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Coastal plants for biofuel production and coastal preservation

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COASTAL PLANTS FOR BIOFUEL PRODUCTION AND COASTAL PRESERVATION

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ABSTRACT

Sustainable and renewable biofuels as well as coastal preservation are important to the State of Louisiana which is losing its coastline at the rate of up to 100 square kilometers per year. This has important implications for other coastal areas worldwide. By managing water hyacinth in canals and lakes in coastal Louisiana the biomass of this fast growing aquatic plant can reduce coastal erosion by absorbing wave energy, and remediate waste water through bioabsorption of contaminants, while also providing a source of biofuel. This research has shown that coastal vegetation can play a part in lessening the impact of storms by reducing wave energy up to14%. Floating booms can hold water hyacinth in place along coastal canals so that it can be contained for growth and harvesting while providing this protection.

Under average growing conditions in Louisiana, water hyacinth produced 2.4 to 2.6 metric tons of hydrated biomass per hectare per day. In addition this research found that this plant has a fermentable glucose and xylose content in excess of 48% by dry weight which is suitable for bioethanol production. Its rapid growth rate combined with its fermentable sugar concentration makes water hyacinth a viable candidate for use as a source of biofuel and for coastal preservation.

Engineered barges fitted with loading mechanisms and harvesting systems were designed to contain and harvest water hyacinth in Louisiana’s coastal canals and to produce biofuel from harvested water hyacinth. Harvesting and growth site accessibility and design for transportation and proximity to coastal ethanol production facilities was integral to the design. Carbon neutral fuels are an important consideration related to environmental sustainability concerns. As the State of Louisiana is losing coastal

wetlands the combination of erosion control with biofuel production will be a great benefit to the state and other coastal areas of the world.

CHAPTER 1. WATER HYACINTH FOR BIOFUEL AND COASTAL PRESERVATION

Introduction

Water hyacinth has shown potential for both biofuel production and coastal preservation. With a measured sugar concentration of 20 to 50% by dry weight water hyacinth can be readily converted into ethanol. Current work has shown that its rapid growth rate could be useful in coastal preservation by absorbing wave energy to protect coastal canals and also by sequestering water contaminants in its biomass.

Based on the sugar yield observed in samples from locations in Louisiana there is potential for biofuel production from water hyacinth. Engineering design for pilot and full scale emplacements in coastal canals and lakes will be discussed. Previous work explored the potential for harvesting *Eichhornia crassipes* as a valuable biofuel resource (Nigam 2002; Mosier et al 2005; Taherzadeh and Karimi 2007; Lundgren and Helmerius 2009; Farrell et al 2006), but the current work also explores the potentical for coastal protection and wetland preservation.

Known for its beautiful flowers and spread worldwide by man due to this ornamental beauty, water hyacinth is also known by the common name water orchid (Batcher, 2013) and it was first introduced to Louisiana and Florida in 1884 at the New Orleans Exposition where it was suggested that it could be used to beautify ponds and streams (Wunderlich, 1964). As an ornamental plant of interest for its beautiful flowers and lush vegetation water hyacinth is still sold shipped and grown today for use in botanical gardens. Named after Johann Albrecht Friedrich Eichhorn, 1779-1856 (Langeland & Cherry, 2008) water hyacinth is an invasive free floating vascular plant with the highest recorded growth rate of any known vascular plant as it is capable of doubling in as little as 6 to 18 days given the right eutrophic conditions (Gutierrez, Uribe, & and Martinez, 2001; Langeland & Cherry, 2008; Tellez, Lopez, Granado, Perez, Lopez, & Guzman, 2008; Westlake, 1963). Its synonyms include *Eichhornia speciosa Kunth*, *Heteranthera formosa*, *Piaropus crassipes*, *Piaropus mesomelas*, and *Pontederia crassipes* (Batcher, 2013; Langeland & Cherry, 2008).

Coming from the family Pontederiaceae the genus *Eichhornia*, is made up of eight species of vascular freshwater plants (Barret, 1988; Batcher, 2013). *Eichhornia natans* is found strictly on the continent of Africa with the other species distributed throughout the New World tropics. The species *Eichhornia crassipes* has been distributed to over 50 countries worldwide by people who desired it for its ornamental flowers (Barret, 1988). The eight species of *Eichhornia* are *E. azura, E. crassipes, E. paniculata, E. heterosperma, E. diversifolia, E. natans, E. paradoxa*, and *E. meyeri* (Barret, 1988). *E. paradoxa* and *E. meyeri* are rare and found only in Guatemala, Venezuela, Brazil, Paraguay, and Argentina (Barret, 1988). Of the eight species of the genus *Eichhornia*, *E. crassipes* is a mat forming free floating perennial that reaches reproductive maturity more rapidly than *E. azurea* which also forms floating mats, but is anchored underneath the water by its roots thereby floating while tethered to the bottom of the shallow section of the water body which it inhabits (Barret, 1988). Both species are prone to grow in permanent water bodies but only *E. crassipes* with its floating root system is able to thrive in water bodies that have a high fluctuation in water level. Unlike *Eichhornia crassipes* the other eight species of *Eichhornia* have more terrestrial root systems and or possess a dependency on periods of dryness for reproductive cycles (Barret, 1988) making them suitable to environments where water supply fluctuates by season. Where there is a great variation in water depth as what is seen in the areas of coastal Louisiana studied for this research only *Eichhornia crassipes* can thrive. Based upon field observations, photographic comparisons, and conditions solely favorable to *Eichhornia crassipes* in sample areas it is concluded that the plant sampled in coastal Louisiana for this study was *Eichhornia crassipes* and not one of the other eight species of *Eichhornia* (Barret, 1988; Batcher, 2013; Jones, 2009).

Based on its sugar concentration water hyacinth could be used for ethanol production. Ethanol has already gained a foothold in the fuel market as a popular additive to gasoline. Ethanol and fossil fuel blends include oxy-diesel, E85, and gasohol, a 10% ethanol 90% gasoline mixture in common use in North America. Ethanol contains 35% Oxygen so when it is burned it emits less Nitrous Oxide and less particulate than gasoline (Tindal, 2010). Bioethanol is a carbon neutral fuel source that when added to gasoline acts as a desiccant, and increases the gasoline's octane rating. The use of ethanol can reduce green house gas emissions and is a positive step towards the carbon neutral green energy solutions needed for energy sustainability and global economic stability (Farrell, Plevin, & Kammen, 2006; Hall & Scrase, 1998).

Non-food based sources of cellulosic ethanol such as water hyacinth can be very cost effective when compared to purchase of food based feedstocks as there is little or no market demand for these plants. The key to making the economics of ethanol production from these plants work is to control the costs of harvesting and processing of the plants (Hall & Scrase, 1998). Currently world fossil fuel prices are a deciding factor in the economic viability of the green fuel movement, and bioethanol is no exception to this economic norm. Even as fossil fuel prices decrease environmental concerns over greenhouse gases along with the need for energy independence may increase the desirability of bioethanol produced from water hyacinth (Tindal, 2010).

Water hyacinth can be fermented using *Pichia stipites. P. stipitis* is of beneficial use as a fermentor to convert water hyacinth to ethanol because it has been shown to ferment xylose and gives a high ethanol yield in the process (Nigam, 2002). *Saccharomyces cervisiae*, a commonly used yeast for fermenting ethanol, is not useful in our case because it cannot ferment pentoses which constitute 40% of the hemicellulosic sugars of water hyacinth. Other benefits of *Pichia stipitis* is that it produces no xylitol, a toxin, and is a very broad range fermentor over all.

Teams consisting of professionals in the fields of biology, engineering, and business, can easily form large scale biofuel production consortiums based on cellulosic ethanol technology. This approach to biofuel production will advance science, manufacturing, and engineering in the areas of cellulosic ethanol production along with coastal preservation. Current ethanol production depends largely on the use of food crops, but this novel use of a non food plant with a suitably rapid growth rate will add to the state of the art in cellulosic ethanol production and contribute greatly to keeping both food and fuel costs low while providing a novel solution to energy needs and scientific advancement in that area (Hall & Scrase, 1998; Motavalli, 2009).

Cellulosic biofuels produced from nonfood based plants have the advantage of not competing with food sources, unlike corn based ethanol production which can greatly affect the world food market (Hall & Scrase, 1998; Motavalli, 2009). Cellulosic ethanol production from nonfood crops is not viewed as causing the moral dilemma which can arise when food sources that could sustain human lives in developing countries such as beats, corn, or sugarcane are used as fuel for machinery and to meet transportation demands. As global demand for biofuels increases it is important that nonfood based crops be tapped for biofuel production (Farrell, Plevin, & Kammen, 2006; Motavalli, 2009).

Even now relatively small scale use of corn based ethanol in gasoline has resulted in corn price instability proving the need for non-food based sources for biofuels especially as their use increases exponentially in the coming years. There will be serious and detrimental economic and social consequences that far outweigh the convenience if food crops are used for global scale biofuel production (Hall & Scrase, 1998; Motavalli, 2009).

In addition to energy independence and environmental sustainability biofuels also offer a never ending renewable source of energy. Fossil fuels have a large, but finite supply. As the world realizes more and more that fossil fuels are finite the demand for renewable biofuels will increase due to the overriding need for stability in global energy markets. For long term economic and security needs governments and individuals prefer stable energy sources that do not have the here today, gone tomorrow feel, potential for violent conflict over finite resources, and price fluctuations that are often associated with fossil fuels (Tindal 2010; Rosillo 2012 ; Tanaka 2011). It is clear that nonfood based plants are a significant storehouse of solar energy which is capable of helping to fuel world energy demand by being harvested as a source of biofuel and the International Energy Agency, founded in 1974, predicts that by 2050 27% of the world's transportation fuel could come from biofuel sources (Tanaka 2011).

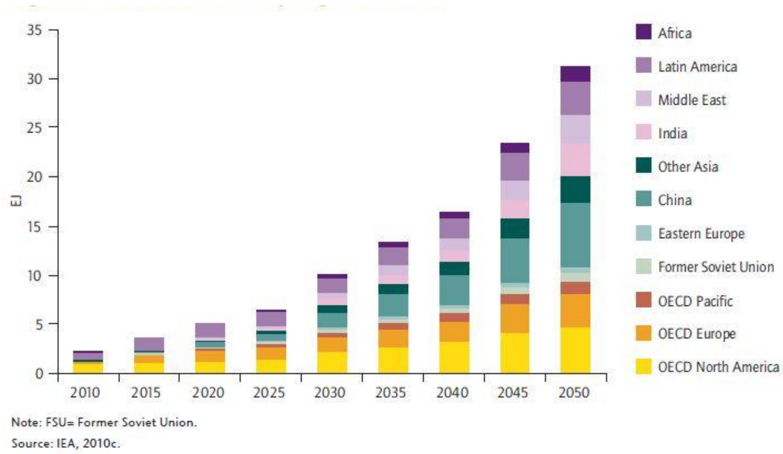

Figure 1 Graph of regional biofuel demand (Tanaka 2011)

As a renewable carbon neutral fuel, bioethanol use does not contribute to the environmental harm which can result from excessive green house gas emissions. Environmental damage from global warming, although not fully quantified by today's economic models, does have an economic cost. When the economic cost of environmental damage is factored in the higher price of renewable biofuels like bioethanol compared to non-renewable carbonaceous fossil fuels is greatly offset by the long term environmental economic savings which can be realized when carbon neutral fuels that have minimal environmental impact are used. One example of this is the cost of climate change if it causes instability in global weather which can lead to severe drought in some places and catastrophic weather events in other parts of the world. With its rapid growth rate, wave energy attenuation, biofuel production potential, and ecological benefits this technology provides a promising area for future research and development.

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CHAPTER 2. CHEMICAL ANALYSIS OF WATER HYACINTH FOR BIOENERGY PRODUCTION AND ECONOMIC ANALYSIS OF WATER HYACINTH BIOFUEL

Introduction

Carbon neutral energy production is important to the environment and now more than ever people are realizing its importance (Herwick, 2005). This research has enormous potential for carbon neutral and otherwise environmentally friendly and sustainable energy production. The development of new non-food based and cost effective methods for ethanol production is vital to the energy economy (Farrell, Plevin, & Kammen, 2006; Mosire, et al., 2005; Nigam, 2002).

A variety of plants were looked at and examined based upon their suitability for combined coastal protection and biofuel production. Water hyacinth was chosen for this research. Its selection was based on its high volumetric growth rate along with its proven ability to thrive throughout coastal Louisiana even in brackish water environments (Cheng, 2004). In Mexico a water hyacinth abatement program removed 3600 metric tons of wet water hyacinth per day over a period of 181 days as part of a water hyacinth control program which did not eradicate the plant, but merely managed it over an area of 40,000 hectares (Gutierrez, Uribe, & and Martinez, 2001). This fast growth rate coupled with water hyacinth's historical ability to grow well in Louisiana's coastal environment (Wunderlich, 1964) makes it a viable candidate for use as a source of biofuel and for the prevention of coastal erosion (Ozaki 2004; Jinhai et al 2003; Das, et al 2010; Burley and Suddeth 2010; Bonham 1983).

Acids and enzymes can be used to hydrolyze cellulosic biomass into fermentable sugars which can be made into ethanol (Galbe M. and Zacchi G. 2002; Huang et al. 2008;

Taherzadeh and Karimi 2007). While a study by Nigam in 2002 concentrated on hemicellulose in water hyacinth this study focused on complete hydrolysis of water hyacinth. While more energy intensive than partial hydrolysis complete hydrolysis can produce substantial amounts of ethanol as according to analysis the plant contains over 59% total sugars by dry weight with most of the sugar found in the form of glucose. In 2002 Nigam asserted that the plant was 48.7% hemicellulose with only 18.2% cellulose meaning that most of the plants sugars could be accessed by light acid hydrolysis of hemicellulose (Nigam, 2002).

The agricultural economics of the project requires that the water hyacinth is grown and harvested near sources of transport. The proximity of coastal canals to state highways, rail and transport via coastal waterways makes affordable transport of material feasible. Large harvesters can be used to gather the water hyacinth and dry it by mechanical and solar means. This will serve two purposes in that the water-hyacinth must be dried as the first step in preparation for acid hydrolysis and secondly in that drying will lessen the transport weight and storage volume that must be carried on the way to coastal area ethanol plants.

Theoretical Basis

Cellulosic materials are made of lignin, cellulose, and hemicelluloses. Total plant biomass in order of concentration consists of cellulose, lignin, hemicelluloses, ash, and extractives. Ash consists mostly of metallic salts, metal oxides, and trace mineral residues left over after burning plant biomass. Lignin and cellulose are both combustible parts of plant biomass and are consumed upon burning thus they are important when considering water hyacinth bioenergy and biofuel production.

Cellulosic molecules exist as long chains of 6-carbon and 5-carbon sugars. Cellulose consists of 6 carbon *D*-glucose molecules bound with glycosidic linkages that make up the primary structure of plant cell walls while hemicellulose consists of mostly 5-carbon sugars. Lignin binds to hemicellulose acting as the glue that gives structural strength to plant cell walls and prevents further penetration of water thereby creating a matrix of water channels in the xylem and phloem of the plant's vascular tissues. Large amounts of lignin make hydrolysis more difficult in that it requires more energy to break its biopolymeric bonds which exist as lignin-carbohydrate complexes (Lawoko, 2005). There is some controversy concerning these lignin carbohydrate complexes and the types of bonds they represent (Lawoko, 2005). The critical point of concern from the engineering prospective however was that lignin bonds are strong and present a processing and fuel production challenge in that the energy required to break the bonds of plant cell walls effects the economics of the biofuel production process.

The polymeric bonds of lignin cross link polysaccharides thereby giving plant cells their structural rigidity and dynamic stress and strain resistance, for example hard woods are higher in lignin than soft woods and this is why hardwoods make more sought after construction material for load bearing structural members of buildings and where popular as tool building materials in ancient times (Lawoko, 2005). Compared to woody plants of all types and compared to many grasses structural analysis shows *Eichhornia crassipes* to be relatively low in lignin and high in cellulosic sugars.

Once sugars were extracted fermentation was used to produce alcohol for use as biofuel. Hemicelluloses produce both pentose and hexose sugars such as mannose, xylose, arabinose, galactose, and glucose. Common strains of yeast can ferment hexoses and special strains of yeast such as modified *Pichia stipitis* can be used to ferment pentose sugars into alcohol (Nigam, 2002). Theoretically 1000 grams of a sugar will produce 580 grams of ethanol, and 420 grams of carbon dioxide, but the yeast must consume some of the sugar for reproduction so the actual alcohol yield is less than 100% (Hashem & Rashed, 1993).

Cellulosic biomass has 4 components, cellulose, lignin, hemicelluloses, and extractives. Hydrolysis is a pretreatment method that can be used in order to separate these components. Methods of hydrolysis include enzymatic hydrolysis, and chemical hydrolysis using acid (Benazzi, Calgaroto, Dalla, & Mazutti, February 2013; Galbe & Zacchi, 2002). By breaking glycosidic bonds hydrolysis fractionates hemicelluloses and celluloses into readily fermentable hexoses and pentoses. For this research acid hydrolysis with concentrated sulfuric acid was used to release plant sugars for calculations of ethanol yield.

