ metal alkoxides ([M(OR)_n]), the metal silicate products are typically generated from the reaction of the desired metal precursor with a Si(OR)₄ or employing metal siloxide [M(OSiR₃)_x] precursors. However, these approaches have met with varying degrees of success in converting to the desired MSiOx. This lead us to investigate tris(trimethylsilyl) silanol (HOSi(Si(CH₃)₃)₃ or H-SST) modified [Group 4 and 5 [M(OR)_n]] as precursors to MSiOx materials. These SST derivatives generated a core@shell geometry as identified by TEM analysis. As we search to expand the utility of the SST ligand and generate scintillators, exploration of the lanthanide cations is warranted. This poster will present on the synthesis of the H-SST ligand, the development of a series of lanthanide amide precursors and the conversion of. All of these will be characterized by a variety of analytical means. Once isolated, their conversion to nanomaterials core@shell will be explored. This work involves the use of air-sensitive synthesis techniques (i.e., Schlenk lines and gloveboxes) and a variety of analytical methods including: FT-IR s, elemental analysis, X-ray diffraction, electron microscopy, and other methods.

Keywords: nanomaterials, metal silica

The synthesis of copper precursors for alkoxide and nanoparticle production

BENJAMIN F. HAMMEL, SANDIA NATIONAL LABS
FRANCESCA FASULO, SANDIA NATIONAL LABS
JEREMIAH SEARS, SANDIA NATIONAL LABS

TIMOTHY BOYLE, SANDIA NATIONAL LABS
PATRICK D. RILEY, SANDIA NATIONAL LABS

The potential utility of copper alkoxides (Cu(OR)_x) as a component of a flow battery was investigated. A variety of precursors were synthesized and characterized prior to battery studies. For this report, we investigated the utility of pyridine 2,-6 dimethanol (H₂-2OPy) as a modifier for Cu(I) and Cu(II) metal centers. The Cu(II) product was identified as [Cu(μ-2OPy)]₂. The synthesis and characterization of this complex will be presented. The stability in water of the Cu(II) and Cu(I) were investigated as well for determination of utility in the battery application. An alternative use of the [Cu(μ-2OPy)]₂ precursor was serendipitously determined as a low temperature preparation of 50 – 80 nm

Cu nanoparticles. This poster will report on the variety of precursors, the conditions under which they were synthesized and their material properties.

Keywords: nanoparticles, copper alkoxides, battery application

Algal based single-step urban wastewater treatment

SHANKA HENKANATTE-GEDERA, NEW MEXICO STATE UNIVERSITY

NIRMALA KHANDAN, NEW MEXICO STATE UNIVERSITY

Present-day urban wastewater (UWW) treatment infrastructure continues to depend on obsolete, multistage technologies to treat UWW that consume significant fossil-fuel derived energy and are unsustainable. Recognizing the value of organic carbon and nutrients contained in UWW, wastewater is now being regarded as a renewable source from which energy, water and nutrients can be harvested for the beneficial use rather than mineralizing and dissipating them into the environment. For example, the activated sludge process that is in use today dissipates more than 50% of valuable organic carbon content in UWW as carbon dioxide while the subsequent nitrification/denitrification step converts most of its ammoniacal nitrogen to inert nitrogen gas. This paper reports a single-step, algal-based wastewater treatment system where the selected strain, *Galdieria sulphuraria*, is shown to be capable of mixed photoautotrophic and heterotrophic metabolism for simultaneous removal of dissolved organic carbon and nutrients from UWWs meeting the mandated discharge standards. Results from laboratory tests scaled up to pilot scale tests conducted under outdoor conditions in batch and fed-batch mode are presented to document *Galdieria sulphuraria*'s ability to treat raw primary effluent to discharge standards with minimal energy input compared to the traditional bacterial-based system.

Keywords: Galderia sulpharia, wastewater treatment, urban wastewater, algae

Quantum mechanics of palladium clusters

AJIT HIRA, NORTHERN NEW MEXICO COLLEGE

JAMES MCKEOUGH, NORTHERN NEW MEXICO COLLEGE

We study the chemisorption of different atomic and molecular species on small clusters of metallic elements, by examining the interactions of H, H₂, Li and O adsorbates with Pd_n clusters (n = 2 through 24). Such a study can reveal the effects of substrate geometry on the behavior of adsorbates. Transition-metal clusters, such as palladium clusters, are suited for the study of quantum size effects and for formation of metallic states, and are ideal candidates for catalytic processes. In this presentation, we focus on the properties clusters Pd₂ through Pd₂₄. Hybrid ab initio methods of quantum chemistry (particularly the DFT-B3LYP model) are used to derive optimal geometries for the clusters of interest. We compare calculated binding energies, bond-lengths, ionization potentials, electron affinities and HOMO-LUMO gaps for the clusters. Of particular interest are the comparisons of binding strengths at the three important types of sites: edge (E), hollow (H), on-top (T), threefold sites and fourfold sites. Effects of crystal symmetries corresponding to the bulk structures are investigated. The capacity of Pd clusters to adsorb H atoms will be considered. Admixture of Pd clusters with Ni atoms will be examine in our future work.

Keywords: palladium, clusters, computational

Characterization of thin-film copper using in situ environmental transmission electron microscopy

CHRIS HIRANI, UNIVERSITY OF NEW MEXICO

Corrosion costs the U.S.A. a few percent of its GNP annually. Atomic scale characterization offers detailed dynamics of corrosion for fundamental understanding. We prepared thin-films (~70 nm) of copper, a model metal system, on single crystal NaCl substrates using e-beam evaporation. We performed in situ reduction/oxidation of Cu within a Hitachi H9500 environmental transmission electron microscope. The Cu films were annealed in hydrogen gas to remove the native oxide and to create clean copper facets, and then exposed to oxygen gas at 250°C. We noticed

facet-dependent differences at the early stages of Cu-oxide growth in situ, where the relative oxidation rates by facet varied such that (100) < (110) < (111). These results can be used to guide future work on how to control corrosion by manipulating the crystal planes and surface defects used in corrosion-protection applications including municipal water transport, turbine blades, and integrated circuits.

Keywords: copper, oxidation, TEM, characterization

Geothermal potential of New Mexico “smokers”: spring vents that show mantle degassing, high CO₂ content, and distinctive microbiology communities along the Jemez lineament and Rio Grande rift