After acid hydrolysis ion exchange columns were used to separate acid from the sugars extracted from the biomass (Huang, Ramaswamy, Tschirnwe, & Ramarao, 2008). Low temperature and low pressure production is planned to reduce industrial costs while also maintaining a positive energy balance. A two step acid treatment process could be used to increase process efficiency. In step 1, pretreatment, sulfuric acid is used to soak hydrolysate at 35% concentration for 3 hours, and then this solution is dehydrated to a concentration of 65% in stage 2 and allowed to soak for up to 5 hours, and the contents are then run through an ion exchange column to separate sugars from the sulfuric acid (Girisuta, Danon, & Janssen L.P.B.M., 2008). Evaporative extraction is then planned to be used to separate the acid from the ion exchange column for reuse. If acid were not recovered then lime would have been needed to absorb it, and disposal costs would have driven the economics of the process in the negative direction.

In photoautotrophs such as aquatic plants chlorophyll in cells capture the energy of sunlight and via the enzymatic processes of photosynthesis take hydrogen from water, and combine this free hydrogen with carbon dioxide from the air to produce a carbohydrate, known as sugar, and release oxygen along with half of the original water lysed (Collegeboard, 2012). In effect the energy of sugar and subsequently the energy of biofuels produced from sugar is a form of stored solar energy.

When hydrocarbon bonds are broken in a process referred to as either burning, in combustion processes, or cellular respiration in living organisms energy is released (Hall & Scrase, 1998). Sugar breaks down in an exothermic reaction so as the hydrocarbon bonds in sugars are broken this surplus energy meets the energy needs of both organic life, and industry. As the burning of sugar is an energy releasing exothermic process, the creation of sugar is an endothermic process which requires energy storage in order to occur.

The energy storage of photoautotrophs such as sugar cane, corn, or aquatic plants can never exceed the energy of the sunlight which reaches these crops. The energy from the sun reaching the earth is given by a calculation of solar flux energy density at the earth's given distance from the sun. The quantity derived from the calculation of Solar Flux is referred to as the Solar Constant S where S = the sun's energy output divided by 4 pie times the square of the average distance of the earth from the sun. The solar constant has a value of 1370 Watts per meter squared. While 1370 watts per meter squared is the total amount of energy from our sun reaching the earth every second the actual energy reaching plants is far less than this due to atmospheric absorption and interference (DeMott & Randall, 2009; Yu, 2009).

In one year the total amount of energy reaching the earth from the sun equates to 178,000 terawatts of power which is 15,000 times current global energy consumption. However, not all the energy which reaches the earth makes it to the surface of the earth and additionally only radiation in the visible wavelengths of 400nm to 700 nm is suitable for photosynthesis. As the blackbody radiation emitted by the sun is at a temperature of 6000K much of it lyes within the visible spectrum wavelength of 400nm to 700 nm and so 45% of solar radiation which reaches the earth can be used by photoautotrophs to store energy in their sugary biomass (DeMott & Randall, 2009; Soper, 2013; Yu, 2009).

Of the energy that comes to the earth from the sun only a limited amount is available for photoautotrophs to store as sugar in their biomass. Albedo represents the amount of solar energy that the earth reflects back into space (the earth reflects energy back into space in the mostly infrared spectrum as a blackbody radiation at 255K). Total energy received minus albedo and atmospheric absorption due to clouds (4%), and dust, water vapor, and ozone (19%) represents the amount of energy available for photoautotrophs to store. As the earth's albedo is 31% the amount of photoautotroph usable energy reaching the earth's surface is 47% of the total energy received from the sun. Numerically this amount is 47% of 1370 watts per meter squared or 644 watts per meter squared reaching the surface of the earth on a daily basis (DeMott & Randall, 2009; Soper, 2013; Yu, 2009).

As only 45% of irradiative energy from the sun is in the proper 400nm to 700 nm wavelength for photosynthesis to occur only a limited percentage of the total wattage from the sun reaching the earth's surface can be photosynthetically stored as sugar in photoautotrophic biomass. Additionally the physics of photosynthesis dictate that due to quantum chemical economics the fixation of a carbon dioxide molecule has a quantum requirement of 10 or more meaning that only 25% of the photosynthetically active radio spectrum energy (PAR) which plant leaves absorb in their chloroplasts can be used per carbon dioxide molecule fixed in a carbohydrate. While based on these figures the theoretical efficiency of photosynthetic energy storage is 11% due to other factors including the reflectivity of plant surfaces, energy lost to respiration, and less than optimal actual solar radiation conditions the actual solar energy storage in plant biomass is only between 3% and 6% of the total solar energy that reaches the surface of the earth. However, as the sun sends 178,000 terawatts of energy to the earth on a yearly basis, and as this is 15,000 times our current global energy demand even 4% is 7120 terawatts which exceeds our 11.9 terawatt global energy demand by 598 times over (DeMott & Randall, 2009; Soper, 2013; Yu, 2009).

Built up through the processes of plant cellular respiration through photosynthesis cellulose is the starchy building material of plant based organisms which makes up stems, leaves, stalks, husks, and other parts. Cellulose is the most abundant material on the planet. Cellulose is rich in carbohydrate energy storage, yet humans lack the enzymes needed to extract energy from cellulose and so it is not a food product for human consumption. Biofuels made from cellulose are known as cellulosic biofuels (Huang, Ramaswamy, Tschirnwe, & Ramarao, 2008). The energy required to break down cell walls has been a limiting factor in conventional plant cellulosic biofuel production. Acid hydrolysis of plant cellulose holds promise as a cost effective method of extracting sugars from plants.

Materials and Methods

Plant Samples from three different state regions were collected, photographed and compositionally analyzed to document any possible subspecies differences in *Eichhornia crassipes* between areas. In the following three illustrations representative samples from the LSU Lakes, the Atchafalaya River Basin, and the Donaldsonville area are shown respectively for comparison. These samples were then separately analyzed using NREL analytical chemical analysis methods to document any compositional differences between them. Sample plants were visually similar but chemical analysis revealed biochemical differences.

Samples were first air dried to simulate real world processing, and then final drying was conducted using a laboratory drying oven heated to 100 degrees Celsius for a minimum of 3 hours. Samples were then ground up and subjected to acid hydrolysis in order to break down cellulose and extract sugars. A 1% v/v sulfuric acid solution was used for hydrolysis. The solution was then run through a distillation column in order to separate sugars from the acid hydrolysis solution. Next a Dionex HPLC was used to analyze the cellulosic sugars extracted from the plants. Finally *Pichia stipitis* yeast can be used for fermentation of the sugars extracted into ethanol.

Figure 2 LSU Lakes *Eichhornia crassipes*

Figure 3 Atchafalaya Basin *Eichhornia crassipes*

Figure 4 Donaldsonville Area *Eichhornia crassipes*

Analysis of variance of samples was conducted based upon sample area and region. The samples have been gathered and this comprehensive analysis was conducted at the Louisiana State University Agricultural Center's Audubon Sugar Institute which has offered analytical support for future research on this exciting macrophyte. No significant difference was found between samples taken from sample locations in Louisiana.

Once ground, the water hyacinth sample was subjected to mildly heated, 100 degrees C, acid hydrolysis in order to break down cellulose and extract sugars. The solution was then run through an anion exchange distillation column in order to separate the sugar hydrolysate from the acid hydrolysis solution. Next an HPLC was used to analyze the cellulosic sugars extracted from the plants (Iguacu, 2005).

Figure 5   Dried and weighed samples of water hyacinth

A Dionex HPLC was used to analyze the cellulosic sugars extracted from the plants. The HPLC unit single injection port connected to a Dionex P680 pump which fed into an ED50 Trimode electrochemical detector reading from an amperometry analysis cell with a dionex carbopac hplc column using Dionex Chromeleon software. Comparative analysis of the area undereneath the ellusion curve of the water hyacinth hydrolysate HPLC to known sugar standard curves allows the sugar yield of the hydrolysate taken from the water hyacinth to be calculated.

Results

The focus of our results was to identify concentrations of fermentable sugars. The following figure shows an HPLC curve of elution times which shows glucose as the highest peak. Table 1 provides glucose and xylose percentages from a series of HPLC analyses.

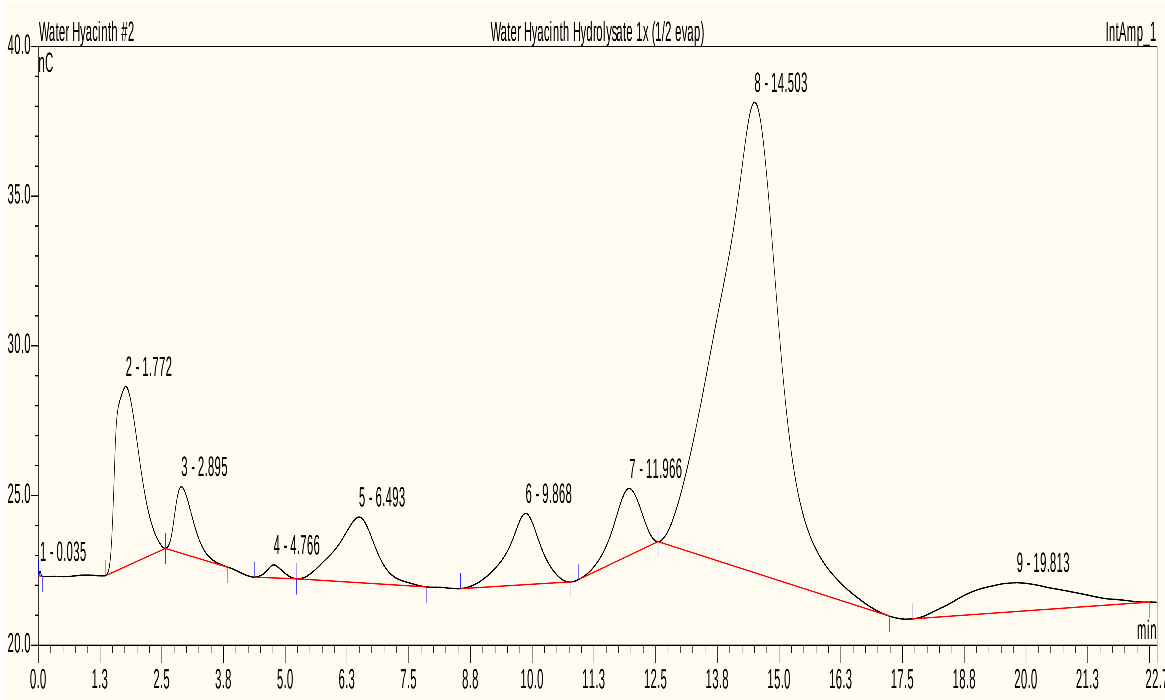

Figure 6 Typical sample HPLC Peak Retention Times for sugar analysis, raw data, glucose is the highest peak.

Table 1, The amount of sugar concentration by location this data was collected from HPLC analysis of water hyacinth samples from the given locations

Sample Area and Date	% Glucose	%Xylose
LSU Lakes 07/22/11	28.05	6.66
Atchafalaya S1 03/24/13	36.86	7.92
Atchafalaya S3 03/24/13	40.86	7.37
Atchafalaya S4 03/24/13	48.72	10.36
Donaldsonville 03/28/13	43.74	8.45

At the time of this writing compositional HPLC analysis on numerous samples from 3 locations within the State of Louisiana has been conducted in an effort to verify promising results in the literature which stated a sugar concentration in the plant of 21% by dry weight (Nigam, 2002). Analysis results using NREL methods on Louisiana's *Eichhornia crassipes* plants have far exceeded the 21% results shown in Nigam's 2002 research paper.

The difference in integrated curve area between the HPLC graph of known sugar standards and the hydrolysate provides the sugar yield of the sample. The maximum yield came from samples in the Atchafalya river basin. All sample yeilds are listed in Table 1.

Statistical analysis of variance between samples was done using ANOVA to analyze differences based upon location or the time of year the sample of water hyacinth was taken, late winter/early spring, or summer. The null hyothesis for both location and harvest time was that there was no significant difference. The following text catalogs ANOVA Analysis results for the two variables studied, location, and time of sample harvest were as follows

Equation 1, Analysis of variance in data

$$F = \frac{\text{Experimental Variance + Error Variance}}{\text{Error Variance}}, \text{(Li, 2010)}$$

Table 2 Typical ANOVA results showing no statistically significant difference between geographic and seasonal samples

Source of Variation	Sum of Squares	Mean Squares	F Value
Between	327.2	81.79	.2390
Error	5134	342.2	
Total	5461		
Probability of this result	.0912		

An F Chart with tabulated values was used to locate the critical value and if the F is below the critical value then we fail to reject the null hypothesis.

F(4,15) Critical Value = 3.056,

The derived F value of .2390 is far less than the critical value of 3.056 so we fail to reject the null hypothesis. We therefore conclude that there is no significant statistical difference between the plant samples to a probability factor, P, > .05 significance level for both cases 1 being that there is a no significant difference by region and case 2 being that there is no significant difference by season of harvest (Li, 2010). No statistically significant differences were found.

Compositional analysis done for this study on samples from the state of Louisiana conducted at Louisiana State University's Audubon Sugar Institute showed a glucose concentration of up to 48%. For all the samples the combined average total yield was 39.6% glucose by dry weight.

Under typical summer conditions in Louisiana, water hyacinth can produce an average of .551 metric tons of dry biomass per hectare per day, meaning a one hectare area of water hyacinth, could produce 1.18 metric tons of hydrated biomass per day (Nigam 2002; Gutierrez, Ruiz, and Martinez 2001; Westlake 1963). A study conducted at the Cruz Pintada Dam in Mexico found that water hyacinth can produce up to 173.9kg of sugars per hectare per day, given ideal weather conditions and eutrophic waters such as those found at Cruz Pintada Mexico. At the observed growth rate in the Cruz Pintada Dam water hyacinth produced 3600 metric tons of hydrated biomass per day over an area of 40,000 hectares. At the experimentally observed .17% dry to wet weight ratio 3600 metric tons per day of wet water hyacinth biomass equates to 612 metric tons of dry biomass per day over 181 days which yields 110772 tons which at a modest 21 percent sugar yield, well below experimental results, can be converted into 23,262,120 kg of sugar which yields 15,325,632 liters of ethanol over a half year long growing and harvesting season.

HPLC compositional analysis at the Audubon Sugar Institute showed a higher actual average sugar yield of 39.646 glucose, and 8.152 xylose for an overall average of 47.798 % glucose and xylose with trace amounts of other 5 carbon sugars. More conservative estimates of dry weight in the literature reports the dry weight of water hyacinth to be from 5 to 10% of its wet weight (Lindsey & Hans-Martin, 2000). Even with these conservative estimates at a ratio of 7% 3600 metric tons of water hyacinth at only 21% sugar yield produces 423,360 liters of ethanol per day.

Discussion

Based on analysis of variance results there is no statistically significant difference in sugar concentration between the plant samples from different areas of Louisiana. However, the greater sugar concentration in the samples taken from Donaldsonville and the Atchafalaya River Basin do suggest that water hyacinth harvested from these areas can produce more ethanol. A possible reason for the difference lyes in the fact that the LSU Lakes is a closed system whereas Donaldsonville and the Atchafalaya river basin are open systems that are subject to fresh water flow and nutrient rich river runoff. Better nutrient availability may account for the differences between the LSU Lakes and the other areas sampled (Gutierrez, Uribe, & and Martinez, 2001).

These experiments showed that water hyacinth had over 48% sugar by dry weight. However for large scale production we assumed a worst case scenario of 21% practical sugar yield and even under this condition we found that 1 metric ton of dry water hyacinth biomass produced 210 kg of sugar which at an experimentally observed rate of .56 liters of ethanol per kilogram of sugar yielded 117.6 liters of ethanol (USDA, 2006).

The use of food crops like corn and sugarcane to produce fuel can greatly increase world food prices (Hall & Scrase, 1998; Herwick, 2005). Instead non-food based cellulosic ethanol production can be used to replace food based ethanol production. This research has shown promising amounts of cellulosic sugars in water hyacinth well in excess of the 18% reported by Nigam. Cellulose is constructed of linked glucose chains joined with glycosidic linkages and so for a sample to have 48% glucose the amount of cellulose in the sample may well be higher than the 18.2% predicted by Nigam as hemicellulose can also contain glucose, but xylose is often the predominant sugar in hemicellulose (Renssellaer Polytechnic Institute Chemical Engineering, 1996). As ethanol production is ramped up to meet large scale world fuel demands cellulosic ethanol will be an essential component of the world fuel supply equation (Farrell, Plevin, & Kammen, 2006; Huang, Ramaswamy, Tschirnwe, & Ramarao, 2008).

Sugar cane must first be harvested, cut into billets, and then crushed in order to extract its sugary juice. The 48% sugar concentration found in water hyacinth shows that it is comptetive with the 17 to 22% found in the juice of the sugar cane plant in addition. Current farming methods use fossil fuel burning tractors and processing equipment along with power from commercial electric generators in order to extract sugar from this plant. For this reason ethanol produced from sugar cane, while more conventional and traditional in its methods, is not necessarily more energy efficient than cellulosic ethanol produced from the sugars found in coastal plants such as water hyacinth. The difference between the production of sugar from sugar cane and other food crops versus the production of sugar from coastal plants lyes only in the methods of production and not in the end result (Farrell, Plevin, & Kammen, 2006; Motavalli, 2009; Nigam, 2002).

Similarly corn ethanol production requires intensive agricultural processes and energy inputs ranging from using diesel fuel to mechanically prepare the soil to applying resource intensive fertilizers and pesticides along with coal fired ethanol production plants (Farrell, Plevin, & Kammen, 2006). As such it is not as efficient a source of energy when compared to water hyacinth which grows naturally and requires no external inputs or diesel fuel use for its growth. It takes 20.2 pounds of feed corn to make 3.785 liters, 1 gallon of ethanol (Shapouri, Salassi, & Fairbanks, 2006; Hashem & Rashed, 1993). At this yield combined with its given growth rate one acre of corn can produce 413 gallons of ethanol per year but in comparison at 38.4 metric tons of dry biomass per acre per year and at a conservative sugar yield of 21% by dry weight water Hyacinth can produce 1910 gallons of ethanol a year. In real world dollars at $1.85 per gallon of ethanol one acre of corn equates to $370 per year minus production, harvesting, and processing costs, but one acre of water hyacinth equates to $3500 per year minus its production, harvesting, and processing costs.

The often cited weakness of cellulosic plant biomass ethanol production lyes in its processing cost difference when compared to other ethanol production methods. However, even if coastal harvesting costs and cellulosic ethanol production costs are 40% higher than the harvesting and fermentation costs of corn based ethanol production water hyacinth at these cost estimates water hyacinth would still be more profitable than corn for ethanol production as it exceeds corns yield by 80%. Feed corn only has a percentage of water hyacinth’s potential ethanol yield and its use to produce ethanol has the added benefit of raising world food prices (Motavalli, 2009).

Conclusions

Meeting world fuel needs in an environmentally responsible way is an issue of great importance. Water hyacinths adequate sugar yield combined with its rapid growth rate makes it an excellent biofuel source. For ethanol production applications areas that are subject to fresh influxes of water are of interest as this preliminary research shows that water hyacinth fed by fresh water influxes could produce a higher ethanol yield with in excess of 48% fermentable sugars based on current work. In future research more samples will be taken from the LSU Lakes and other closed systems and then compared to samples fed by river and river tributary runoff.

Observed regional differences exist and more research needs to be done to investigate the reasons for those differences. However, regardless of the slight regional differences the explosive growth rate of water hyacinth makes it a viable candidate for further research and development of water hyacinth biofuels throughout the gulf coast region of Louisiana and beyond provided efficient cellulosic ethanol production can make the cost of production equal to or better than current ethanol production costs. For future research it would be beneficial to study the placement of water hyacinth in coastal areas for land preservation and waste water abatement.

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CHAPTER 3. DESIGNED WATER HYACINTH EMPLACEMENT FOR COASTAL PROTECTION BIOENERGY AND PHYTOREMEDIATION

Introduction

Water hyacinth emplacements were designed for phytoremediation coastal protection, and biofuel production. Preserving the environment and the coastline is of vital interest to the State of Louisiana and other coastal areas. Coastal plants can perform a number of ecological functions ranging from conversion of carbon dioxide to oxygen; biomass production; providing habitat for fish and wildlife; wave energy reduction; and waste water abatement (Ajayi & Ogunbayo, 2012; Anderson, McKee, & McKay, September 2011; Bonham, 1983; Cheng, 2004; Das, Iimura, & and Tanaka, 2010; Farrell, Plevin, & Kammen, 2006; Hall & Scrase, 1998). Among the coastal plants in Louisiana water hyacinth grows very quickly while also simultaneously removing excess nitrogen and phosphorus from the water. Using controlled water hyacinth growth for combined erosion control and bioenergy production will greatly benefit the State of Louisiana which is losing coastal wetlands at a rate of as much as 100 square kilometers per year (Britsch & Dunbar, 1993). Funding this carbon neutral energy production is important to the environment now more than ever.

The Atchafalaya River Basin has many canals which are suitable for the emplacement of water hyacinth for coastal protection while also providing adequate facilities for barge, rail, and road transport of water hyacinth for bio fuel production. Extensive mapping of this area shows numerous coastal canals and water bodies where many hectares of Water Hyacinth can be grown and processed. Funding designed water hyacinth emplacements in this area could pay large dividends in both environmental benefit and carbon neutral biofuel production.

Although current research did not focus on phytoremediation, previous research showed that Zinc, Copper, Nickel, Lead, and Cadmium, common industrial pollutants found in industrial waste water, are absorbed by the roots and shoots of water hyacinth plants (Das, Iimura, & and Tanaka, 2010; Liao & Chang, 2004). Concentrations are as high as 26.17 kilograms per hectare for Zinc, 21.62 kilograms per hectare for Copper, 5.42 kilograms per hectare for lead, and .24 kg/hectare for Cadmium (Liao & Chang, 2004).

The use of water hyacinth for bioabsorption of metals can add additional profitability to remediation efforts which incorporate the plant. Water hyacinth can be used to produce gas or ethanol and valuable metals can be extracted from the left over sludge and plant material. Continuous harvesting is needed to keep young plants growing and to remove older plants so that bioabsorbed pollutants do not leach back into the treated water. Industrial run off can be rich in silver and water hyacinth can even be used for the recovery of this valuable metal. When placed in water with a silver concentration of 40 milligrams per liter for 24 hours and subsequently removed, dried water hyacinth plant material contained a silver concentration of 28 milligrams per liter. Plants can be used to produce biogas (or ethanol) and valuable metals such as silver and copper can be recovered from the remaining plant material (Liao & Chang, 2004; Pinto, Caconia, & Souza, 1987). Water hyacinth contains numerous metal binding sites that have polyfunctionality and it can bind both negative and positive metal complexes (Mahamadi, 2011). Water hyacinth can absorb metals with a rate equal to 200 times the concentration of those metals in a given body of waste water (Liao & Chang, 2004; Mahamadi, 2011; Pinto, Caconia, & Souza, 1987).

Theoretical Basis

Water hyacinth growth patterns can be mathematically modeled. The concentration of nitrogen and phosphorous in water and the growth rate of water hyacinth can be described by a hyperbolic function. The growth of water hyacinth follows the Micahelis-Menton model for exponential growth wich parallels the following growth curve model (Dette & Wong, 1999; Saidu, 2009; Wilson, Holst, & Rees, 2005).

Equation 2, Model of water hyacinth growth

$f(Wn,Wp)=\{Wp/(Wp+hp)Wn/Wp > (hn/hp)$, $Wn/(Wn+hn)Wn/Wp \leq (hn/hp)$, (Wilson, Holst, & Rees, 2005)

Hn and Hp in this equation represent the half-saturation coefficients for nitrogen and phosphorous. The resulting equations fits experimental data recording water hyacinth growth which follows the sigmoid growth curve represented by this equation. The growth of water hyacinth is congruent to the effects of temperature and nutrient availability (Saidu, 2009; Wilson, Holst, & Rees, 2005). While the natural growth rate of water hyacinth is high an ebbing of plant growth was observed in mesotrophic areas such as the LSU Lakes once carrying capacity was reached (Wilson, Holst, & Rees, 2005). With its high influx of fresh nutrient rich water water hyacinth that grew in the Atchafalaya river basin did not experience this slow down in growth (Gutierrez, Uribe, & and Martinez, 2001).

Continuous harvesting of water hyacinth throughout the growing season will ensure that coastal containment boom areas do not reach their carrying capacity and so growth will be continuous and a slow growth phase will not be reached. If regular harvesting was not to occur then Water Hyacinth growth would reach a plateau phase during which rapid growth would not occur. The availability of nutrients is a limiting factor and so farm runoff is a key factor to consider when selecting coastal areas suitable for Water Hyacinth growth.

Materials and Methods

Four sites were selected to study natural water hyacinth growth rates along the LSU Lakes. To measure water hyacinth growth rate the 4 sections of the LSU Lakes were measured out and samples were taken at each of the selected locations. The samples were then weighed and measured to obtain the surface area covered per plant along with its mass. Once the diameter of each plant was known the surface area covered by the plant was computed as the area of a circle of diameter equal to the diameter of the plant at its root base. While singular plants spread out and take up more diameter as the plants grow and clump together they stand tall and so the area at the plants base gives a more accurate estimate of plant coverage per unit area. From these measurements averages of mass and surface area covered were computed and graphs were plotted. The observed change in surface area covered per unit time in days was used as a multiplier to estimate the change in mass over time in days and establish the growth rate of water hyacinth in the LSU Lakes. The observed growth rate was then graphed. When graphed the observed growth rate matched the sigmoid curve of a hyperbolic function which matches the observed growth rate in the literature concerning this species of plant (Gutierrez, Uribe, & and Martinez, 2001; Wilson, Holst, & Rees, 2005).

Several areas were studied and multiple samples were taken from the Donalsonville area, the Atchafalaya Basin, and the LSU Lakes during the summer and early spring/ late winter season to allow for analysis of variance statistical analysis. For the test the null hypotheses was that there was no difference in the concentrations of sugar and other empirical sample properties by location, and that there was no difference in concentrations of sugar and other empirical sample properties based upon the difference in season.

Figure 7 LSU Lake water hyacinth, separate root systems joined by a clonal propagation shoot between the two plants

Results

Observed growth rates of 2.41 metric tons of wet biomass per hectare per day of these plants were high, but appeared to be limited by the availability of nutrients in the LSU Lakes. Canals which receive supplemental nutrients from sources such as farm water runoff or direct fertilization will be ideal environments for rapid plant growth. Water Hyacinth was observed to double within 30 days. During mild Louisiana winters the plant was able to maintain colonization of the LSU Lakes year round. This impressive growth rate results in an ability to absorb water contaminants that will be investigated further later in this chapter as literature in this area is reviewed.

In coastal Louisiana the water hyacinth plant has no natural predators capable of preventing its rapid growth. The calculated growth rate for water hyacinth varies based upon conditions and water nutrients. During research for this thesis growth rates equivalent to a doubling of water hyacinth populations in 30 days have been observed in local lakes.

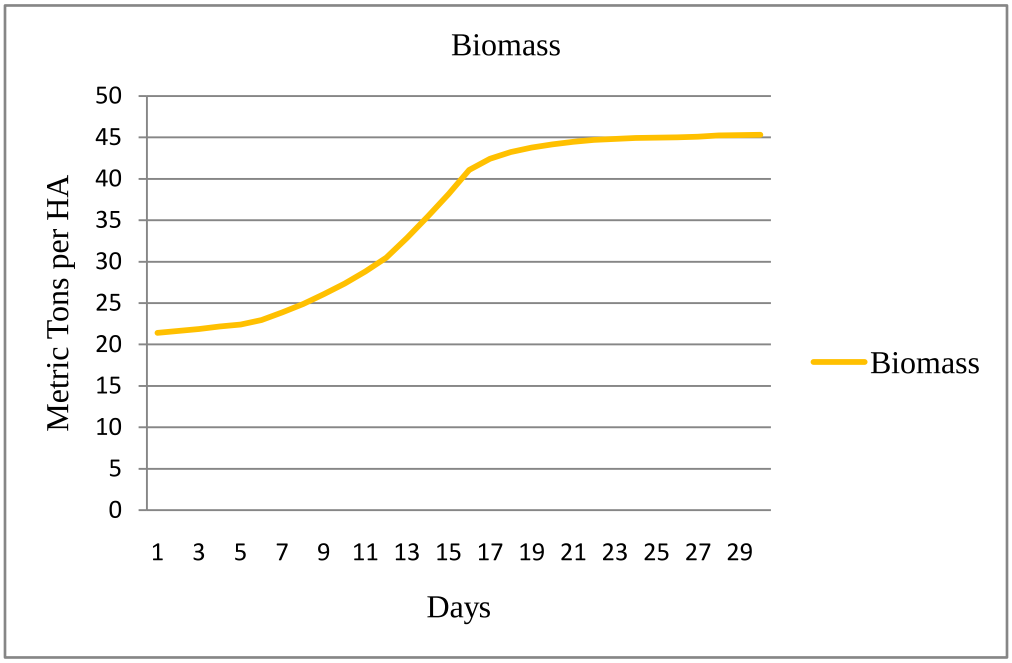

Figure 8 Estimated Biomass yield over time as projected in the LSU Lakes.

It is the rapid growth rate of water hyacinth as modeled here and expressed by the Michaelis-Menton model (Dette & Wong, 1999) that makes it suitable for producing fuel and for coastal preservation. Charts were generated based upon the observed growth rate of water hyacinth as seen in the LSU Lakes and in accord with reported growth rates in the literature (Gutierrez, Uribe, & and Martinez, 2001). Using excel spreadsheet software water hyacinth growth per unit area was calculated, entered into a spreadsheet, and then expressed graphically.

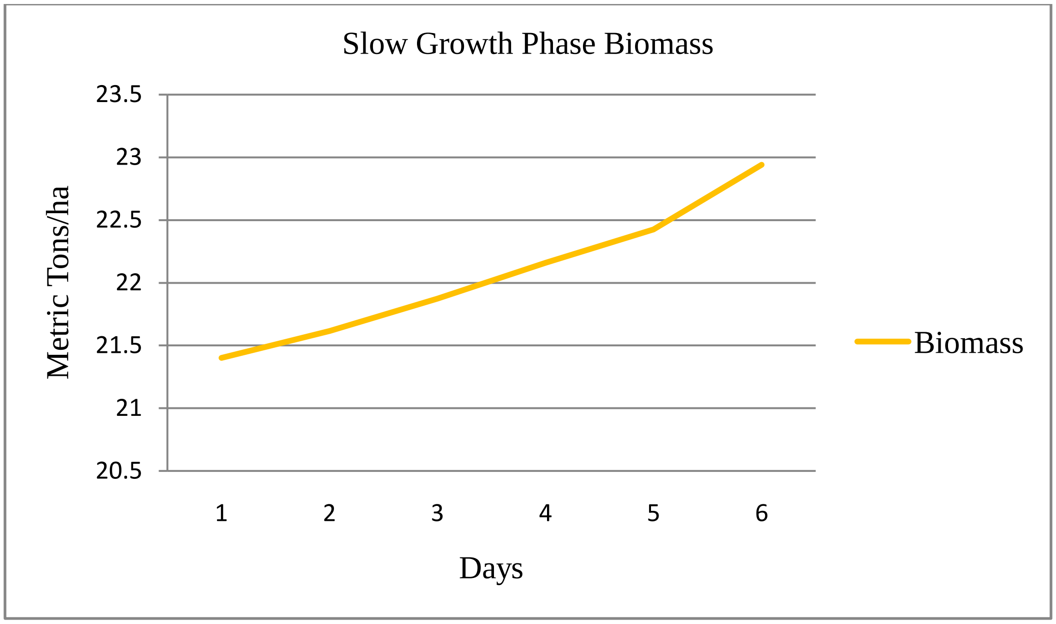

Figure 9 Estimated biomass yield over time during the slow growth phase as projected in the LSU Lakes

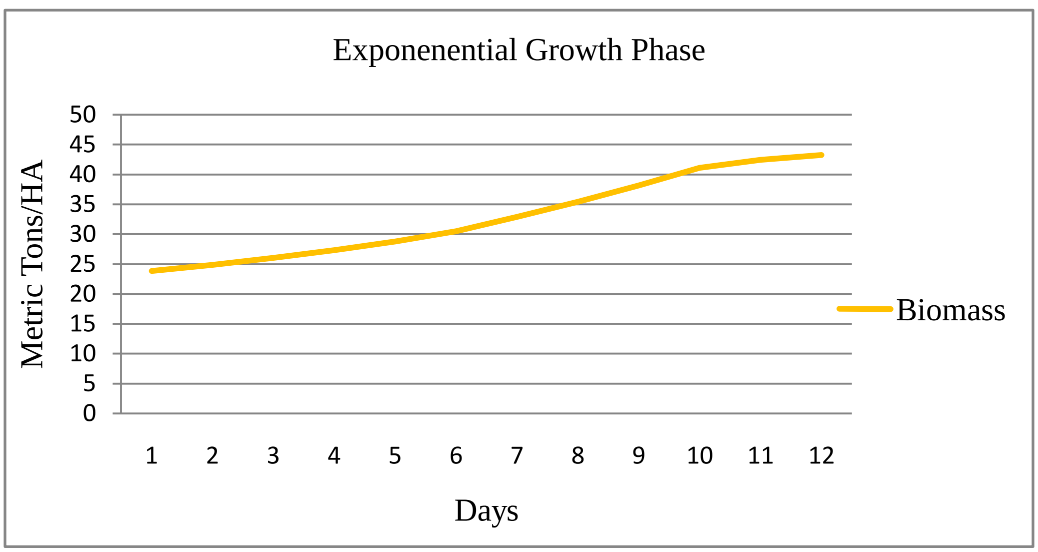

Figure 10 Estimated biomass yield overtime during the projected exponential growth phase in the LSU Lakes

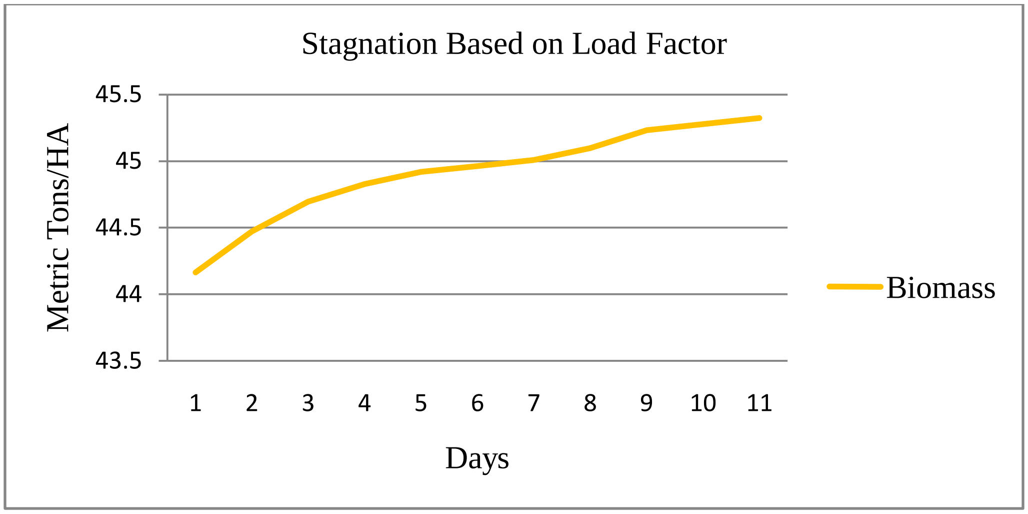

Figure 11 Estimated projection of drop in growth rate during stagnation based on depletion of nutrients as observed in the LSU Lakes

In order to calculate the observed yield of water hyacinth in the LSU Lakes a 60.96 x 60.96 cm (2 foot by 2 foot area) was measured out at the LSU Lakes at three different locations and plants covering that area were counted along with the calculation of the average hydrated biomass which was 307.9 grams per plant with a standard deviation from the norm of 109.8 grams. From this mass per unit area was calculated to be 2.14 kg/m^2 this number closely matched the literature which was 2.18 kg/m^2 density as observed by Gutierrez, Ruiz, and Martinez in 2001.