BENJAMIN HOLT, UNIVERSITY OF NEW MEXICO

LAURA CROSSEY, UNIVERSITY OF NEW MEXICO

THOMAS DARRAH, OHIO STATE UNIVERSITY

CHRIS MCGIBBON, UNIVERSITY OF NEW MEXICO

VALERIE BLOMGREN, UNIVERSITY OF NEW MEXICO

MARK PERSON, NEW MEXICO TECH

KARL KARLSTROM, UNIVERSITY OF NEW MEXICO

SHARI KELLEY, NEW MEXICO BUREAU OF GEOLOGY

COLIN WHYTE, OHIO STATE UNIVERSITY

JARED SMITH, UNIVERSITY OF NEW MEXICO

JEFF HRNCIR, UNIVERSITY OF NEW MEXICO

CORY WALK, UNIVERSITY OF NEW MEXICO

This study is a compilation of water and gas data from springs and wells throughout New Mexico. The springs discussed here have detectable mantle-derived helium, are located along major faults, have high P_{CO2}, are generally travertine depositing, and are located above areas of low mantle velocity. This combination of parameters helps identify windows into zones of high crustal permeability and flux of deeply derived fluids within regions of extension and high heat flow. Springs and wells with the highest helium isotope ratios in NM (non-atmospheric-like ³He/⁴He (R/R_A) and elevated He/Ne in groundwater) are located above the Valles Caldera (3.86 to 6.16 R_A), Rico area of SW Colorado (4.75-5.88 R_A), NM Bootheel area (up to 4.23 R_A), Bravo Dome (up to 3.78 R_A), and Socorro magma body (NM Tech wells = 1.41 to 1.91 R_A). Lowest, non-mantle-like values (< 0.1 R_A) are seen in San Juan and parts of Delaware basins. The best correlation between ³He/⁴He values and deep geophysical parameters is relative S-wave velocity (at 60 and 195 km), consistent with mantle partial melt as the deep source of helium- and CO₂-bearing volatiles. Helium isotope values do not correlate strongly with crustal thickness suggesting that crustal conduit systems may be less important than mantle source regions. Multiple tracer geochemical analyses include helium and carbon isotopes that can help evaluate fluid mixing end members, fluid pathways, and geothermometry of deeper fluids. Combined with other geothermal datasets, these data provide part of an exploration strategy for geothermal systems in New Mexico.

Keywords: geochemistry, mantle degassing, geothermal, CO₂ flux, helium isotopes

Analyzing temporal dynamics of natural gas demand in New Mexico

JANAK JOSHI, UNIVERSITY OF NEW MEXICO

JANIE CHERMAK, UNIVERSITY OF NEW MEXICO

JENNIFER THACHER, UNIVERSITY OF NEW MEXICO

Natural gas is an increasingly valuable fuel source in the context of growing environmental and energy security concerns. Despite the relative abundance of the natural gas reserves, it is an exhaustible resource. Moreover, the natural gas consumption is not free from environmental externalities. Integrated energy planning requires a wide range of well-informed policy tools to deal with the multitude of issues associated with the energy sector (e.g. ensuring reliable supply, neutralizing the growing consumption and promoting energy source diversity). A key to this includes a superior understanding of both supply and demand response. The extant literature primarily focuses on comparing demand response across states. We contribute to the literature by developing a demand analysis disaggregated to the state level. We estimate natural gas demand function at the state level and for the residential, commercial, industrial and electric sectors in New Mexico, by utilizing monthly data from 2001 to 2016. We find that own price of natural gas at the state level as well as in the sectoral demand estimations has a significant impact on the natural gas consumption while income effect is weak. The change in natural gas demand ranges between -0.01% to -0.4% for

one-dollar increase in its price in different sectors. The impacts of heating and cooling degree days on consumption are positively significant at the state level, and in the residential, commercial and electric sectors, while such impacts are not significant in the industrial sector. Substitutability between natural gas and petroleum oil is also not significant.

Keywords: natural gas, consumption, price effect, New Mexico

Nutrient recovery from algal based wastewater treatment system

MOSHEN KARBAKSHRAVARI, NM STATE UNIVERSITY
SHANKA HENKANATTE-GEDERA, NM STATE UNIVERSITY

NIRMALA KHANDAN, NM STATE UNIVERSITY
LAMBIS PAPELIS, NM STATE UNIVERSITY

Growth of global population continues to exert stress on three resources essential for mankind: food, energy, and water. On-going research at New Mexico State University is developing an algal-based process configuration to recover and recycle resources within the food-energy-water nexus in an energy-efficient and sustainable manner. The proposed approach is based on the following premises: i) urban wastewaters (UWW) that are rich in organic carbon and nutrients (nitrogen, N, and phosphates, P) can serve as medium to cultivate energy-rich algal biomass; ii) algal biomass cultivated in UWW could be processed by hydrothermal liquefaction (HTL) to produce biofuels; iii) nutrients in the byproducts of HTL could be extracted to formulate crop fertilizers; and iv) the effluent from the process could be tailored as agriculture-quality water for food-crop cultivation. Objective of this study is to demonstrate the ability of the above process in recovering crop fertilizers from UWW. Algal biomass cultivated under field conditions in primary-settled urban wastewater was used in this study. Byproducts resulting from hydrothermal liquefaction of the biomass were processed in this study to produce struvite for use as fertilizers. Results to be presented include physical/chemical characterization and separation of the N and P from the aqueous stream and biochar resulting from HTL, and the conditions for precipitating N and P as struvite powder. It is concluded that P extraction from biochar is a pH dependent process, and P recovery of up to 90% is achievable through struvite precipitation.

Keywords: wastewater treatment, urban wastewater, algae, nutrient recovery, hydrothermal liquefaction

Chlorella vs. Coelastrella: Allelopathic interaction

KELLY LAJE, NEW MEXICO STATE UNIVERSITY

Invasion of outdoor cultures by weedy algal species presents difficulties in the cultivation process for biodiesel production. Minimizing such risks/scenarios is critical to efficient biomass cultivation and the future of algal based energy. We observed an invasive algal species in outdoor cultures of *Chlorella sorokiniana*, which we isolated and genetically identified as a novel strain of *Coelastrella* sp. (Genbank 18S RNA sequence accession number KP167584). A series of experiments was conducted to observe the interaction between the novel *Coelastrella* sp. and *Chlorella sorokiniana*, in which an allelopathic compound secreted from *Coelastrella* sp. is suspected to cause growth inhibition of *Chlorella sorokiniana*. We report the interaction between both species of algae when grown as a bi-culture under laboratory conditions, as well as the possible identity of the aforementioned allelopathic compound using HPLC analysis.

Keywords: Coelastrella sp., *Chlorella sorokiniana*, algae, allelopathic interactions

A comparison of population demographics and body condition of Western River Cooter, *Pseudemys gorzugi*, between two distinct regions of their distribution

ANDREW LETTER, EASTERN NEW MEXICO UNIVERSITY
DAN FOLEY III, SUL ROSS STATE UNIVERSITY

MICHAEL FORSTNER, TEXAS STATE UNIVERSITY
IVANA MALI, EASTERN NEW MEXICO UNIVERSITY

Western River Cooter, *Pseudemys gorzugi*, is one of the least studied species of freshwater turtles in North America, with very little known about their biology. In the US, species occur only in New Mexico and Texas and their range is restricted to the Pecos and lower Rio Grande Basin. Western River Cooter is listed as a state threatened species in New Mexico and near threatened by the International Union for Conservation of Nature (IUCN). Given their

conservation status, it is important to monitor populations of Western River Cooter across their range. In this study, we compared population demographics and body condition indices between two distinct regions of *P. gorzugi* distribution: Black River in New Mexico and Devils River in Texas. In New Mexico, we collected 196 turtles during 2016 field season, while in Texas, we collected 170 turtles during 2015/2016 field seasons. Our preliminary analyses show that there are fundamental differences in demographic parameters between New Mexico and Texas populations. While Texas population consists of larger turtles and adults only, New Mexico population contains turtles of all age classes (i.e., hatchlings, juveniles, and adults). Analysis of body condition between two separate populations will help further our understanding of *P. gorzugi* ecology and create opportunities for future studies, such as resource availability and food habits.

Keywords: Western River Cooter, animal population, distribution

Morphologically controlled Bi₂O₃ nanomaterials

JESSIE LINDER, SANDIA NATIONAL LABORATORIES

KHALID HATTAR, SANDIA NATIONAL LABORATORIES

TIMOTHY BOYLE, SANDIA NATIONAL LABORATORIES

During our investigation in the synthesis of scintillator material bismuth germanium oxide (BGO), hexagons of bismuth oxide (Bi₂O₃) was observed. Due to its electronic conductor properties, it became of interest in generating morphologically varied Bi₂O₃ nanomaterials. The initial study focused on modifying bismuth nitrate hydrate with a variety of ‘poisons’ under solvothermal conditions. This was followed by a study concerning the ligands bound to the Bi (i.e, Bi-O vs Bi-N vs Bi-C) and their impact on the final morphology. This required the synthesis of in-house precursors. A comparison (PXRD, SEM, TEM) of commercial versus in-house precursors, their ligand set, poisons, and processing impact on the final morphology will be reported.

Keywords: morphology, nanomaterials, Bi₂O₃

Anatomical observation on abortive seeds in endangered Dove Tree (*Davidia involucrata*)

ZHIMING LIU, EASTERN NEW MEXICO UNIVERSITY

J. PENG, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

M. LI, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

X. XU, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

F. CAO, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

R. REN, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

X. DONG, CENTRAL-SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY J. LIU, EASTERN NEW MEXICO UNIVERSITY

Dove tree (*Davidia involucrata*) is an endangered species endemic to China. Reproduction of dove tree is difficult due to its low fecundity. Seed abortion has been thought as one of the key factors limiting its sexual reproductive capability. In this project four hundred fruits were collected from ten dove trees randomly selected from a naturally distributed population in Hunan Province of central China. The fruits were weighed and their length and width were measured. The fruits were dissected to expose the seeds. The number and shape of normal seeds and aborted seeds were recorded. Seed abortion ratios were then calculated. Preliminary analysis of the dissected fruits and seeds showed the fruit of dove tree had an eight-carpel structure. In most fruits the number of normal seeds was one to three, indicating more than half of the seeds were aborted. The number of aborted seeds was not related to the weight and length-width ratios of the fruits; furthermore, the aborted seeds were much smaller than the normal seeds. This observation confirmed that seed abortion is a serious problem and could be a limiting factor for reproduction in this endangered species. Further study of seed abortion at the cellular and molecular level will be useful for addressing the issue of offspring production and the survivability of this endangered species.

Keywords: dove tree, Davidia, seed abortion, endangered

The impact of air pollution on emergency room visits for respiratory diseases in New Mexico

NA LU, UNIVERSITY OF NEW MEXICO

JENNIFER THACHER, UNIVERSITY OF NEW MEXICO

JANIE CHERMAK, UNIVERSITY OF NEW MEXICO

Though the impact of air pollution on health has been addressed in existing literature, little research has been conducted in areas with moderate levels of air pollution. Air pollution in New Mexico mainly comes from coal-fired power plants in Northwest, oil and gas production in San Juan and Permian Basin, transportation and energy consumption in the middle Rio Grande Area. As Clean Power Plan proposed, reducing coal-fired power plants will also lower the air pollution level, which will reduce total health cost in New Mexico. This paper utilizes a fixed effect panel model to estimate the impact of three major air pollutants on emergency room visits for respiratory diseases in New Mexico. Employing a dataset covering five counties in New Mexico from 2010-2014, we find that ozone has a significant impact on respiratory emergency room visits. The result indicates that 1 ppb (2% of current level) decrease in monthly average ozone level will on average decrease 1.887 emergency room visits per 100,000 people per month for respiratory diseases. Using San Juan County as an example, if we reduce 5 ppb of monthly average ozone level by implementing Clean Power Plan, there will be about 12 less ER visits for respiratory diseases per month. In separate analysis on different age groups, the effect of ozone on respiratory emergency room visits is significantly positive for children age 1-14 and adults age below 45 which might be caused by more exposure to air pollution than other age groups.

Keywords: air pollution, ozone, emergency room visits, New Mexico

Different parameters controlling the biocrude yield in hydrothermal liquefaction of microalgae

KWONIT MALLICK, NEW MEXICO STATE UNIVERSITY
SHANKA HENKANATTE-GEDERA, NEW MEXICO STATE UNIVERSITY
CATHERINE BREWER, NEW MEXICO STATE UNIVERSITY

FENG CHENG, NEW MEXICO STATE UNIVERSITY
GRAHAM HOFFMAN, NEW MEXICO STATE UNIVERSITY
NIRMALA KHANDAN, NEW MEXICO STATE UNIVERSITY

Research into alternate sources of fuel or renewable energy reveal many promising ideas for alternative energy sources. One of these possibilities is converting biomass to biofuel. Under high pressure and temperature, microalgae can be polymerized to biofuel. There are some thermo-chemical processes available to convert the biomass like pyrolysis and gasification, but these processes require dry feedstock. Thus these processes encounter large energy loss by vaporizing the moisture. Hydrothermal Liquefaction (HTL), a high temperature, high-pressure polymerization process, can convert wet biomass, including water to biocrude oil, biochar, and nutrient rich water. The biocrude obtained from HTL are environmentally friendly and can be directly used as fuel or can be upgraded to transport fuel. Many researchers are working on increasing the efficiency of HTL. In the present study an attempt is made to optimize the HTL reactor for maximizing the biocrude yield. Batch reactions are carried out to correlate the biocrude yield with different parameters like the reaction temperature (300°C - 350°C), reaction time (30 mins – 60 mins), initial solid concentration (5% - 20%) and also different species with different lipid contents. Experiments are also carried out to see the effect of different cultivating medium (wastewater and freshwater) on the crude yield after HTL. Experimental results show that different operating conditions can result in the biocrude yield to vary between 5% and 60%. These parameters are also related to the amount of heavier biocrude oil produced. This paper carefully examines and explains the relationships between the operating conditions and the biocrude yield to be able to optimize a HTL batch scale reactor for maximum crude yield.

Keywords: hydrothermal liquefaction, biocrude, alternative fuel, algae

State and local potential socioeconomic and environmental impacts from proposed renewable energy projects: A case study of New Mexico

JAMAL MAMKHEZRI, UNIVERSITY OF NEW MEXICO
JANIE CHERMAK, UNIVERSITY OF NEW MEXICO

JENNIFER THACHER, UNIVERSITY OF NEW MEXICO

Recent federal legislation, such as Clean Power Plan, is motivating the move away from coal-fired electricity generation to increase renewable resources. This provides a mechanism that can result in reduced Greenhouse Gas emissions and saving water, but may also impact economic growth and jobs in the state. The goal of this research is to assess the trade-offs of increasing renewable energy at the county and plant level in terms of jobs and economics, as well as

greenhouse gas emissions and water. An analysis of these twelve potential renewable energy projects, constituting nearly 1,202 MW of power capacity, are estimated to result in close to 4,753 job-years during construction period from 2015 to 2019 in New Mexico. Over the operations period beyond construction, we demonstrate that statewide projects are estimated to result in 131 onsite jobs and 183 total jobs annually over the life of the plants. These projects are mainly located in the eastern part of New Mexico, which is a potential boom for economic development of the area. The expected amount of electricity that could be generated from these 12 renewable energy plants and replacing equivalent amount of coal-fired electricity would result in saving 44,000 million gallon of water, along with avoiding 81 million tons of greenhouse gases.