Discussion

Scalability of the harvesting and growth area is essential to efficient water hyacinth bio-fuel production and economy of scale. There is a scale that must be reached where water hyacinth growth and speed of water hyacinth harvesting results in optimum maintenance of a high growth rate and also results in optimal bio-fuel production at coastal bio-fuel facilities as shown in the following figure. The harvester must leave 1/3 of water hyacinth in place to maintain growth rate for the next harvesting phase.

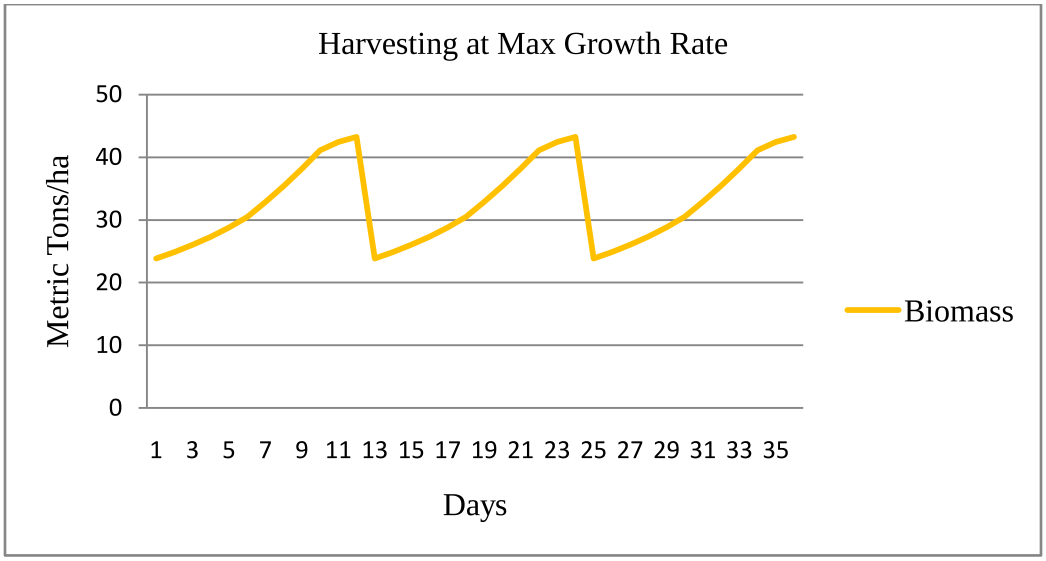

Figure 12 Designed theoretical harvesting of water hyacinth during periods of maximum growth

In the case of coastal canals where nutrient rich farm water runoff is readily available growth rates which allow the plant to double its population every two weeks are very likely to occur. At this rate coastal plants will grow at a rate equal to .26 tons of dry biomass/hectare/day. Literature shows a growth rate of .551 ton/ha/day (Guitierrez 2001.) This fast growth rate coupled with water hyacinth's ability to grow well in Louisiana's coastal environment makes it a viable candidate for use as a source of biofuel and as an energy absorbing barrier which could absorb wave energy and thereby prevent coastal erosion.

The observed growth rate of 2.41 metric tons of wet biomass per hectare per day in the LSU Lakes at Baton Rouge showed a population capable of doubling every 30 days under normal weather conditions. While still impressive the average growth rate in the LSU Lakes was not as high as that observed in my review of the literature. Several factors may have affected the growth rate of water hyacinth including the fact that the

LSU Lakes is a closed mesotrophic system and therefore it may not contain enough nutrients for water hyacinth to reach its maximum growth rate potential.

Where variation was found in sugar concentration and other properties these could have been caused by the availability of sunlight and nutrients at different times of the year, with the optimal observed growing season being the summer months even though with a mild winter water hyacinth has been observed to survive year round through the winter of 2012 during the process of this research in the LSU Lakes at Baton Rouge, Louisiana. The hyacinth concentrations in the Atchafalaya basin indicate that water hyacinth survived Louisiana's winter in that area as well. Slight variations observed between summer and winter samples could have been caused by the plant's consumption of stored sugars in winter months and high accumulation of sugars in summer months when photosynthesis is at its maximum. Variations in concentrations based upon locations are likely related to variations in the availability of nutrients.

The economic potential of water hyacinth as a bioenergy source is exceeded by the economic benefit of its potential to remove water pollution in the form of dissolving nitrates, phosphorous and heavy metals. Its use in water treatment can be invaluable to fish farmers and by using water hyacinth abatement ponds expensive filter system which need cleaning and maintenance can be eliminated. In the past water hyacinth abatement programs have used substantial amounts of government funding to remove water hyacinth plants from bodies of water. Once removed the water hyacinth was disposed of as waste instead of being used for bioenergy production. Millions of dollars of state and federal funding were used to remove and dispose of water hyacinth simply as a nuisance plant and waste material with no consideration of its bioenergy potential and its ability to remove nitrogen, phosphates, and other contaminants from water systems while preserving coastal areas. These activities may have contributed to the loss of wetlands and increased pollution.

Water hyacinth abatement funding can be used for water hyacinth bioenergy and waste water remediation. Harvesting water hyacinth to produce energy will manage water hyacinth's population while also producing carbon neutral biofuels and allowing water hyacinth to remediate wastes and contaminants from water bodies and aquaculture remediation ponds as it grows. Current abatement programs have a negative effect on the State's budget while bioenergy and coastal preservation programs using water hyacinth can be self sustained from the profits derived from biofuel production and the savings from unneeded plant abatement programs. The potential benefits from the use of water hyacinth as planned to coastal preservation, fish health, plant management, and the overall ecology would be a great improvement in environmental management and the use of engineering to solve energy problems in an efficient and cost effective manner.

As water hyacinth grows it takes up minerals in the water at a rapid rate in order to build up its biomass, absorbing metals, nitrates, and phosphates in the process. Farm runoff from pig farms and other industrial activities in areas upstream of the Mississippi River Basin are the leading causes of the Gulf Coast Dead Zone. If this water could be diverted into canals using diversion inlets such as the designed Myrtle Grove diversion (Louisiana Coastal Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority, 1998) large amounts of waste water could be cleaned by growing water hyacinth in the coastal wetlands flooded by the canals. This cleaned water could then flow back out to the Mississippi River and into the Gulf of Mexico helping to remediate the current dead zone caused by upstream farm runoff.

Water hyacinth would phytoremediate billions of gallons of water in coastal Louisiana. Surface water remediation can be a billion dollar industry in and of itself (Kutty, Ngatenah, Isa, & Malakahmad, 2009). As an in-situ remediation solution placing water hyacinth in run off canals and onsite remediation farms will create a novel natural solution to surface water contamination from industrial agriculture as well as aquaculture operations (Liao & Chang, 2004). Catfish, alligator, tilapia and other aquaculture operations will benefit greatly due to decreased filtration costs, and the ability to recirculate water from water hyacinth holding ponds back into fish and gator tanks (Ajayi & Ogunbayo, 2012). Bio-engineers with a focus on Coastal Engineering can use water hyacinth to clean up and restore contaminated wetlands while also preserving the coastal line by limiting the effects of storm surge (Liao & Chang, 2004). In addition this same water hyacinth can be continuously harvested during its long growing season in the subtropical coastal marshes of Louisiana. Apart from this the use of this incredible plant for remediation of contaminated surface water has global implications in the developed as well as the developing world.

Using coastal plants for erosion control and phytoremediation can offset the higher cost of biofuel by adding additional environmental benefits to the economic considerations of state actors. Economies of scale must also be considered and for this reason coastal ethanol production facilities must be located near canal, and or rail access points which are also nearby to biomass growth areas in order to increase the economic feasibility of aquatic coastal plant based coastal preservation and cellulosic ethanol production. Louisiana's coastal oil industry and agricultural infrastructure readily fits this need and so ramping up coastal plant bioethanol production in this state while also preserving the environment could be done with relatively little changes to current infrastructure.

The Coastal Canals of southern Louisiana are rich in nutrients and make an excellent site in which to grow water hyacinth for both biofuel, and the prevention of erosion. Acting as an absorber for wave energy these plants will help prevent coastal erosion. Floating booms can be placed along the banks of canals to contain the plants. These plants can then be harvested periodically using loading mechanism placed on a barge (Bhatia, 2010). Once loaded the plants can then placed onto dump trucks for transport to nearby outdoor drying areas where the plants can sundry for three days before being trucked to coastal ethanol facilities (Bhatia, 2010).

Canals for biofuel production and coastal protection were selected based upon proximity to the coast, tolerable salinity levels, intermediate to fresh water only with 5ppm salt content or less Cheng, (2004). Even though coastal fresh water areas were subject to periodic salt water intrusions, but water hyacinth did survive in water up to 9 ppt (Cheng, 2004). Historically water hyacinth plants have grown well in many of Louisiana's coastal canals (Bonham, 1983).

Areas mapped and cataloged where within the coastal zone between the I-10 corridor and the Louisiana shoreline at a minimum of 10 miles inland and subject to fresh water flow from local rivers and tributaries with a special concentration of the Atchafalaya River Basin area due to its high nutrient flow and fresh water supply. All areas of interest where also chosen based upon their proximity to means transport that could be used to move cultivated biomass.

Figure 13 Designed coastal canal system showing water hyacinth containment area which measures 53,100 square meters located at 29º52'53.12" N latitude and 91º50'57.83"W longitude (Google, 2013)

Using GIS data of existing Louisiana coastal canals water hyacinth containment areas were drawn. In experimental calculations over a distance of 80.5 Kilometers along designed coastal canal containment areas a continuous 4.6 meter wide containment barrier system loaded with water hyacinth covered an area of .37 square kilometers which is equivalent to 37 hectares. A hectare is equal to 100 square meters and a hectare by definition is 100 acres or .01 square kilometers. At a conservative biomass production rate of .26 metric tons of dry biomass per hectare per day under proven growing conditions in Louisiana these containment areas yielded 9.62 metric tons of dry biomass per day thus producing 2020.2 kg of sugar for an experimental yield of 1131.3 liters of ethanol per day.

Figure 14 Designed coastal canal system showing water hyacinth containment area which measures 32,500 square meters located at 29º45’49.90” N latitude, and 92º42’33.25” W longitude (Google, 2013)

Figure 15 Designed coastal canal system showing water hyacinth containment area which measures 28,000 square meters located at 29º51’38.51” N latitude, and 91º58’33.25” W longitude (Google, 2013)

Coastal canals dot the land scape on the gulf coast of Louisana. The previous figures showed only three canal sites that covered 11.4 hectares of land meaning that at the observed growth rate in the literaure (Gutierrez, Uribe, & and Martinez, 2001) of .551 metric tons of dry biomass per hectare per day these designed canal harvesting areas would have yielded 6.3 metric tons of dry biomass per day. Given the experimentally observed average sugar yield of 48% by dry weight for water hyacinth in the Atchafalaya River Basin these site would have produced 1,694 liters of ethanol per day. At $.49 per liter which is equal to $1.85 per gallon this equated to $830 in ethanol per day for just these three areas. On satellite maps the Louisiana coast was observed to be dotted with hundreds of similar locations. Conservatively taking this figure and multiplying it by 100 such areas revealed that managing water hyacinth in this way yielded 169,400 liters of ethanol per day at a rate of $83000. At this daily rate and given a harvesting of period from April to November of 244 days (Gutierrez, Uribe, & and Martinez, 2001) water hyacinth managed in this way yielded $20,252,000 per year in ethanol alone in addition to the added ecological benefits of using the plant along with the savings in unneeded abatement program funding.

Conclusions

Given good growing conditions and an adequate predominance of young plants, water hyacinth in Louisiana is easily capable of growing at an average rate of .551 metric tons of dry biomass per hectare per day (Gutierrez, Uribe, & and Martinez, 2001). Space, compaction, climate, and the amount of nutrients in the water all contribute to growth rate, and so in comparison to the good observed growth rate of 2.41 metric tons of hydrated biomass per hectare per day in the mesotrophic LSU lake coastal canals, lakes, and wetlands of the Louisiana Atchafalaya river basin have a constant supply of fresh water carrying additional nutrients and will show an even more impressive growth rate that will be perfect for the envisioned erosion control methods. Therefore, the relatively high growth rate observed in the mesotrophic LSU Lake was encouraging when this plant was considered for coastal protection.

Coastal Louisiana has been subject to one of the fastest rates of erosion in our nation (Britsch & Dunbar, 1993). Efforts to sustain the Louisiana coast are essential to the economy, and to the preservation of culture and lifestyle on the Louisiana Gulf Coast. Experimental results show that areas subject to an influx of fresh water that is rich in nutrients and runoff are the best sites for the managed harvesting of water hyacinth as the abundance of nutrients will yield the highest sugar concentration. Coastal preservation and bioenergy production through the growth and managed harvesting of water hyacinth can benefit the State of Louisiana along with other coastal regions and give added ecological benefits which offset the higher economic costs of biofuel production while also saving invasive plant species abatement program dollars. For future work it would be beneficial to analyze the wave energy absorption ability of water hyacinth.

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CHAPTER 4. COASTAL PRESERVATION BY WAVE ENERGY REDUCTION

Introduction

Louisiana is losing coastal wetlands at a record pace of up to 100 square kilometers per year (Britsch & Dunbar, 1993). If coastal plants are to be used to absorb wave energy, then the amount of wave energy which they absorbed during experimental observations had to be understood by analysis. Water hyacinth plants contain air bladders that allow the plant to float on the surface of lakes and canals. Observed growth rates in the literature show that the plant's populations can easily double every two weeks (Gutierrez, Uribe, & and Martinez, 2001; Westlake, 1963). As such the plant produces an enormous amount of biomass which floats on the surface of water ways. The weight of this biomass can be used to absorb wave energy and help shield the shore line of coastal canals in order to prevent erosion (Anderson, McKee, & McKay, September 2011; Bonham, 1983; Burley, 2010). There is little research in the area of wave energy attenuation by floating plants and so there is much room for novel and innovative research in this area.

The observed tendency of water hyacinth to hug the shore line can be enhanced by the use of thin floating booms similar to those used to contain oil spills. These booms can be tethered together and stretched throughout the length of coastal canals. Linked together the free floating booms can be used to create containment areas for water hyacinth growth and control. Free floating water hyacinth plants can be gathered up, and placed in these containment boom areas during harvesting runs to prevent them from interfering with boat traffic and increase culture density for maximum growth and harvesting efficiency.

Figure 16 LSU Lake, Observed Water Hyacinth with simulated containment boom in place

Theoretical Basis

Even under strong wave action the water hyacinth was able to clump together inside the simulated oil booms and held its shape requiring little if any adjustment between runs. Each sample mass was test run three times with each of the two wave types under identical conditions in order to get an adequate sampling of wave energy effects. 2048 samplings were recorded from each pressure transducer per run for a total of 12,288 sampling for each of the three amounts of plant biomass tested in the wave tank. The total mass tested was 34.0194 kg divided into thirds with an initial run mass of 11.461 kg run three times for each wave type and subsequent runs of 22.922 kg and finally 34.0194 kg.