Keywords: renewable energy, economic impacts, environmental impacts, job comparison

Geothermal membrane distillation in industrial greenhouse application

CAROLYN MEDIN, NEW MEXICO TECH
CHEYENNE RIVERA, NEW MEXICO TECH
LYNDA LAUMBACH, NEW MEXICO TECH

RILEY REPROGLE, NEW MEXICO TECH
FRANK HUANG, NEW MEXICO TECH

Masson Greenhouse is a large-scale indoor greenhouse that employs geothermal brackish water for space heating. Coupling heat exchangers with membrane distillation (MD) would allow Masson to simultaneously extract energy and water from the geothermal fluid thereby reducing the cost of water purification for irrigation. Polyvinylidene fluoride (PVDF)-based hollow fiber membranes (HFMs) were fabricated via the dry-jet wet-spinning process and the structure of the membranes was characterized using porometry and scanning electron microscopy. A bench-scale MD system was set up with the PVDF HFMs to evaluate the effects of membrane post-treatment, temperature gradient, and thermal boundary layer on the water flux.

Keywords: membrane distillation, geothermal water, irrigation, water purification

A hydrogeochemical analysis and recharge evaluation of Cienega Spring located in the Sandia Mountains, NM

ALEXANDRA MINITREZ, UNIVERSITY OF NEW MEXICO
LAURA CROSSEY, UNIVERSITY OF NEW MEXICO

CHRIS MCGIBBON, UNIVERSITY OF NEW MEXICO

In the southwestern United States, water resources are increasingly depleted due to multiple demands including anthropogenic use and climate change. Springs are particularly sensitive to change, and also serve as an important habitat. In an effort to assist water managers, we report on the status of springs in the Sandia mountains, New Mexico. We focus on Cienega Spring, located in the East Mountain area, and serves as a water source to over 50 surrounding homes. The spring is tapped by pipes using gravity, overflow supplies a stream and wetlands. Total discharge rates are unknown, as is any seasonal change in discharge. In order to examine potential hydrologic flowpaths, we perform a hydrogeochemical analysis on the spring and compare with regional groundwaters. We have also installed continuous sensors to examine seasonal fluctuations in recharge and use. By performing a hydrogeochemical analysis and recharge evaluation, a proper conclusion can be determined for Cienega Spring and provide further insight on spring flow sustainability.

Keywords: hydrogeochemistry, spring water, groundwater

Carotenoid synthesis and lipid production of a *Chlorococcum* sp.

SA'RAE MONTOYA, NEW MEXICO STATE UNIVERSITY
BARRY DUNGAN, NEW MEXICO STATE UNIVERSITY
NEIL PAZ, NEW MEXICO STATE UNIVERSITY

TANNER SCHAUB, NEW MEXICO STATE UNIVERSITY
JUERGEN POLLE, BROOKLYN COLLEGE
OMAR HOLGUIN, NEW MEXICO STATE UNIVERSITY

As the shift toward environmentally renewable resources occurs algae cultivation for lipids, co-products and biomass, as a source of antioxidants, food, livestock feed, cosmetics and renewable fuel feedstock is of continuing growing interest. In this work we describe the profile and content of carotenoids and lipids of a promising microalgae

identified as a *Chlorococcum* sp. Experiments were performed in environmental photobioreactors (ePBRs) and incubators under constant, low and high intensity irradiance. Metabolite, lipid, and carotenoid profiles determination was done during the transition from green vegetative cells to the highly pigmented carotenogenic cells. The objective of this work was to gather a better understanding of carbon allocation and lipid synthesis/remodeling events of the *Chlorococcum* sp. strain under increased photooxidative stress and other environmental stressors. This biochemical basis of the relationship between stress inducing conditions, carotenoid synthesis, high lipid content and fatty acid composition is beneficial for further increasing the productivity and economic development of this *Chlorococcum* strain.

Keywords: *carotenoids, fatty acids, lipids, photooxidative stress, renewable resources, microalgae*

Characterization of growth and lipid profile in the red alga *Galdieria sulphuraria*

KHADIJEH MOZAFFARI, NEW MEXICO STATE UNIVERSITY
UJALA SEHAR, NEW MEXICO STATE UNIVERSITY

TANNER SCHAUB, NEW MEXICO STATE UNIVERSITY
OMAR HOLGUIN, NEW MEXICO STATE UNIVERSITY

The present study was conducted to analyze the biomass and lipid accumulations in the red alga *Galdieria sulphuraria* under mixotrophic conditions. It has also proven that *G. sulphuraria* to be useful for biofuel and other valuable compound production. In recent studies, it has been seen that sugar beet molasses and glucose yielded higher biomass and lipid content. However, these studies have not led to the analysis of the role of other sugars as the carbon sources. The first goal of this research effort is to evaluate the biomass and total fatty acid, lipid and Calvin cycle in different sugars as carbon sources. According to this study the specific growth rate was higher when the cells were grown under mixotrophic culture condition on equal molar concentration of C atoms from glucose, fructose, sucrose and glycerol. However, maximum biomass production was achieved in the cultures grown on glucose and glycerol as the carbon sources. These results showed that glycerol is the best carbon source for the *Galdieria* growth under mixotrophic condition. Furthermore, we present the amount of total lipids and fatty acids and metabolism in the mixotrophic culture conditions.

Keywords: *Galdieria sulphuraria, biomass, mixotrophic culture, lipid analysis*

Cation exchange in PbTe quantum dots

TOM NAKOTTE, NEW MEXICO STATE UNIVERSITY

Core/Shell nanocrystal quantum dots have become very popular structures over recent years due to their applications in solar cells, detectors, and light emitting devices. Lead chalcogenide (PbS, PbSe, and PbTe) quantum dots have emerged as a building block for many innovative photovoltaic devices, with PbTe quantum dots being the least well studied due to their instability when exposed to air. Using an in solution cation exchange method at low temperatures (80°C) we have synthesized PbTe/CdTe (core/shell) quantum dots that display a type-I band structure and have well defined cores by TEM imaging. The cation exchange reaction was monitored with absorption, PL, and TEM imaging, to relate shell thickness to reaction time. After the reaction time was optimized to yield a shell thickness of 1 nm, layer-by-layer shell growth techniques were employed in an attempt to grow a CdSe shell onto the PbTe/CdTe quantum dots. The PbTe/CdTe/CdSe structure is a good candidate for carrier multiplication, which is an important factor for high performance solar cells, due to the large conduction band offset of CdSe compared to PbTe.

Keywords: *quantum dots, solar cells, PbTe*

The synthesis of copper and metal nanoparticles

THAO NGUYEN, SANDIA NATIONAL LABORATORIES
TIMOTHY BOYLE, SANDIA NATIONAL LABORATORIES

LARICO TREADWELL, SANDIA NATIONAL LABORATORIES
JEREMIAH SEARS, SANDIA NATIONAL LABORATORIES

Direct Write manufacturing is a method that can precisely print microcircuits and computer chips. Currently, silver nanoinks are in demand due to silver's high conductivity; however, silver is very expensive, so we have been

investigating the use of copper as an alternative. Copper (I) has comparable conductivity, but is much more cost competitive. The copper nanoparticles were synthesized using a newly developed, simple, low-temperature route that employs octylamine and hexadecylamine only. Once we verified that we had clean copper nanoparticles, formulation of the nanoinks (N-inks) began. Additives such as Solsperse and benzotriazole were added to the inks to increase dispersion and reduce the potential oxidation of the N-inks. Also, the viscosity of the N-inks were varied by increasing the weight percent of copper and then measured using a rheometer. All aspects of the synthesis, formulation and properties of the inks will be presented.