To raise 34.0194 kg by a height of .1397 meters a wave must perform work which is equivalent to force times distance. The work of the wave equals mass multiplied by acceleration multiplied by the distance over which that mass is accelerated. In this case the distance is .1397 meters in the vertical direction as this is the height of the transverse water wave from trough to crest as measured on a yard stick. As the mass is moved in the vertical direction the acceleration is the acceleration due to gravity at sea level which is calculated to be 9.81 meters per second squared. From this equation the work needed to raise the plant biomass to the full height of the waves is equivalent to 46.6221 joules per second (kilogram meters squared per second squared) for wave two and 29.985 joules for wave 1.

Equation 3

$$S_{ds,veg} = -\sqrt{\frac{2}{\pi}}\, g^2\, \tilde{C}_D\, b_v N_v \left(\frac{\tilde{k}}{\tilde{\sigma}}\right)^3 \frac{\sinh^3 \tilde{k}\alpha h + 3\sinh \tilde{k}\alpha h}{3k\cosh^3 \tilde{k}h} \sqrt{E_{tot}}\, E(\sigma, \theta)$$

The preceding equation (Swan Team Delft University , 2013) gives wave dampening for standard vegetation in water. Water hyacinth in containment booms pushing up against the shore line is both fixed in place and floating. In addition to the drag that it creates it also dissipates wave energy by causing the wave to have to lift its biomass as it passes underneath. There is very little research into wave energy dissipation by floating plants and future research is warranted based on wave tank data.

Current wave energy reduction equations such as equation 3 above solve for only part of the wave energy reduction accomplished by floating vegetation. As the mass of the plant is lifted against the acceleration of gravity this results in a force which opposes the rising action of the waves. Large mats of floating water hyacinth that can easily have a mass of 40,000 kg per hectare. The energy to lift this mass must also be considered in future equations.

Figure 17 Booms hold plant biomass in place so that wave energy absorption can be observed

Deep water waves undergo dispersion and so this allows deep water waves to travel at speeds as great as 500m/s, however shallow water waves do not undergo dispersion and so their speed is significantly slower and is dependent upon water depth. The waves generated in the MTS 407 wave tank qualify as shallow water waves because their depth is less than one-half their wavelength, and the wavelength of the wave tank was found by observing videotaped waves as they passed over the transducers whose position was known to be at .6 meters for transducer 1, 1.448 meters for transducer 2, and 2.3495 meters for transducer 3 from the starting point of the wave at the end of the MTS

407 wave generator. The wavelength is necessary to calculate the speed of the wave, and the speed of the wave is necessary for a complete understanding of the propagation of the wave over pressure transducer 1 and pressure transducer 3.

Engineers must note that wave propagation speed of a water wave is always subject to turbulence, water temperature, frictional forces, and other non conservative forces such as the strong interaction of polar water molecules and weak Van der Waals forces, and so the exact speed of a water wave can be most readily calculated by timed observations as seen here otherwise shore slope dissolved particles, temperature and other factors have to be applied to a water wave equation that will still only give an estimated model of wave velocity. For a wave which does not propagate as part of a dispersive media it should be noted that the wave's propagation speed is equivalent to its wavelength times its frequency with the wavelength and frequency varying to maintain a uniform velocity in the medium which results in the Doppler effect where as the velocity of a wave source changes the wavelength of the wave and the frequency rises upon approach or falls upon retreat of the object to compensate for the change in speed of its source as in the case of an approaching train or the visible red shift compensation of a star as the wavelength of its light is elongated by its retreat thus resulting in a subsequent drop in frequency which we see as light from the red end of the spectrum, thus we call it a red shift.

Materials and Methods

The energy of a water wave is directly proportional to its wave height as water density and gravity at a fixed point are constants. This wave energy was computed through the use of pressure transducers positioned longitudinally along the path of the wave studied.

To analyze *Eichhornia crassipes* for wave energy reduction and coastal protection 18 data collection runs were made. 9 runs were made for each wave type with a data collection rate of 10 hertz and a sample collection of 2048 data points per run for a total of 36,864 data points collected.

Averaging the difference in max pressure over pressure transducer 1 and pressure transducer 3, seen as wave crests on the graphs of pressure transducer data gives the wave energy reduction of the water hyacinth biomass. All the data points, the sampling rate of the data logger program, 10 times per second, and the speed of the wave crest as it moves between transducer 1 to transducer 3, a distance of 1.7495 meters, must be considered in the analysis of the wave energy absorbed so that the pressure of the wave as measured by transducer 1 can be matched to its corresponding measurement at transducer 2. By doing this we can accurately measure the pressure exerted by the wave at transducer 1 and transducer 3 at the exact same point in the wave's cycle. For a shallow water wave such as the one generated in the wave tank the wave's velocity of propagation is congruent to the square root of gravitational acceleration times the square root of water depth. In shallow water the bottom of the water body causes a turbulent interaction which resists the spiraling motion of the water molecules as the wave passes over the area effectively resulting in a nonconservative frictional force which slows the wave down.

The expression of wave speed and scanning rate is also expressed on the graph in the form of the space between wave crest data points. By syncing data to match wave crests pressure transducer 1 can be matched to pressure transducer 2 as the speed of the wave and the pressure transducer data collection rate is constant, k. The pressure transducers must be at the same depth for analysis to work as the wave speed is reduced as the water progressively shallows at the shore line, and so our measurement of speed is only an average that is close, but never exact due to constant variance as the differential velocity of the wave approaches zero at the shoreline. By shifting the normalized graph data of pressure transducer 3 down to match the first wave crest data of pressure transducer 1 with the first wave crest data of sensor two the data points are then matched and we are looking at the same point on the wave for each sensor. Because the depth of each pressure transducer is the same any decrease in pressure at transducer 3 can be seen as a change in wave height due to wave energy reduction as gravity and water density are constant.

In order to generate waves for wave energy reduction analysis controlled and measured waves were generated using an MTS Portable Piston Wave generator and three Druck pressure sensors (model PDCR 1830). The wave energy data from these sensors was cataloged by a Campbell Scientific data logger model CR 23X which was programmed in CR Basic to record transducer data at a sampling rate of 10 hertz with 2048 data collections per wave energy analysis run.

Campbell Scientific Logger pro software was used to record the data in real time and display this on a desktop computer screen for real time monitoring while also creating a .dat file which was then loaded into Microsoft Excel for data processing as a comma separated data file. Microsoft Excel was then used to filter out baseline discrepancies between pressure transducers one and three in order to normalize the wave energy readings so that a clear picture of what the water hyacinth's effect was on wave energy. Data can be normalized by taking the sum of the psi readings from the two sensors used for baseline readings. The sum of the larger data set is then divided by the sum of the smaller data set. This then gave a multiplier that was used to multiply each individual data reading from transducer 3 in order to have had a graph that gave two waves which were normalized and without error. These waves were then analyzed and showed quantified wave energy reduction.

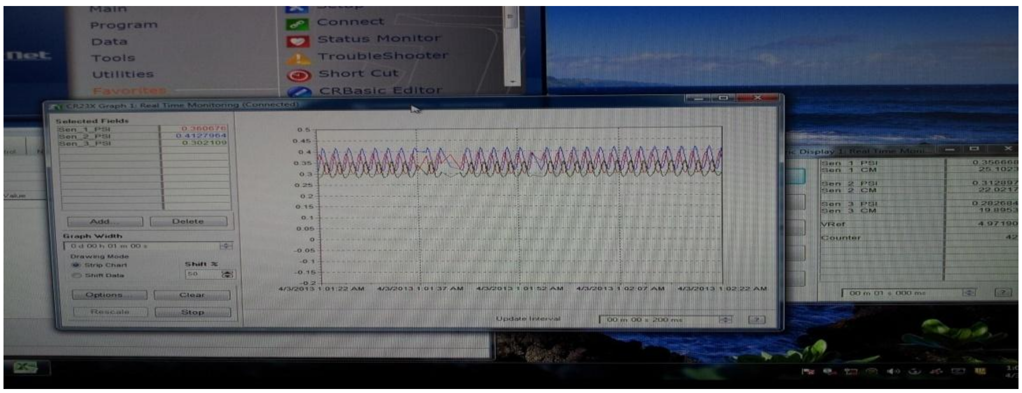

Figure 18 Real Time Software Monitoring of Wave Tank Pressure Transducer Data from CR 23X Data Logger

For wave energy reduction analysis progressive 1/3, 2/3, and 3/3 sized amounts of water hyacinth were used for each run and wave type. I employed energy absorbing woven mats at either side of the wave generator in order to dampen wave reflections which could have interfered with pressure sensor data. The woven mats were very effective and no reflective waves hyacinth plants were added to the wave tank between pressure transducers one and three and directly over pressure sensor two. The plant biomass was added in thirds and Styrofoam floats with ropes passing through their center were used to corral the water hyacinth plants with the back boom simulating the shoreline and the front boom simulating and oil boom holding the water hyacinth in place centered between pressure transducers one and three. The normalization step included readings taken only with the floats so that their energy reduction was not included. The wave tank results were observed and videotaped for analysis and discussion.

The force that a column of water exerts on a pressure transducer is equivalent to the height of the column of water multiplied by the density of water multiplied by gravitational acceleration. As such pressure transducer number one is positioned such that it records the full pressure of the wave at its maximum height and pressure transducer number three is also positioned to record the full pressure of the wave at its maximum height. A change in water pressure over time is also a physical expression of work in the form of a change in energy moving through time and dimensional analysis shows the equations to be identical. With pressure transducer number three normalized to pressure transducer number one, as mentioned previously, any drop in pressure noted as the wave propagates from pressure transducer number one to pressure transducer number three is a negative change in energy meaning that the plant biomass has absorbed that energy. It should be noted that the simulated booms were also accounted for with a numerical normalization factor of 1.10612 for wave type one and 1.114127 for wave type two.

Figure 19 MTS 407 Wave Tank Controller set to Wave Type I , .53 hz, 2” span

Figure 20 MTS 407 wave tank controller set to Wave Type II, .42 Hz, 5.5" Span

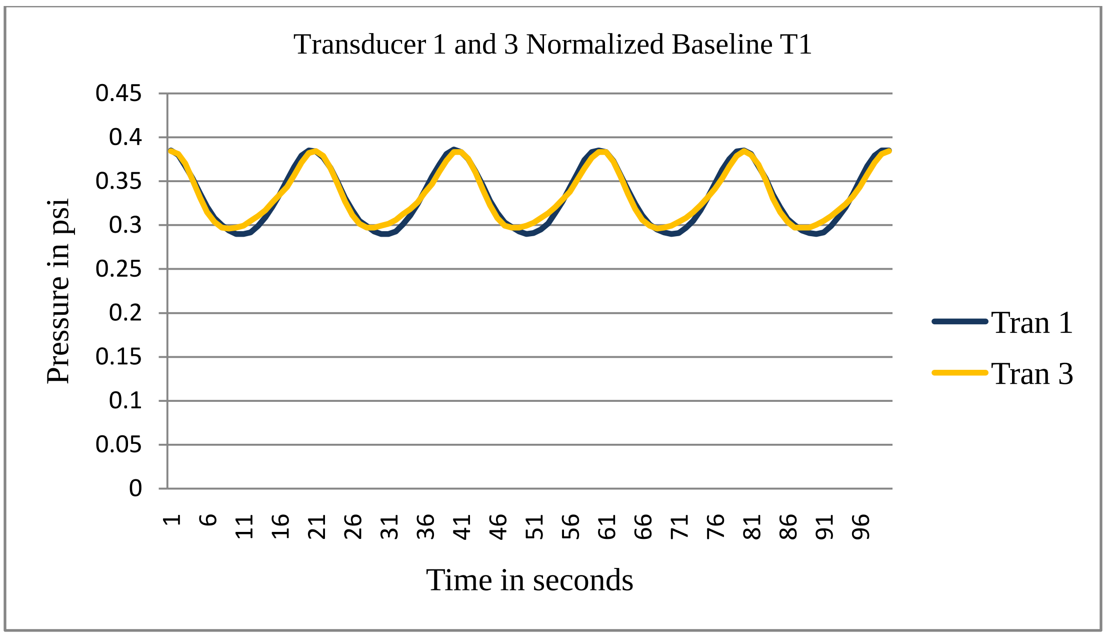

Figure 21 Typical base line readings from transducers 1 and 3

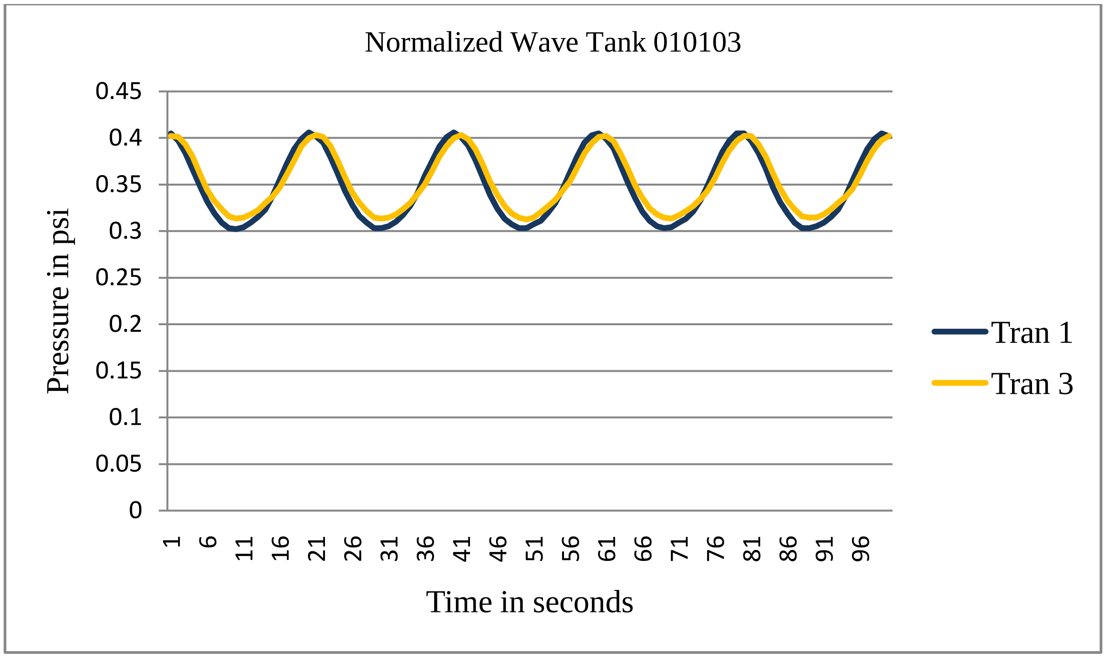

Figure 22 Typical readings from transducers 1 and 3 during the third run using wave type 1 and using the total available biomass

Results

During the experiment it was observed that the water hyacinth plants fit together nicely when floating up right and their geometric shape locks one plant together with the others to create the effect of a singular floating matt. This clinging effect due to the plant's shape fit can also be observed when they are being harvested. The plants often intertwine and when one is picked up it often brings along two or three more.

Two types of waves were used to measure and analyze the plant's effect on wave energy. The first, wave type 1, was a lower energy wave set to a frequency of .5291 hertz and a span of .05 meters +/- .009 meters with a wave height of .0889 meters +/- .009 meters. The second wave, type 2, was a higher energy wave with a frequency of .4258 hertz and a span of .1397 meters +/- .009 meters with a wave height of .1397 meters +/- .009 meters.