Keywords: nanoparticles, copper, conductivity

No title provided

HOLLY NUMMERDOR, WESTERN NEW MEXICO UNIVERSITY

Energy research plays an important role in meeting the need for affordable energy in our technological society. Conventional sources from fossil fuels have received increasing competition from alternative energy sources whose environmental impact is less pronounced. Mother Nature, as usual, has led the way featuring an organism that is highly efficient at transforming solar energy into lipids and fats that can then be converted into a diesel-like fuel. Biodiesel from algae has an alluring appeal similar to producing power from burning garbage whereby an otherwise nuisance species becomes a valuable resource. Algae can be grown at a lower cost compared with other higher maintenance feedstocks such as corn because of its more aggressive and flexible nature. The algal biomass is dried and the lipids within extracted with organic solvents. These extracted compounds are then converted into fatty acid methyl esters (FAMES) which are chemically similar to conventional diesel fuel. This project addressed several challenges that exist in making algal biofuels cost-effective. Because a great variation in the yield of lipids from algae is observed depending on growing conditions, our experiments explored the optimization of these parameters using carefully developed analytical methods. Pitfalls associated with growing algae will be presented. In addition, a qualitative analysis of the complex FAMES mixture resulting from our particular algae growth methods will be presented including the pros and cons of how variation in FAMES would affect the production of useful bio-products.

Keywords: energy, biodiesel, fatty acid methyl esters

Semiconductor photocatalysis of bicarbonate to solar fuels: Formate production from copper (I) oxide

HANQING PAN, NEW MEXICO TECH
SANCHARI CHOWDHURY, NEW MEXICO TECH

MICHAEL HEAGY, NEW MEXICO TECH

In this study, micron- and nano-sized copper (I) oxide (Cu_2O) were chosen as photocatalysts for the reduction of bicarbonate to formate using ambient solar energy. Cu_2O was chosen because it is nontoxic, earth abundant, and because its band gap resides at energies comparable to ZnS ; a proven photocatalyst in bicarbonate reduction. In our comparative study, composite nanoparticles having a silver core encapsulated by Cu_2O shell ($\text{Ag@Cu}_2\text{O}$) were synthesized to demonstrate their ability to enhance photocatalysis. Lastly, silver nanoparticles (AgNP) were added to Cu_2O in solution to improve bicarbonate reduction by acting as a plasmonic sensitizer. These experiments mark the first set to utilize Cu_2O as a photocatalyst in a cooperative role with metallic nanoparticles and core@shell structures toward enhancing bicarbonate reduction to formate. To achieve these goals, these photocatalysts were tested in solution phase for their ability of bicarbonate reduction. They were studied in two different hole scavengers (isopropyl alcohol and glycerol) using a solar simulator with air mass coefficient 1.5 and 0 (AM 1.5, AM 0) filters. Formate production increased significantly with AM 0 solar irradiation due to the inclusion of the ultraviolet portion of the solar spectrum, and nano-particulate Cu_2O showed improved photocatalysis relative to micron Cu_2O . Green chemistry solvent, glycerol proved to be a far superior hole scavenger in comparison to 2-propanol. AgNP added to Cu_2O showed no enhanced formate production, while $\text{Ag@Cu}_2\text{O}$ showed considerable enhancement. We attribute these

marked production improvements to direct electron transfer (DET) from metal to semiconductor, and plasmon-induced resonant energy transfer (PIRET).

Keywords: solar fuels, formate production, copper oxide

Film study of pellet-clad interactions using cerium oxide as a surrogate

DIANA PERALAS, SANDIA NATIONAL LABORATORIES
TIMOTHY BOYLE, SANDIA NATIONAL LABORATORIES

KHALID HATTAR, SANDIA NATIONAL LABORATORIES
REMI DINGERVILLE, SANDIA NATIONAL LABORATORIES

Nuclear reactors are powered by radioactive fuel pellets that are stacked together into so-called 'fuel rods'. These fuel rods last about three years in the reactors and are then considered 'spent fuel'. They must be removed and disposed of, which is really storage. During storage, it is reported that the outer surface of the pellets swell and comes in contact with the inner surface of the container (cladding). The integrity of the storage of this spent fuel is dependent of the pellet-clad (P-C) interaction; however, little is known about what occurs at this interface. Therefore, this project is aimed at developing a computational model verified with experimental data that details this interaction. Surrogates, such as cerium oxide (CeOx), are often used in place of studying 'hot' spent fuel. For this effort, thin and thick films of CeOx deposited onto Zircaloy were analyzed using PXRD and TEM in attempt to mimic the P-C interactions. A number of commercial and in-house synthesized precursors were evaluated for film production. The initial results from this study and their comparison to real-life samples will be presented.

Keywords: pellet-clad interactions, nuclear storage, cerium oxide

Microalgal crop protection by allelopathic control

HANAH RHEAY, NEW MEXICO STATE UNIVERSITY

Mass cultivation is an important process that still needs significant improvement to make algae a viable source of renewable energy. The allelopathic interaction in polycultures of *Chlorella sorokiniana* LANL1228 and *Coelastrrella* sp. was investigated to determine if this phenomenon could be utilized as a crop protection strategy. The culture exudate was collected, purified, and used to introduce allelopathic compounds into 96-well microplates for cultivation of algae. Exudate bioassay experiments were performed with three exudates (*Chlorella* 1228 exudate, *Coelastrrella* exudate, 50/50 polyculture exudate) each at five concentration treatments. Fractionation of the exudates was performed using solid-phase extraction in methanol. The fractions were used to culture bioassays of *C. sorokiniana* LANL1228 in 96-well microplates. Based on bioassay activity, fractions were classified as either active or non-active, and analyzed using Fourier transform ion cyclotron resonance mass spectrometer (FT-ICR MS) to identify presence of allelopathic agents. Based on experimental results, *Coelastrrella* is identified as a superior competitor and the interaction is classified as a negative allelopathic interaction. Allelopathic compounds are only present in exudates procured from cultures with *Coelastrrella* under direct competition with *Chlorella*. The exodume of algal interactions as shown by FT-ICR MS is complex and chemically diverse. Two fractionation regions of allelopathic activity suggest there are two potential compounds or compound classes to be elucidated. The observed allelochemical interaction likely includes long-chain fatty acids, wax esters, or another lipid type compounds. Selective use and design of polycultures is a likely solution to prevent negative allelopathic interactions and will be investigated.

Keywords: energy, algae, polycultures, allelopathic agents

Solar energy assisted water purification: Incorporation of an environmentally benign porous graphitized carbon nitride photocatalyst with graphitized polyacrylonitrile for efficient oxidation of toxic arsenite

STEPHANIE RICHINS, NEW MEXICO STATE UNIVERSITY
LARA TEICH, NEW MEXICO STATE UNIVERSITY

SWAGOTOM SARKER, NEW MEXICO STATE UNIVERSITY
HONGMEI LUO, NEW MEXICO STATE UNIVERSITY

The presence of toxic arsenic in various water bodies is a matter of concern in New Mexico. It is urgent to develop an efficient process for toxic and carcinogenic arsenic removal from water, while this contaminant is sourced from mining, industrial waste, etc. Recently, graphitized carbon nitride g-C₃N₄ with proper bandgap (2.7 eV) has attracted increasing attention. However, the efficiency for g-C₃N₄ needs further improvement due to its low charge separation efficiency and low surface area. Polyacrylonitrile (PAN) is an inexpensive polymer, when it is heated, it will form graphitized g-PAN with graphite-like sheet network structure, which is expected to facilitate the charge separation efficiency and larger surface area of g-C₃N₄. In this work, we report the synthesis of g-C₃N₄ and its composites with g-PAN with different compositions; characterization including their BET surface area, morphology, crystal structure and microstructure by N₂ adsorption and desorption, electron microscopies, x-ray diffraction and Raman spectroscopy. Their photocatalytic oxidation of As(III) under visible light irradiation as a function of the percentage g-PAN in g-C₃N₄ is evaluated. The correlation between their photocatalytic performance with their composition, microstructure, and surface area will be discussed.

Keywords: water purification, photocatalysts, oxidation

Solar assisted model aircraft for rangeland monitoring

ANDREW RODRIQUEZ, NEW MEXICO STATE UNIVERSITY

Rangeland crop monitoring with remote controlled aircraft is inexpensive and very effective. Combustion engine powered models do however have a limited flight time of typically about 20 minutes. This projects aims at developing a hand-made aircraft model that is battery powered during takeoff and solar powered during cruise (based on Las Cruces ambient data) to allow for day-long eco-friendly and quiet flights. Performance estimates have shown that a 12ft wing span model with 10lb empty weight would be able to carry a 5lb payload. The full-scale aircraft will be covered with more than 40 5x5in monocrystalline solar cells. To test the aerodynamics and handling a half-scale model was recently built and test flown. The half-scale model also helped clarify questions we had about the full-scale design. The full-scale model is an exact 1:2 scale of the half-scale model except for the fuselage which was altered to accommodate instrumentation. The full-scale has to be exceptionally light weight and aerodynamically efficient to be able to cruise solely on solar power according to prior calculations. Towards this end work on a fiberglass composite fuselage shell has been completed. The final wing has been designed and is currently being built. This current research that I am working on will fly on solar power and monitor crop rangeland efficiently and inexpensively.

Keywords: rangeland monitoring, model aircraft

Thin layer g-C₃N₄ nanosheets for enhanced visible-light photocatalytic activity

SWAGOTOM SARKER, NEW MEXICO STATE UNIVERSITY

HONGMEI LUO, NEW MEXICO STATE UNIVERSITY

Bulk graphitic carbon nitride (g-C₃N₄), a photocatalyst, was synthesized by annealing at an elevated temperature under air in a muffle furnace. The transformation from bulk to thin layer was performed using the ultrasonication and the hydrothermal process. While XRD, TEM, and FTIR confirm formation of the photocatalyst, photocatalysis analysis demonstrates that thin layer g-C₃N₄ significantly improves rhodamine-B reduction under the photoillumination. Electrochemical analyses reveal that thin later g-C₃N₄ possesses reduced resistivity in contrast to bulk catalyst and n-type behavior.

Keywords: g-C₃N₄, photocatalysis, rhodamine-B, n-type

Bioremediation using microalgae and biotechnology involving produced water extracted during hydraulic fracking operations in New Mexico

JONATHAN SCHWILLING, SANTA FE COMMUNITY COLLEGE

Oil and Gas companies extract approximately 28 billion gallons of produced water annually during fracking operations in New Mexico. This figure spikes to 880 BGY on a national level. Produced water presents high contents of

impurities and therefore, should be remediated to provide an alternative water resource and avoid further environmental contamination. Nationally, the amount of fresh water extracted annually since 2005 exceeds over 239 billion gallons. The ultimate goal is to recycle produced water in order to reduce the need to extract fresh water. Microalgae such as *Nannochloropsis salina* and *N. oculata* strains have demonstrated the ability to remove impurities from produced water. The biomass that is created by the microalgae could then be used in anaerobic digestion as a value added product. Modification by biotechnology may result in the ability for this water to be recycled by oil and gas companies during fracking operations, while meeting the ultimate goal of releasing treated waters safely back into the environment. Recycling produced water would alleviate the strain on our limited reserves of fresh water. Current levels of human growth will force us to find intelligent, sustainable ways to manage our limited and precious resources. Water is the primary vital resource, as it is critical to sustaining life and the natural balance of the environment.

Keywords: *N. salina*, *N. oculata*, *produced water*, *oil & gas*, *recycled water*, *fresh water*, *biotechnology*, *microalgae*

Using electromagnetic geophysics to better understand geothermal systems in New Mexico

MICHELLE SHERMAN, SANTA FE COMMUNITY COLLEGE
JEFF PEPIN, NEW MEXICO TECH
MARK PERSON, NEW MEXICO TECH

MATTHEW FOLSOM, NEW MEXICO TECH
ADRIANNA NIETO, NEW MEXICO TECH

Understanding the groundwater flow patterns of known geothermal systems is critical for developing prospecting methodologies. It is likely that there are many undiscovered geothermal systems in the Rio Grande rift of New Mexico that have no surface expression. In this study, we focused on better understanding the Truth or Consequences, NM and Rincon, NM geothermal systems. Alamosa Creek is the hypothesized upstream end of the Truth or Consequences system, where groundwater temperatures are approximately 35 °C at depths less than 200 m. Rincon is one of the hottest systems in the State with shallow temperatures upwards of 100 °C. Previous studies suggest that shallow geothermal systems in the rift are commonly attributed to deep circulation in crystalline basement rocks. The geothermal fluids ascend to shallow depths through permeability windows in overlying confining units. We used electromagnetic (EM) geophysics to try to image the geothermal upflow zones in our study areas. Magnetotellurics (MT) and transient electromagnetics (TEM) are two EM methods that have the ability to map subsurface electrical conductivity. Geothermal waters are often more conductive than their surroundings, making their flow patterns apparent in EM results. We collected 10 MT stations and 37 TEM stations along Alamosa Creek and 5 TEM stations along a fault zone in Rincon. The results from both study areas are consistent with focused geothermal flow along fault zones. It is believed that these faults provide windows for groundwater to ascend from great depth. Ongoing MT work aims to constrain the circulation depth of both systems.

Keywords: *permeability*, *hydrologic windows*, *geothermal*, *electromagnetics*

Synthesis and spectroscopic investigation of substituted salen and phthalocyanine chelating ligands

ORION STAPLES, UNIVERSITY OF NEW MEXICO
JEREMIAH SEARS, SANDIA NATIONAL LABORATORIES

DIANA PERALES, SANDIA NATIONAL LABORATORIES
TIMOTHY BOYLE, SANDIA NATIONAL LABORATORIES

This research focuses on the synthesis and characterization of novel, substituted Salen-type and phthalocyanine ligands and their respective metal complexes. These compounds present interesting and potentially applicable spectroscopic properties for a variety of industrial applications including subterranean fluid-flow monitoring. Through simple and high-yielding methods we have successfully synthesized a large number of novel, thermally stable, and variably soluble Salen-type and phthalocyanine derivatives. Focusing on first-row transition metals we were able to synthesize numerous coordination complexes with unique and distinct variations in infrared and Raman spectroscopic frequency shifts. These compounds also can be designed to be soluble in either hydrocarbon or aqueous

solutions, thus giving flexibility to possible uses. All of the synthesized compounds have been characterized by a variety of techniques including single-crystal X-ray analysis. Metal-ligand exchange reactions using these new complexes will also be discussed.