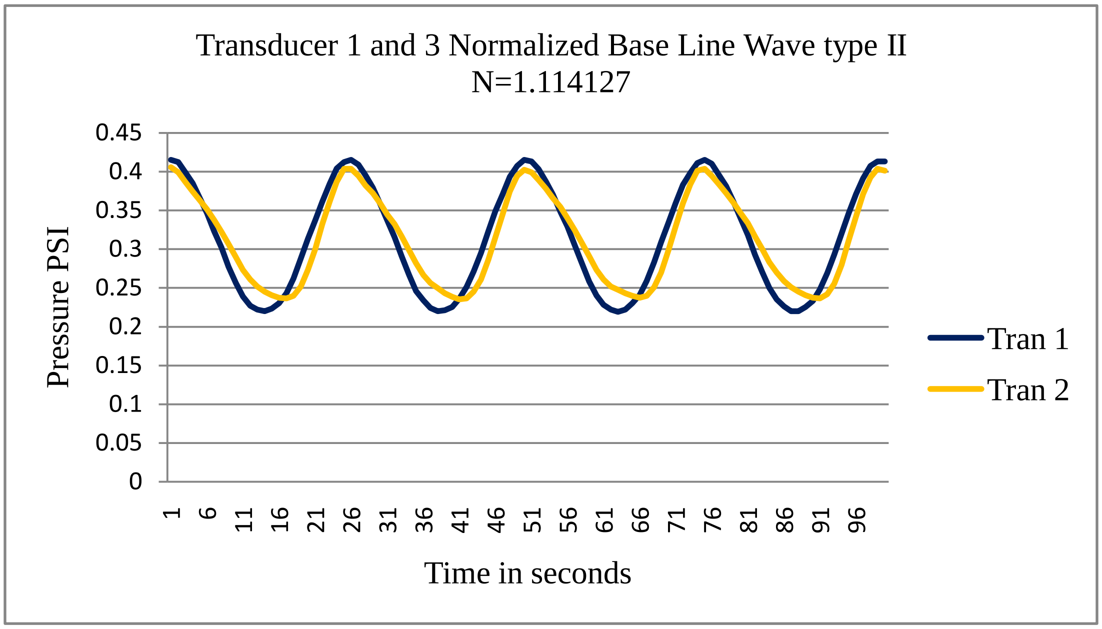

Figure 23 Typical normalized readings from transducers 1 and three during wave type II, the largest wave run

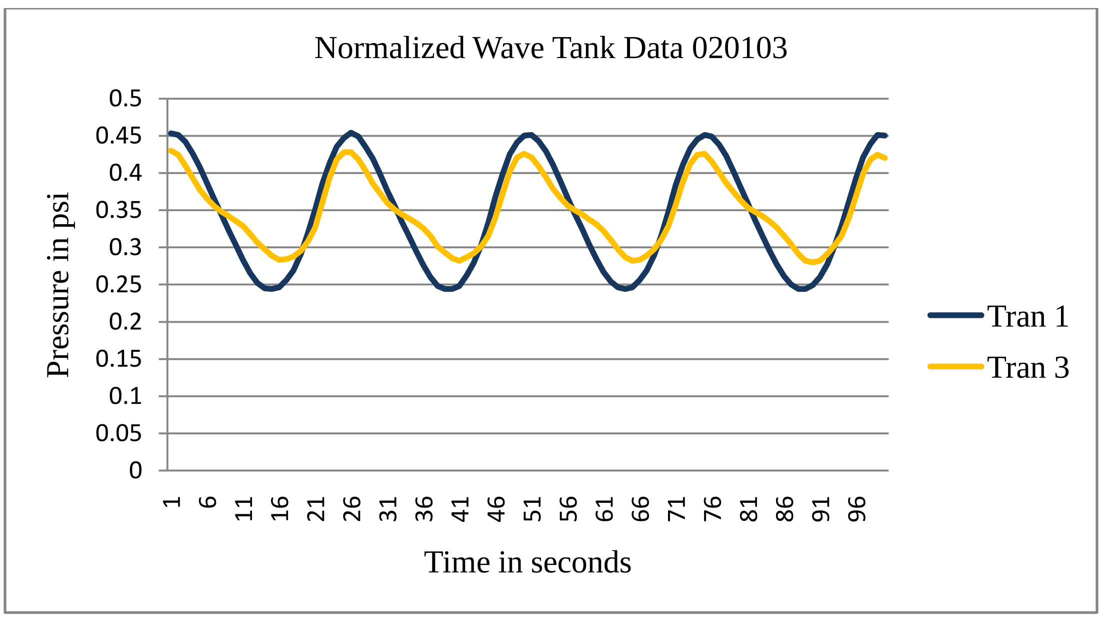

Figure 24 Typical wave tank data during the third run of wave type 1 using the total available biomass

In accord with the calculations the larger wave exerts more energy and this can be seen on the graph in figure 20 as a larger difference between transducer 1 and transducer

3 than the difference between transducer 1 and transducer 3 for wave type 1 in figure 18. While only a 2.7% reduction in wave energy was observed for wave type I the difference between transducer 1 and transducer 3 equates to a 14% reduction in wave height as seen in figure 21 for wave type II. This is a significant result which indicates that floating mats of water hyacinth were useful for coastal protection.

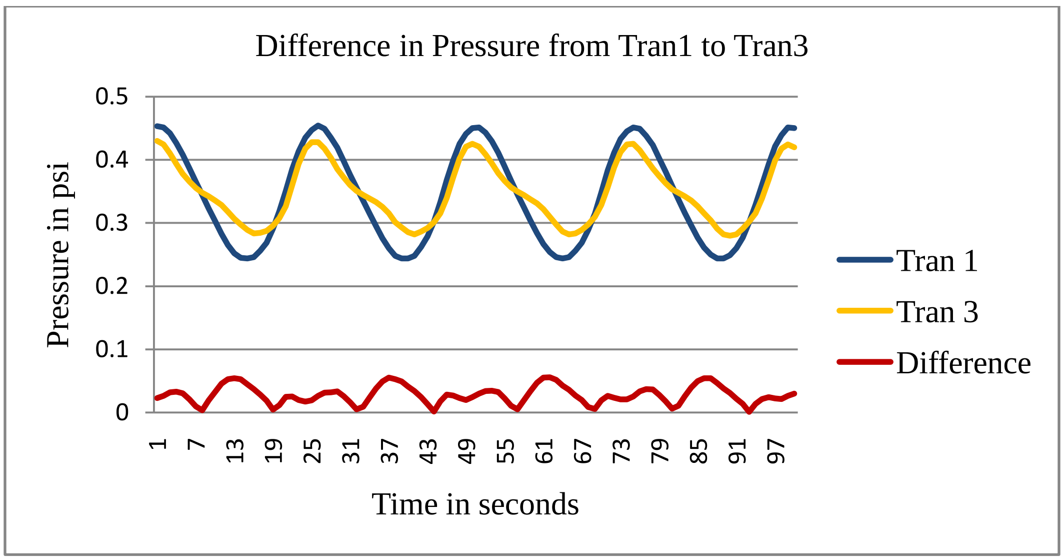

Figure 25 Typical readings at max wave height and maximum biomass, a 14% reduction in wave energy by floating water hyacinth biomass was observed and recorded in this graph of pressure transducer data

At a tank water depth of .3175 meters wave type one which had a frequency of .5291 hertz had a wave speed as calculated by the shallow water wave speed equation of 1.764 meters per second which closely matched timed video observations which placed the speed at 1.925 meters per second with a standard deviation of .113844 between observed and calculated velocity. Timed observations of wave type two, frequency .4258 hertz, was consistent with water as a dispersive medium in that the wave propagation speed for wave type two was not uniform with wave one and it had an observed velocity of 2.4384 meters per second which was expected as its wavelength at 1.3208 meters was 25 percent bigger than wave type two which had a wavelength of 1.02 meters.

Discussion

When the base line graphs are compared to the plant bio mass in maximum wave energy graphs for both wave types I and II shifts and deformations in the normalized graphs can be noticed. These deformations and shifts in the graphs are an expression of the change in wave energy as the plant biomass acts as a buffer absorbing the energy of the incoming wave from the MTS 407 wave generator. This change in wave energy is observed as a change in wave height which is the only variable which changes in regards to the pressure seen by the transducer as pressure is a function of the density of the fluid medium multiplied by gravity and the height above mean sea level where gravity and density are constants in the case of the wave tank.

For the analysis of wave data the null hypothesis is that the *Eichhornia crassipes* had no effect on the energy of wave propagation as the wave moved through the medium. As moving the biomass to the full height of the wave crest required 47.12 joules per second (kilogram meters squared per second squared) for wave two and 29.985 joules for wave 1 the experiment showed how much of this required energy can be seen as a reduction in wave energy as an expression of wave height, seen as a pressure reading on pressure transducers one and three. A significant reduction in pressure was seen as shown on the graph of wave type II and so this indicates that the biomass of the plant was able to absorb wave energy.

Using existing floating boom technology and only modifying it slightly to make it suitable for water hyacinth plant aquaculture and large scale cost effectiveness will mean that the movement from the planning, and development stage to full scale implementation of a water hyacinth biofuel production and a plant biomass based coastal protection system will be rapid and as seamless a transition as possible. Depending on the size of the given coastal canal's navigable waterway, as determined by the Army Core of Engineers, containment boom systems can range in size from as little as 5 feet from the bank to as much as 20 feet from the bank of the water way.

Figure 26 An example of booms which could be used to contain water hyacinth at the shoreline of coastal canals for harvesting and growth (Hydrotechnik, 2012)

Geographic Information System map data from the Louisiana Department of Environmental Quality was used to locate canal areas available for growth and harvesting of water hyacinth. Using this GIS imagery coastal areas have been mapped and measured for preliminary size estimates and planning. Using existing GIS mapping of

Rockefeller State Wildlife Refuge and Game preserve the prospective enclosed area of a 662 meter long test canal was mapped measured. A large to mid size 4.6 meter wide containment boom system was projected onto satellite imagery of wide canal sections and smaller 2.5 meter wide containment boom systems were projected onto satellite imagery of narrow mouthed canal sections. From this the contained growth area can be calculated as a product of the length and width of containment areas. A 662 meter long section of canal provided a total of 4,766.4 square meters of growth area while also leaving the navigable portion of the canal clear for boat traffic. Harvesting barges can be used to harvest hyacinth from enclosures (U.S. Department of Transportation, 1994).

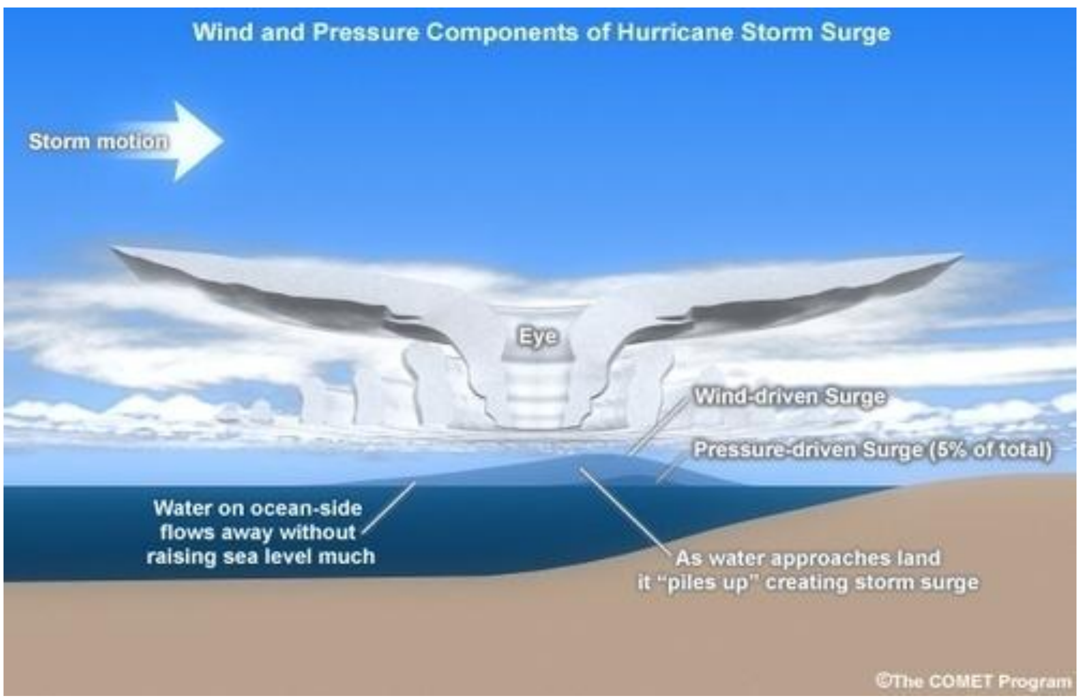

Figure 27 An illustration of storm surge (National Weather Service, 2013)

Conclusions

Once the plants are contained in booms along the shoreline they will absorb wave and storm surge energy and in so doing they will encourage land accretion as well as preserve the existing shore line of coastal canals. Water Hyacinth plants will protect coastal canal banks by forming thick floating mats along the shoreline. Floating water plants have an impact on wind induced water flow as well as wind induced waves in a closed water (Anderson, McKee, & McKay, September 2011; Bonham, 1983; Burley, 2010; Jinhai, Zhong, & Yang, 2003; Ozaki, 2004). Man made break waters that mimic enmeshed floating plants have been designed and have been proven to absorb the energy of incoming waves (Jinhai, Zhong, & Yang, 2003). Wave height is a function of the wave's energy, and floating mat breakwaters have been shown to cause a 78% reduction in wave height (Jinhai, Zhong, & Yang, 2003).

Every year coastal storm surge contributes mightily to the loss of Louisiana's coast line. The amount of land eroded by storm surge is proportional to the amount of storm surge energy that is transferred to the coast. Coastal plants can act as a storm surge buffer by absorbing the energy of incoming storm surge reducing both its velocity and cyclical wave height, Das et al. (2010).

The wave tank analysis I have done for this research showed that coastal plants can reduce wave energy by 14%. In the case of storm surge the force of the flowing water is known to dig out and widen channels along the banks of water ways, and the existing literature shows that floating vegetation reduces the current flow by up to 49 percent (Das, Iimura, & and Tanaka, 2010). For future work it would be beneficial to devise plans and funding oppurtunities for the operation of large scale water hyacinth harvesting equipment.

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CHAPTER 5 ENGINEERING DESIGN FOR LARGE SCALE HARVESTING OF WATER HYACINTH

Introduction

Large scale production of water hyacinth biofuel can result in sustainable cellulosic ethanol production while also protecting the coast from erosion (Bonham, 1983; Burley, 2010; Das, Iimura, & and Tanaka, 2010). Ideal fresh water growing conditions for water hyacinth are met in Southern Louisiana’s coastal canals of the Atchafalya river basin because these canals are river fed with an influx of freshwater eventhough they are only a few miles from the salty waters of the Gulf of Mexico. Large amounts of water hyacinth can be produced under these ideal growing conditions and in the past boat traffic was choked off when water hyacinth plants were allowed to grow freely in these areas and so boat based abatement system were designed by the engineers of old many decades ago to keep these areas clear.

Now efficient harvesting systems must be designed in order to give feasibility to the planned modern use of water hyacinth for bioenergy and coastal protection. Current boat and barge based water hyacinth abatement technology involves the use of mechanized barges to harvest and dispose of water hyacinth clogging water ways. This effective and time proven technology can be redesigned and adapted to fit the needs of a new industry built around the cultivation, harvesting, and production of water hyacinth for bioenergy and coastal preservation.

Design Materials and Methods

A combination of flat bottom boats and barges with automated front end loading mechanisms and pneumatic bulk loaders could be used to harvest water hyacinth from coastal boom containment areas. The agricultural economics of the project requires that water hyacinth be grown and harvested near sources of transport. The proximity of levees to both rail and water transport via Louisiana's intra-coastal canal and established railways meet this need. Large harvesters could be used to gather the water hyacinth and dry it by mechanical and solar means. This will serve two purposes in that the water-hyacinth must be dried as the first step in preparation for acid hydrolysis and secondly in that thorough drying will lessen the transport weight and storage volume that must be carried on the way to coastal area ethanol plants (Performance, 2010).

Autonomous, semiautonomous, and or piloted barges can be used to harvest large quantities of water hyacinth from coastal canals. Advances in automated control system technology can increase the efficiency of harvesting efforts by lessoning the amount of human labor needed to harvest water hyacinth (Performance, 2010). While small automated harvesters can be effective for smaller areas, the size of the water hyacinth plant, coupled with the scalability needed for effective biofuel production will require the use of larger harvesting vessels. Barges of a minimum length of 30 feet or more will be required so that harvesting can be conducted in a timely fashion (Kruse, Protopapas, Olsen, & Bierling, 2009).

A designed harvesting solution by C and C Performance involves the addition of a grated front end loader on the front of a motorized loading barge. The barge will be placed inside long water hyacinth containment pens in coastal canals and then driven either autonomously or by a human operator through the containment pen longitudinally, using its front in loader to scoop up 66% of water hyacinth while leaving 33% in order to maintain water hyacinth at a sufficient population for exponential growth so that frequent harvesting is possible (Performance, 2010). Based on studies of observed growth patterns, if too much water hyacinth is harvested then a lag in growth will result, while if water hyacinth is allowed to over populate its holding areas then carrying capacity will be reached and that will also result in stagnated growth. For this reason harvesting must be optimized in order to encourage a high growth rate and maintain cost effective biofuel production.

Scalability of the harvesting and growth area is essential to efficient water hyacinth biofuel production and economy of scale. There is a scale that must be reached where water hyacinth growth and speed of water hyacinth harvesting results in optimum maintenance of a high growth rate and also results in optimal biofuel production at coastal biofuel facilities (Performance, 2010).