Keywords: phthalocyanine ligands, subterranean fluid-flow monitoring, spectroscopy

Ecological changes due to water level fluctuations in conchas reservoir

TERRILL STOWE, MESALANDS COMMUNITY COLLEGE
GRETCHEN GURTLE, MESALANDS COMMUNITY COLLEGE

CASEY WEST, MESALANDS COMMUNITY COLLEGE

The United State Army Corps of Engineers (USACE) began the construction of Conchas Dam in 1939 as part of the New Deal Program. The dam is located downstream from the convergence of the South Canadian and Conchas Rivers, northwest of Tucumcari, NM. Water stored in the Conchas Reservoir is transferred to the land in the Conchas Canal and its branch, the Hudson Canal. These canals deliver the water to a distribution system named the Arch Hurley Conservation District; and the Bell Ranch, located northeast of the reservoir. Water is released into the canals by the USACE to maintain a permanent pool elevation of 4,155 feet above mean sea level. However, dramatic effects of climate changes in 2002 to 2013 caused large and extended water-level fluctuations (WLF). According to the U.S. Drought Monitor, the state of New Mexico experienced the highest level of drought, “exceptional”, between 2002 and 2013. The WLF affected the ecosystems of Conchas in several ways: aquatic habitats and feeding and breeding grounds were lost; the absence of aquatic plant life affected the amount of dissolved oxygen in the reservoir; and pH levels rose. The study uses USACE data to consider the ecological effect WLF had on Conchas Reservoir. Elevation data provided by USACE is compared to the dissolved oxygen and pH reading taken by USACE monthly. The amount of water released to the Bell Ranch and Arch Hurley Conservation District were considered when determining elevation.

Keywords: water-level fluctuations, drought, Conchas Reservoir, climate change

Hydrochemistry of Sulphur Creek and Alamo Canyon, Valles Caldera: Effect of geothermal systems on surface water quality

GRAHAM THOMAS, UNIVERSITY OF NEW MEXICO

LAURA CROSSEY, UNIVERSITY OF NEW MEXICO

The Valles caldera in northern New Mexico is a large, Quaternary silicic volcanic complex (1.25 Ma to 40 ka) containing a liquid-dominated geothermal system. Sulphur Creek and Alamo Canyon in the southwestern part of the caldera contain acidic geothermal features. There are also other snow fed tributaries such as Redondo creek that feed into the Jemez river. In this study, we examine the hydrochemistry and diffuse gas input into the acid-sulfate waters and examine their influence on water quality of the surface waters draining the Valles caldera. Waters from several tributaries as well as the Jemez river were sampled in multiple campaigns in 2015. These results were compared with prior studies at the same locations. We report hydrochemical results for 23 waters. Sampled waters exhibit pH ranging from 2.5 to 8.5, temperature from 16 C° to 21 C°, and total dissolved solids range from less than 100 ppm at Redondo up to 1370 ppm at Soda Dam Spring. Major, minor and selective trace elements were also quantified in each sample. Using solute concentrations (including sulfate, chloride and bicarbonate) we are able to quantify the mass loading of geothermal constituents to the stream system. Elevated sulfate levels correspond with low pH in the waters and serve as a proxy for geothermal input in the upper reaches. In addition to the water parameters, diffusive CO₂ flux measurements have been taken in the study area to quantify the CO₂ released in association with thermal features. The acidic geothermal contributions have a major effect on the water quality in streams and shallow groundwater systems; especially pH, temperature, sulfate and metal content in the upper stream reaches of Alamo and Sulphur creeks. This study has implications for quantifying influence of geothermal inputs to the Jemez river with changes in discharge.

Keywords: water quality, geothermal, hydrochemistry, Valles Caldera, Jemez River

An investigation of the carotenogenesis of two North American microalgae

AUBREE TURNER, EASTERN NEW MEXICO UNIVERSITY

The research investigates two North American microalgae. One species of *Haematococcus pluvialis* and two species of *Coelastrella* were analyzed. The goal is to determine which health beneficial antioxidants, otherwise known as carotenoids, each species produce when stressed. The species of algae were stressed using fluorescent lighting and an altered media. The media is deprived of nitrogen, therefore reducing carbon fixation. The media has never before been used with these specific species of algae, proving this research unique. The algae were stressed and observed for 12 days. The carotenoid profile presented lutein as the most abundant antioxidant produced in all three species. Lutein can be used to prevent several eye diseases. The results of the study may provide a more environmentally friendly source for antioxidants that have been proven beneficial to human health.

Keywords: microalgae, human health, carotenoids

Zinc, lead, copper, chromium, and arsenic accumulation associated with naturally accumulating iron–manganese oxide coatings on in-situ stream substrates in streams comparing geothermal and non-geothermal waters

MARGARET TURPIN, UNIVERSITY OF NEW MEXICO

Geothermal trace metals (As, Cr, Cu, Pb, Zn) can have negative health effects on humans and wildlife. Previous studies utilized in situ pebbles, glass, or ceramic substrates with iron-manganese oxide coatings to understand chemical cycling. Here we develop a tracing method in a distal geothermal environment (upper San Antonio river, Valles Caldera, NM) using adsorption onto substrate surfaces to better understand trace metal transport. We focus on natural oxide-hydroxide accumulation on 24mm silica bead substrates at sites near and away from geothermal inputs. Results show that adhesion of iron and manganese oxides were closely correlated at both sites and showed a positive trend of accumulation over an 8 week trial period. Manganese at the thermal vent showed a decrease at the 6 week mark potentially indicating an unknown component of reduction for that metal. The adsorption of arsenic, chromium and lead on iron-manganese oxide coatings were significantly higher on substrates in the geothermally influenced waters than those not near the thermal input. All trace metals in the study were shown to have patterns of adsorptions and desorption over the course of the trial.

Keywords: trace metals, geothermal waters, in-situ streams

The social construction of water and water use in the CAERT Curriculum

KRISTIN WALDO, EASTERN NEW MEXICO UNIVERSITY

MARSHALL SWAFFORD, EASTERN NEW MEXICO UNIVERSITY

The CAERT Curriculum was created as a resource for agricultural and environmental educators in order to provide secondary students the necessary intellectual and practical training for sustainable agriculture. Given the critical water issues in New Mexico, our research objective was to identify cultural water discourse across a purposeful sample of the New Mexico CAERT Curriculum. We asked: Within the CAERT Curriculum, how are humans situated within the socio-ecological system and what is the relationship between human activity and water? Qualitative content analysis using first cycle domain coding and second cycle taxonomic coding revealed that the human-environment interaction within the CAERT Curriculum is largely consistent with the empty world socio-ecological regime arising during the Industrial Revolution. These findings are significant because the empty world regime is grounded in the assumption of resource abundance, an assumption that is inconsistent with resilience and adaptive responses to critical water issues. The implication is that the cultural lag in the CAERT Curriculum may actually exacerbate system decline, contrary to its intended purpose.

Keywords: water; CAERT Curriculum, socio-ecological system, sustainable agriculture

Willingness to pay to meet clean power plan requirements: Evaluation of New Mexico's options to meet requirements

KARA WALTER, UNIVERSITY OF NEW MEXICO
JANIE CHERMAK, UNIVERSITY OF NEW MEXICO

JENNIFER THATCHER, UNIVERSITY OF NEW MEXICO

New Mexico (NM) is a top US fossil-fuel producer and energy contributes to the state's budget—over 30% of the General Fund in 2013. A push towards renewables through the renewable portfolio standards and the Clean Power Plan (CPP) to reduce emissions could impact this. While the CPP lets each state choose their own path for reductions, suggested methods are to improve coal efficiency or increasing natural gas use and/or renewables. Specifically, NM's reduction requirement is 36% from 2012 levels (EPA 2015). The state's energy plan argues for an "all of the above approach" (NM EMNRD 2016). The extant literature primarily focuses on comparing preferences for characteristics and tradeoffs between different renewable energies. We contribute to this literature by considering the tradeoffs between energy sources themselves, that is fossil fuels and renewables, when policy requires a change in the energy mix. To evaluate NM's response to the CPP, we employ a choice experiment and evaluate each of NM's options to meet the requirements. Utilizing multinomial logit and random parameter models we find observable differences in preferences (living in fossil fuel producing county, climate change opinion, and political leanings) and unobservable heterogeneity. The difficulty in developing policy under these conditions is evident if we consider the largest electricity provider in the state's plan to increase electricity from nuclear power. We find significant variation in preferences; some are highly supportive of nuclear while others are highly opposed. These outcomes suggest challenges in energy policy development, but also directions residents will support.

Keywords: energy preferences, choice experiment, carbon emission reduction, random parameter logit, CPP

Reactor design and operation variables to improve mixed algae biomass production and stability with the addition of sodium bicarbonate

DEREK WICHART, UNIVERSITY OF NEW MEXICO

ANDREW SCHULER, UNIVERSITY OF NEW MEXICO

Imposing selection pressures on mixed communities of bacteria is commonly done to improve performance of activated sludge systems for wastewater treatment. Much less research has been done on reactor design and operation to impose selection pressures in algal polycultures, in part because biofuels research has largely focused on algal mono-cultures. It is hypothesized that imposing a selection for algae with improved settling characteristics will provide enrichment for high biomass and/or lipid storage, and that imposing a selection pressure for settling algae will improve solids separation, which is a major challenge in algal cultivation and recovery. The objective of this study was to determine if polycultures of algae can be enriched for useful functions, such as improved solids separation and/or lipid storage, by incorporating a settling phase into the operational cycle and to observe what the effects of excess carbon in the form of bicarbonate are. This study incorporated three sequencing batch reactors with defined media, run with a hydraulic residence time of two days in reactors 1 and 2 (R1 and R2) and five days in the control, and a solids retention time of twenty-three days in reactors 1 and 2 and five days in the control. The settling time was one hour in reactors 1 and 2, with no settling phase in the control. The solids separation was assessed using the sludge volume index (SVI) test and settlability. The experiment was run in two phases; the first was run with carbon addition, and the second was run with excess carbon addition. Results demonstrated that incorporation of a settling phase improved mixed culture sedimentation. For example, the reactors that included a settling phase (R1 and R2) produced biomasses with a sludge volume index (SVI) value of 222 and 944 ml/g respectively and good solids separation values (90 % or more); the control reactor with no settling phase produced biomass with an SVI of 773 ml/g and a solids separation value of 32 %. SVI is a commonly applied settlability parameter used in wastewater treatment systems, with lower values indicating better settling biomass.

Keywords: algae biomass, photobioreactors, polycultures

Metabolomic and lipidomic profiling in *Nannochloropsis salina* under sinusoidal temperature control

STEPHANIE WILLATTE, NEW MEXICO STATE UNIVERSITY
SABA GILL, NEW MEXICO STATE UNIVERSITY
BARRY DUNGAN, NEW MEXICO STATE UNIVERSITY
JACKIE JARVIS, NEW MEXICO STATE UNIVERSITY

TANNER SCHAUB, NEW MEXICO STATE UNIVERSITY
ROLSTON ST. HILAIRE, NEW MEXICO STATE UNIVERSITY
OMAR HOLGUIN, NEW MEXICO STATE UNIVERSITY
NEIL PAZ, NEW MEXICO STATE UNIVERSITY

The growing demand for large-scale sustainable, low-cost production of polyunsaturated fatty acids (PUFAs), carotenoids, and other high-value bioproducts has led to increased research in prospective microalgal species within the past several decades. The oleaginous marine microalga *Nannochloropsis salina* has received attention for its high oil yield (37-60% wt.) and production of the dietary PUFA ω -3 eicosapentaenoic acid (EPA). Marine microalgae found in temperate waters are subject to dynamic temperature fluctuations, which require mechanisms for temperature modulation. The incorporation of unsaturated fatty acids into membrane lipid pools is particularly important for maintaining membrane fluidity and cellular structure; therefore, the composition and content of membrane lipid pools is thought to be heavily regulated by temperature. Previous research has shown that *N. salina* grown under “cold stress” ($\geq 10^{\circ}\text{C}$ below optimal temperature) results in both increased lipid production and desaturation of fatty acids. Reduced biomass productivity is a consequence of cold stress; however, regulation of cold stress through sinusoidal temperature control has been shown to reduce the effect on growth. Here, we demonstrate the effects of cold stress under 12:12 hr sinusoidal control on *N. salina* using four temperature regimes: 5°C , 10°C , 15°C and 20°C that all increase to 25°C during peak light intensity, while the control is maintained at a constant temperature of 25°C . Physiological stress is determined through growth rate, chlorophyll fluorescence and dissolved oxygen measurements. Metabolomes were sequenced and quantified using GC TOF MS, and the results were analyzed for statistical significance using MetaboAnalyst V3.0. In addition, a pathway enrichment analysis was performed using VANTED V2.6.3 that reveals depletions in TCA cycle intermediates, particularly acetyl-CoA pools, under cold stress. Total fatty acid (TFA) content is quantified using fatty acid methyl ester analysis, and increases in both the amount and desaturation of fatty acid pools are observed at lower temperatures. Whole lipidome profiling is performed using FT ICR MS, and at reduced temperatures there is an increased proportion of EPA in both triacylglycerol and membrane lipid pools.

Keywords: algae biomass, photobioreactors, polycultures

Assessing uranium concentration in stream sediment on the Laguna and Isleta Pueblos

BRIANNE WILLIS, EASTERN NEW MEXICO UNIVERSITY

As a summer internship through a New Mexico EPSCoR funded STEMAP program. Myself and another intern worked with the uranium team from New Mexico Tech. We collected sediment samples from streams and washes on Laguna and Isleta Pueblo lands. These samples were collected to analyze the heavy metal content washing down from upstream uranium mines. This research program was funded because the uranium legacy these mines left behind are still a present health and safety risk to those that live in the area. Knowing the type and quantity of heavy metals washing down these washes, could help with further clean up or reclamation efforts in the area. Samples were collected from the Rio Puerco, San Jose, Del Valle, and Paguete washes. The samples needed to be dried, sieved, ground into a fine powder, then digesting in acid. Analysis of heavy metals was done using an ICP-MS for heavy metal content. We also performed a mass fraction of grain size on each sample to get a coarse sand content vs. the finer grain content. Our hypothesis being that uranium particle adheres to larger surface area by volume to the clay material better than coarse sand. Uranium concentrations were present on samples we collected from the washes downstream of the main uranium mines. Our data also supported our hypothesis when we correlated the amount of finer grained material a sample had with the concentrations of uranium that was present.

Keywords: water quality, uranium, Isleta Pueblo, Laguna Pueblo

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CONTACT INFORMATION

The New Mexico Academy of Science
c/o The New Mexico Museum of Natural History and Science
1801 Mountain Road NW
Albuquerque, New Mexico 87104
nmas@nmas.org
<http://www.nmas.org>

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