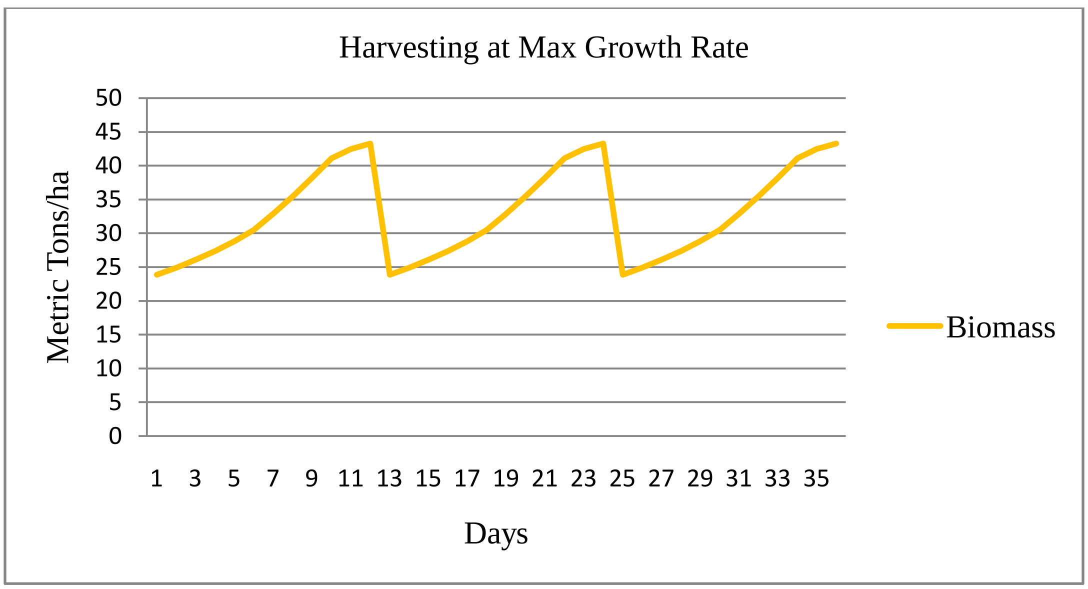

Figure 28 Designed theoretical harvesting of water hyacinth during periods of maximum growth

Another method of harvesting water hyacinth for biofuel production is pneumatic bulk loading. Harvesting barges equipped with pneumatic bulk loaders can be used to vacuum harvestable hyacinth plants from containment boom enclosures. By pushing barges through open waterways using tugboats or special purpose boats designed specifically to interlock with the barges pneumatic bulk loading barges can be moved adjacent to water hyacinth enclosures removing harvestable percentages of water hyacinth as they pass through and dumping excess water overboard. Future systems may also use automation and machine vision in order to harvest plants more efficiently by reducing labor costs (Performance, 2010). Pneumatic bulk loading is an industry proven and cost effective method for moving bulk materials (Performance, 2010). By its nature pneumatic bulk loading is suitable for a wet or dry environment and so it is easily adaptable to being used to move bulk plant biomass from containment boom areas to harvesting barges for delivery to sun drying areas. Other loading methods would include the use of cranes, scoops, or tracks to harvest plants, but these methods are very bulky and will take up valuable barge space that could otherwise be used to contain harvested plants. An innovative design for a new harvesting system will be designed in the next chapter.

Figure 29 A pneumatic bulk loader loading from a barge at a port facility (Neuro, 2013)

Figure 30 Coastal Plant Harvester circa 2005 (University of Florida IFAS Extension, 2012)

As seen in the picture barges have already been used to mechanically remove aquatic vegetation. A barge with a front in loading conveyor mechanism, as pictured in figure 2, will pick up the hyacinth and then the conveyor system will feed the hyacinth into a compactor which will press the water hyacinth and thereby remove excess water. The entire system will be run by multiple or single diesel engines which will turn hydraulic pumps which will intern power hydraulic motors (Performance, 2010). The hydraulic system will turn large metallic paddle wheels as pictured on the harvester in figure 2. The metal paddle wheels will be capable of both pushing the barge forward by moving water, and will also be capable of pushing the barge forward with bottom mud layer traction when canal areas become too shallow (Performance, 2010).

Once the conveyor system grabs water hyacinth and brings it aboard the barge it will then carry the water hyacinth into an adjacent compaction system which will crush the water hyacinth to allow more storage and remove the water from the plant (Performance, 2010). Antifouling equipped hydraulic water pumps will be constantly running and will remove water from the barge. As the water hyacinth is crushed the large compactor will force it to the back of its loader. The compactor design for the barge will be based upon existing industrial compactors, as pictured in figure 3. Mechanical grinding has been designed to solve the problem of water removal for efficient harvesting barge loading, however, grinding the plant could result in a loss of some sugary plant material since it will create small particles which could be drained off and dumped overboard by the barge's hydraulic water pumps. Compaction is a better choice as it preserves all of the plant's biomass (Performance, 2010).

Figure 31 Water Hyacinth Harvester (University of Florida IFAS Extension, 2012)

Limited Life Cycle Analysis

This limited life cycle analysis was done in the interest of future applications of water hyacinth for biofuel and coastal preservation. As evidenced by the picture from the turn of the 20th century in the next figure water hyacinth harvesting barges have been used for almost 100 years. The use of large complex vessels to deal with water hyacinth goes back even further than the 1937 Louisiana water hyacinth Crusher boat, christened

The Kenny, which served the Army Corp of Engineers in Coastal Louisiana and successfully cleared hundreds of miles of water ways (Herwick, 2005; Wunderlich, 1964).

Figure 32 Water Hyacinth Mechanical Elevator Barge from the early 1900's, unknown photographer (University of Florida IFAS Extension, 2012)

After compaction on the harvesting barge to remove excess water the biomass will be offloaded from the barge using a front end loader dried and transported to coastal ethanol facilities. Three days of full sun are intended for initial plant drying in open fields. Plants will then be further dried at processing facilities using heat generated from biofuel burners which will use some the harvested waterhyacinth as fuel in a method similar to the practices of the sugarcane industry when they burn bagasse to generate heat and power at sugar mills. At these water hyacinth processing mills the heat from burning some of the collected plant material will be used to drive heated dilute acid hydrolysis of the majority of plant material for cellulosic ethanol production (Performance, 2010). Before acid hydrolysis the material will be mechanically ground in order to facilitate a quicker cellulolysis. Elecrtro-mechanical grinders will also be run by co-generated electrical power similar to the practices of the sugar cane industry (Deepchand, 2001; Performance, 2010).

Not only useful for harvesting operations barges will also be used to move crushed water hyacinth from harvesting sites to coastal ethanol production facilities. Based upon efficiencies of scale barges can be very useful in transporting water hyacinth for ethanol production. At an average capacity of 1500 tons an inland barge is capable of carrying much more weight than other means of transportation (U.S. Department of Transportation, 1994).

By strategically locating water hyacinth growth areas near the intracoastal canal efficient transportation will be achievable. One barge is capable of carrying the cargo of of 60 semi trailers and 15 rail cars. 40 barges can be pushed by a single tug boat and this is equivalent to the cargo capacity of over 2,200 semi trailers, and 600 rail cars. One gallon of fuel can carry a ton of cargo 155 miles by truck, but that same gallon of fuel can take a ton of cargo 576 miles by barge (Kruse, Protopapas, Olsen, & Bierling, 2009; U.S. Department of Transportation, 1994).

As a carbon neutral source of biofuel water hyacinth can help reduce overall greenhouse gas emissions. The implementation of cogeneration in processing water hyacinth will help offset production costs while also having a positive environmental impact (Performance, 2010). Current remediation methods consume diesel fuel and gasoline in an open looped process to only harvest and destroy water hyacinth. However, by closing the loop and actually producing energy from water hyacinth while also using it as an agent of coastal preservation this process will have net positive environmental and economic impact as the research shows that water hyacinth is effective at phytoremediation, wave energy reduction, and as a source of fermentable sugars.

Conclusions

The large amount of funding already made available for closed loop abatement programs (University of Florida IFAS Extension, 2012) can be redirected into pilot studies aimed at economically opened loop water hyacinth bioenergy production and biomass product market development. In over 100 years of effort we have not been able to eliminate water hyacinth (Wunderlich, 1964), so we should instead turn this plant into a useful source of carbon neutral biofuel and in so doing effectively control its population through active harvesting and responsible biomass resource management. Man made hydrological modifications such as dams and navigatory canals along with people carrying the plant to diverse locations as an ornamental plant has been responsible for the resulting invasive spread of this plant (Batcher, 2013; United Nations Environment Programme Global Environmental Alert Service, 2013; Wunderlich, 1964). It is fitting that further hydrological and aquaculture engineering was used in these designs to provide a productive harvesting and transport solution to change water hyacinth from an invasive nuisance plant to a manageable source of sustainable biofuels and useful biomass. For future research it would be beneficial to explore several engineering methods of producing bioenergy from water hyacinth.

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CHAPTER 6. A REVIEW OF METHODS OF BIOENERGY PRODUCTION FROM WATER HYACINTH

Introduction

Innovative and efficient methods of converting water hyacinth into bioenergy are needed in order to make plans for the use of water hyacinth practicable given current market conditions. Using a portion of harvested water hyacinth to provide heat energy for the processing of remaining water hyacinth is similar to methods used in sugar cane processing and this will offset some of the processing costs (Deepchand, 2001). At sugar processing mills cellulosic sugar cane waste referred to as bagasse is burned to produce energy in the form of heat which makes steam for running all the processes of the sugar mill while also generating electricity in a process known as cogeneration (Deepchand, 2001). Existing technologies that allow for efficient power generation by burning bagasse which not unlike water hyacinth also has a high moisture content can be adapted to the burning of water hyacinth in order to close the production energy balance loop of water hyacinth ethanol production.

As in sugar cane production economics require that the processing of water hyacinth be kept as close to a closed loop production system as possible. Energy from the water hyacinth itself should be extracted in order to aid in the processing and drying of other water hyacinth plants (Deepchand, 2001; Performance, 2010). Therefore, a percentage of the water hyacinth harvest must be dedicated to processing for drying and other production process energy needs.

Designed Engineering Methods of Proscessing for Water Hyacinth

Acid hydrolysis of finely ground water hyacinth is a practical method for extracting sugars from the water hyacinth plant. Strong sulfuric acid and heat from burning a percentage of the water hyacinth harvest can be used to remove sugars from water hyacinth plants via heated acid hydrolysis. After this industrial scale anion exchange columns can be used to separate sugars from the hydrolysate (Performance, 2010). Fermentation of cellulose without acid hydrolysis takes to long to be practical for biofuel production (Hashem & Rashed, 1993).

Another method that shows promise and may be sustainable is supercritical water gasification (Antal Jr., 1996; Benazzi, Calgaroto, Dalla, & Mazutti, February 2013). This is a method which can be used to produce energy from wet water hyacinth by converting it into a combustible hydrogen rich gas. In this method water at super critical temperatures and pressures is applied to water hyacinth and effectively gasifies the plant. This gasification process was patented by Michael Antal of the University of Hawaii (Antal Jr., 1996).

In addition to the use of supercritical water supercritical carbon dioxide gas extraction is another method that should be explored for the processing of water hyacinth hydrolysate. Experiments with sugar cane bagasse employing supercritical carbondioxide to produce hyrdrocarbon gas show promising results. Burning a portion of the water hyacinth in order to create supercritical fluids can make the process energy neutral and this should also be explored as a possible biofuel production method (Benazzi, Calgaroto, Dalla, & Mazutti, February 2013; Performance, 2010).

A portion of water hyacinth used for power generation to run water hyacinth ethanol production mills can be used to produce methane gas which can be added to water hyacinth burning boiler furnaces to increase their efficiency. A wet biodigestion using methanogenic bacterium is a proven method of methanol biofuel production from water hyacinth. The production of methane in this way follows the sigmoid growth curve of the methanogenic bacteria used as it is a function of the bacteria's growth so if the bacteria can be maintained in a high growth phase methane yield can be very high (Patil, Raj, Muralidhara, & Desai, April 2012). One good source of methanogenic bacteria is from animal waste (Patil, Raj, Muralidhara, & Desai, April 2012). Coastal farms can provide an excellent source of animal waste for use in the conversion of water hyacinth into methane gas.

As engineers we must be open to expedient and efficient solutions. In Europe the extrusion of biomass into pellets is a popular way of producing carbon neutral biofuel. In order to extrude water hyacinth into burnable fuel pellets it only needs to have 85% of its water removed, and this can be done by burning a sundried percentage of the plant while extruding the rest (Deepchand, 2001; Penn State, 2009). These fuel pellets may have a market in Europe and Canada and if the cost of transportation does not exceed economies of scale then a valuable biofuel business could be created in this way. The beauty of this method lyes in the fact that while ethanol production gives a liquid biofuel that is compatible with gasoline and diesel, burning the plant as pellets allows for complete combustion while ethanol conversion can only work for the comparatively small percentage of the plant which can be converted into fermentable sugars.

Discussion and Design

In sugar cane mills wood is often introduced into furnaces and initially burned at facility start up in order to prepare furnaces for the introduction of bagasse (Deepchand, 2001). Instead of using wood or other fuel sources from outside of the water hyacinth bioenergy production process my design is to operate with fuels derived from inside the water hyacinth bioenergy production process in as much as a closed loop process as possible. As has been proven in the sugarcane industry closed loop energy production is essential to the economical operation of a sugar processing facility and processing the sugars found in water hyacinth to produce ethanol is no different (Farrell, Plevin, & Kammen, 2006; Hall & Scrase, 1998).

Wet water hyacinth can be mixed with animal wastes to form slurry. As methane is produced by bacteria in the slurry pumps can be used to extract the methane. Extracting methane in connection with the removal of excess water and the addition of water hyacinth feed stock drive the kinetics of the process to the right in accord with Le Chatelier's principle and keep methanogenic bacteria out of a stationary growth phase, (Patil, Raj, Muralidhara, & Desai, April 2012). Steam turbines can be run using boilers fueled by methane gas and in this way electricity can be generated. The remaining steam can be used to supply plant processes. Excess methane gas can be sold or used to produce additional electricity which can be sold back into the energy grid. Existing sugar cane facilities which collectively produce megawatts of cogenerated power are an excellent model of what a production scale water hyacinth processing mill could look like (Deepchand, 2001).

Conclusions

Efficient methods must be devised to process water hyacinth in order to make water hyacinth bioenergy production and coastal preservation economically feasible. Methods ranging from traditional ethanol production to super critical extraction techniques, methanogenic digestion, and fuel pellet production should be explored to find efficient methods that can meet the requirements of production economies of scale.

Current technologies involving cogeneration as used in the sugarcane industry as well as other power generation innovations provide a road map which can be used to design efficient and profitable water hyacinth bioenergy processing mills. Existing technology and research has paved the way for future work in bioenergy production and coastal preservation using water hyacinth.

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CHAPTER 7. CONCLUSIONS AND FUTURE WORK

Discussion of Results

Analysis of water hyacinth samples taken from the Donaldsonville area, the Atchafalaya River Basin, and the Baton Rouge area indicated that the average fermentable sugar concentration of the plant approached 40% with a maximum of 59.08% by dry weight found in an area of the Atchafalaya River Basin. These fermentable sugar concentrations coupled with the observed growth rate of 2.41 metric tons per hectare per day observed in the mesotrophic LSU Lakes along with much higher growth rates seen in the literature at Mexico's eutrophic Cruz Pintada Dam (Gutierrez, Uribe, & and Martinez, 2001) indicated that water hyacinth was an excellent candidate for bioenergy research and future development of large scale biofuel production and coastal protection efforts.

Both storms and boat traffic generate waves in coastal canals and this is a cause of erosion. A 14% reduction in wave energy was observed during wave tank experiments which simulated the types of waves that boat traffic and storms can generate indicating that floating water hyacinth biomass is capable of reducing erosion caused by waves along the banks of coastal canals.

Conclusions and Future Work

Studies into the comparative efficacy and economics of the use of water hyacinth to produce ethanol versus the use of water hyacinth to produce methane gas in anaerobic digestion are warranted. Additionally the effectiveness of water hyacinth for coastal surface water remediation warrants further research and development including sample deployments for actual waste water treatment with quantitative analysis of remediation results computed as comparative concentration of contaminants in treated and untreated waters. Aqua cultural waste water remediation provides an ideal test bed for the implementation and study of waste water treatment and brown water abatement utilizing water hyacinth.

Harvesting these plants and using them as an energy source is a natural progression of human technology as we move from merely attempting to control our environment to manipulating our environment in order to maximize its potential to meet society's energy needs in a responsible, safe and sustainable fashion. In this case our solar energy needs can be met not through expensive photovoltaic cells, but rather through the natural solar power collection provided by the photosynthetic energy storage of an existing plant.

Groups of professionals in the fields of Biochemistry, Engineering, and Business, could form large scale biofuel production consortiums based on this technology. Water hyacinth biofuel production mills can be designed and this approach to biofuel production will advance science and manufacturing in the area of Cellulosic ethanol production along with erosion control (Anderson, McKee, & McKay, September 2011; Bonham, 1983; Farrell, Plevin, & Kammen, 2006; Das, Iimura, & and Tanaka, 2010; Hall & Scrase, 1998).

Current ethanol production depends largely on the use of food crops, but food based ethanol production is not sustainable given increasing global food demands and food market price instability driven by the increased scarcity which results from the use of food products to produce fuel (Motavalli, 2009). Given its rapid growth rate this research shows that the use of water hyacinth to produce biofuel is a sustainable process that can contribute greatly to keeping both food and fuel costs low. This provides a novel engineering solution to our energy needs that advances scientific research in the field of cellulosic ethanol production (Hall & Scrase, 1998).

Coastal plants like water hyacinth can perform a number of ecological functions ranging from remediation of waste to coastal protection (Ajayi & Ogunbayo, 2012; Anderson, McKee, & McKay, September 2011; Bonham, 1983; Jinhai, Zhong, & Yang, 2003; Liao & Chang, 2004; Pinto, Caconia, & Souza, 1987). With the evolutionary competitive edge that water hyacinth has over other plants it is virtually impossible to fully eliminate (Gutierrez, Uribe, & and Martinez, 2001; Wunderlich, 1964). This fact has been proven by over 100 years of money spent on water hyacinth abatement. For this reason it is better to adapt and use water hyacinth to meet the energy and coastal preservation needs of society in a beneficial way rather than wasting resources in an effort to eliminate the plant, an effort that for the past century has been proven to be futile (Wunderlich, 1964).

While sequestering carbon to make sugars water hyacinth plants also remove nitrogen and phosphorus biocontaminants from water bodies. In addition these plants can readily clean water of heavy metals and other pollutants thanks to the strong anionic and cationic binding sites located in their root system (Liao & Chang, 2004). The combined ability to remove heavy metals and organic wastes means that these plants can remediate waste water while also being and excellent source of green energy.

The energy economy of the United States depends upon sustainability and increasing energy independence is vital to our national security. As the State of Louisiana is losing coastal wetlands at a rate of as much as 100 square kilometers per year the combination of erosion control with biofuel production will be a great benefit to the state. Additionally with the threat of carbon emissions resulting in ecological changes to the environment carbon neutral energy production is important.

In Louisiana Verenium Corporation, an industrial biotechnology firm with a corporate base in San Diego, California, has begun production of cellulosic ethanol from sugar cane waste. This cellulosic ethanol production facility is located in Jennings La only 60 miles north of the La. Coast. The facility has existing rail access making transport of water hyacinth a convenient and cost effective option. As the facility is already tooled to produce cellulosic ethanol from sugar cane bagasse it can quickly be adapted to process water hyacinth for biofuel production. A design proposal sent to British Petroleum, the new owner of Verenium's Louisiana facility, with state backing could result in a pilot project for coastal protection and water hyacinth cellulosic ethanol production.

The energy policy act of 2005 required that 7.5 billion gallons of renewable fuel be produced and used by 2012. Now the government's renewable fuel production standard has been raised to 36 billion gallons by 2022. Included in this amount is 16 billion gallons of nonfood based cellulosic biofuels of which water hyacinth could make a large part. The plan also signifies a shift away from food sources for ethanol production as it only calls for 15 billion gallons of corn based ethanol. Innovative methods of ethanol production from non food based sources such as water hyacinth can lead the way into a new green and highly sustainable energy future while also not causing problems and instability in world food markets. Before a final shift is made to a very likely hydrogen based energy economy in the far future, efficient water hyacinth ethanol production may be used to meet near term low carbon footprint green energy needs.

Water hyacinth has been labeled as an invasive aquatic nuissance. Every year millions of dollars are spent in efforts to remove and destroy water hyacinth plants. A better use for this funding is to control water hyacinth populations by regularly harvesting it as a biofuel source and using advanced aquaculture engineering methods and equipment to manage the plants in areas where they are already growing. The current method of water hyacinth control using wasteful removal methods, and chemical treatments is a closed loop process where energy and funds are invested at a minimal rate of return that is only equal to marginally quantifiable navigation related improvements to bodies of water at unknown opportunity costs. Instead water hyacinth can be harvested thus creating an energy market built around water hyacinth which will then solve the water hyacinth abatement problem through demand based active harvesting of the plant and free market economic incentives. In turn the economics of water hyacinth biofuel production will result in a net positive economic and ecological impact.

The answer to our quest for energy lyes within nature itself and by using carbon neutral fuel sources such as water hyacinth we will increase power production and sustainability in the long term. The encouragement of further education, research, and innovation in this area of cellulosic bioenergy production and coastal protection is a goal of my continued research.

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APPENDIX A. WATER HYACINTH WAVE ENERGY REDUCTION WAVE TANK DATA

This appendix contains wave tank data for wave energy reduction analysis of *Eichhornia crassipes*. The table shows the method of calibration brought out to 200 data points along with the standard deviation of the readings of the two pressure transducers used.

Two pressure transducers were used to measure the change in wave energy as the change in pressure as the water wave moved over them in a linear progression from pressure transducer 1, upstream of the floating biomass mat, to sensor 3, downstream of the floating biomass mat. While the waves were passing underneath the mat of *Eichhornia crassipes* it was held in place between the two sensors by floating booms in shallow water at a depth of .3048 meters.

Two different wave heights and frequencies were used for this test. The first, wave type 1, was a lower energy wave set to a frequency of .5291 hertz and a span of .05 meters +/- .009 meters with a wave height of .0889 meters +/- .009 meters. The second wave, type 2, was a higher energy wave with a frequency of .4258 hertz and a span of .1397 meters +/- .009 meters with a wave height of .1397 meters +/- .009 meters. The wave energy data from these sensors was cataloged by a Campbell Scientific data logger model CR 23X which was programmed in CR Basic to record transducer data at a sampling rate of .1 seconds, 10 hertz and take 2048 data collections per wave tank analysis run.

The first set of table data in this appendix shows baseline data for wave 1 and wave 2 adjacent to normalized wave tank data for wave 1 and wave 2 synchronized and matched crest to crest for an accurate representation. Data was normalized by taking a sum of all baseline pressure transducer data with containment booms in place (for corralling vegetation) and comparing the sums of transducer 1 and transducer 3 and then dividing them into each other in order to get a multiplier that would make the sum of transducer three match the sum of transducer 1 this multiplier was then distributed into transducer 3 data in order to equalize readings between them, accounting for sensor reading noise and irregularities between these two identical Druck pressure transducers. The data is cataloged by wave type, transducer number, fit, and whether or not it is normalized with B13F1N meaning that the data is baseline data (B), from analysis of wave type (1), on transducer (3) fit to transducer (1), and normalized (N). The last two numbers in each column are the standard deviation and the sum of the data respectively.

Table 3 Pressure transducer calibration and readings

B11	B13	B21	B23	B11F3	B13F1N	B21F3	B23F1N
0.331	0.277	0.311	0.33	0.3850	0.3843	0.415	0.406
0.347	0.27	0.288	0.35	0.3800	0.3810	0.412	0.399
0.364	0.269	0.265	0.362	0.3670	0.3699	0.399	0.387
0.376	0.269	0.246	0.361	0.3530	0.3511	0.385	0.374
0.384	0.271	0.232	0.352	0.3360	0.3313	0.366	0.363
0.385	0.275	0.224	0.342	0.3210	0.3147	0.346	0.351
0.38	0.279	0.221	0.331	0.3080	0.3036	0.323	0.338
0.367	0.286	0.222	0.32	0.3000	0.2970	0.302	0.322
0.353	0.292	0.226	0.308	0.2940	0.2959	0.277	0.306
0.336	0.3	0.236	0.296	0.2900	0.2970	0.256	0.290
0.321	0.309	0.251	0.281	0.2900	0.2992	0.239	0.273
0.308	0.32	0.275	0.266	0.2920	0.3048	0.227	0.261
0.3	0.332	0.3	0.251	0.2990	0.3103	0.222	0.252
0.294	0.343	0.327	0.238	0.3090	0.3169	0.22	0.245
0.29	0.348	0.352	0.229	0.3210	0.3257	0.223	0.241
0.29	0.345	0.375	0.222	0.3350	0.3346	0.23	0.237
0.292	0.335	0.397	0.216	0.3510	0.3434	0.243	0.236
0.299	0.318	0.41	0.212	0.3660	0.3567	0.262	0.240
0.309	0.3	0.415	0.21	0.3790	0.3710	0.288	0.252
0.321	0.285	0.412	0.213	0.3850	0.3821	0.313	0.273
0.335	0.275	0.399	0.222	0.3840	0.3843	0.337	0.300
0.351	0.269	0.385	0.237	0.3770	0.3787	0.361	0.332
0.366	0.268	0.366	0.259	0.3650	0.3644	0.384	0.361
0.379	0.269	0.346	0.287	0.3490	0.3467	0.404	0.387
0.385	0.271	0.323	0.314	0.3310	0.3268	0.412	0.403
0.384	0.276	0.302	0.339	0.3170	0.3114	0.415	0.403
0.377	0.281	0.277	0.357	0.3050	0.3014	0.409	0.394
0.365	0.287	0.256	0.364	0.2990	0.2970	0.395	0.382
0.349	0.295	0.239	0.358	0.2930	0.2970	0.379	0.372
0.331	0.303	0.227	0.347	0.2900	0.2992	0.358	0.359
0.317	0.311	0.222	0.336	0.2900	0.3014	0.337	0.344
0.305	0.323	0.22	0.326	0.2930	0.3059	0.315	0.332
0.299	0.336	0.223	0.315	0.3010	0.3125	0.291	0.316
0.293	0.346	0.23	0.303	0.3110	0.3180	0.267	0.299
0.29	0.348	0.243	0.289	0.3240	0.3257	0.246	0.282
0.29	0.343	0.262	0.275	0.3390	0.3368	0.234	0.266
0.293	0.33	0.288	0.26	0.3550	0.3467	0.224	0.256
0.301	0.314	0.313	0.245	0.3690	0.3611	0.22	0.250
0.311	0.296	0.337	0.234	0.3810	0.3732	0.221	0.243

B11	B13	B21	B23	B11F3	B13F1N	B21F3	B23F1N
0.324	0.282	0.361	0.226	0.3860	0.3832	0.225	0.238
0.339	0.273	0.384	0.22	0.3830	0.3832	0.236	0.235
0.355	0.269	0.404	0.216	0.3750	0.3754	0.251	0.236
0.369	0.269	0.412	0.213	0.3610	0.3600	0.271	0.245
0.381	0.271	0.415	0.212	0.3450	0.3401	0.295	0.261
0.386	0.273	0.409	0.215	0.3280	0.3224	0.323	0.286
0.383	0.277	0.395	0.226	0.3140	0.3081	0.349	0.315
0.375	0.283	0.379	0.245	0.3030	0.2992	0.371	0.345
0.361	0.288	0.358	0.269	0.2980	0.2970	0.393	0.374
0.345	0.295	0.337	0.298	0.2930	0.2970	0.407	0.394
0.328	0.305	0.315	0.324	0.2900	0.2992	0.415	0.402
0.314	0.314	0.291	0.347	0.2910	0.3025	0.413	0.399
0.303	0.327	0.267	0.362	0.2950	0.3081	0.403	0.389
0.298	0.338	0.246	0.362	0.3020	0.3136	0.387	0.378
0.293	0.347	0.234	0.354	0.3140	0.3202	0.37	0.365
0.29	0.347	0.224	0.343	0.3270	0.3290	0.348	0.354
0.291	0.34	0.22	0.334	0.3430	0.3379	0.329	0.340
0.295	0.326	0.221	0.322	0.3580	0.3511	0.305	0.324
0.302	0.308	0.225	0.309	0.3740	0.3644	0.281	0.307
0.314	0.292	0.236	0.298	0.3830	0.3765	0.258	0.291
0.327	0.279	0.251	0.284	0.3850	0.3832	0.24	0.273
0.343	0.271	0.271	0.268	0.3830	0.3832	0.228	0.261
0.358	0.269	0.295	0.253	0.3730	0.3721	0.222	0.252
0.374	0.269	0.323	0.239	0.3570	0.3556	0.219	0.247
0.383	0.271	0.349	0.23	0.3400	0.3357	0.222	0.243
0.385	0.274	0.371	0.224	0.3240	0.3180	0.23	0.240
0.383	0.279	0.393	0.218	0.3110	0.3059	0.241	0.237
0.373	0.284	0.407	0.214	0.3010	0.2992	0.259	0.240
0.357	0.29	0.415	0.211	0.2950	0.2959	0.283	0.251
0.34	0.298	0.413	0.212	0.2920	0.2970	0.309	0.270
0.324	0.306	0.403	0.22	0.2900	0.2992	0.334	0.299
0.311	0.318	0.387	0.234	0.2910	0.3036	0.359	0.329
0.301	0.33	0.37	0.257	0.2970	0.3081	0.383	0.359
0.295	0.341	0.348	0.283	0.3050	0.3147	0.398	0.383
0.292	0.347	0.329	0.31	0.3170	0.3224	0.411	0.401
0.29	0.347	0.305	0.336	0.3310	0.3313	0.415	0.403
0.291	0.337	0.281	0.354	0.3470	0.3412	0.41	0.394
0.297	0.322	0.258	0.361	0.3630	0.3533	0.395	0.383
0.305	0.304	0.24	0.358	0.3750	0.3666	0.381	0.372
0.317	0.288	0.228	0.349	0.3840	0.3787	0.361	0.360
0.331	0.277	0.222	0.339	0.3850	0.3843	0.34	0.346
0.347	0.271	0.219	0.328	0.3810	0.3798	0.318	0.333

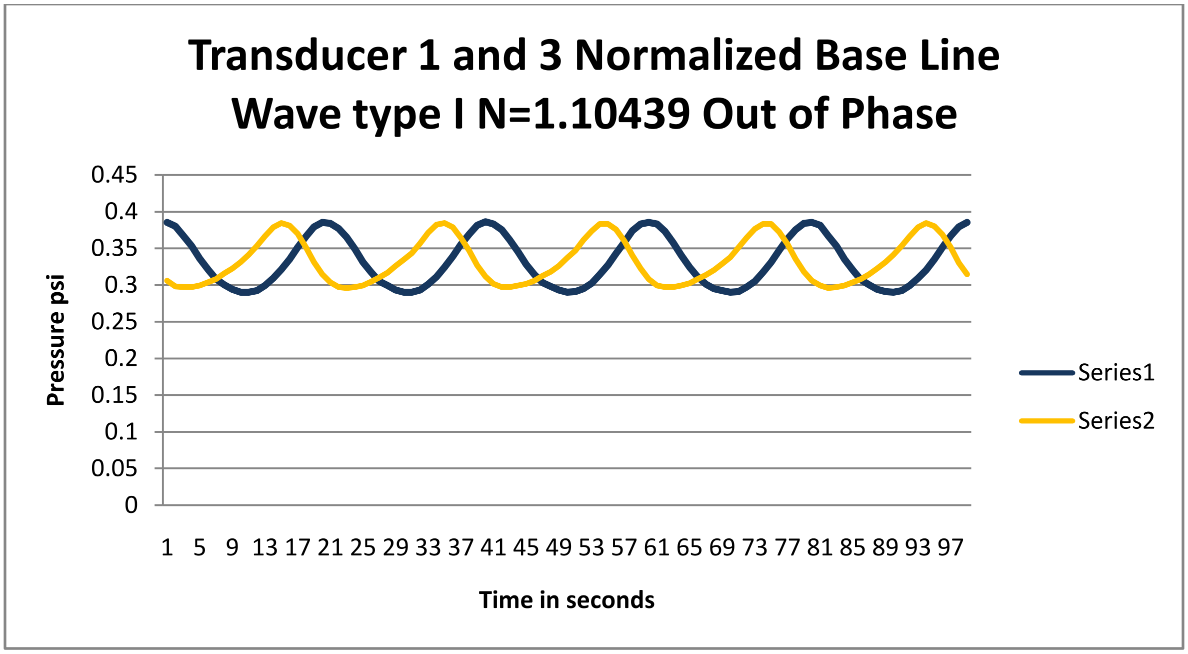
B11	B13	B21	B23	B11F3	B13F1N	B21F3	B23F1N
0.363	0.268	0.222	0.318	0.3670	0.3688	0.293	0.316
0.375	0.269	0.23	0.305	0.3530	0.3511	0.27	0.300
0.384	0.271	0.241	0.291	0.3350	0.3302	0.25	0.283
0.385	0.275	0.259	0.276	0.3200	0.3147	0.235	0.270
0.381	0.279	0.283	0.261	0.3070	0.3036	0.226	0.258
0.367	0.285	0.309	0.245	0.3000	0.2970	0.22	0.251
0.353	0.292	0.334	0.234	0.2940	0.2970	0.22	0.245
0.335	0.3	0.359	0.226	0.2910	0.2970	0.225	0.241
0.32	0.309	0.383	0.222	0.2900	0.3003	0.233	0.237
0.307	0.32	0.398	0.218	0.2920	0.3048	0.248	0.236
0.3	0.332	0.411	0.215	0.2990	0.3103	0.269	0.242
0.294	0.343	0.415	0.213	0.3090	0.3169	0.293	0.255
0.291	0.348	0.41	0.215	0.3200	0.3235	0.32	0.280
0.29	0.344	0.395	0.225	0.3350	0.3324	0.346	0.311
0.292	0.334	0.381	0.242	0.3510	0.3434	0.371	0.342
0.299	0.318	0.361	0.268	0.3670	0.3578	0.391	0.371
0.309	0.299	0.34	0.295	0.3790	0.3710	0.407	0.392
0.32	0.285	0.318	0.322	0.3850	0.3810	0.413	0.403
0.335	0.275	0.293	0.344	0.3850	0.3843	0.413	0.401
0.351	0.269	0.27	0.36	0.3780	0.3776	0.405	0.390
0.367	0.269	0.25	0.362	0.3650	0.3644	0.389	0.378
0.379	0.269	0.235	0.354	0.3490	0.3445	0.371	0.365
0.385	0.272	0.226	0.344	0.3310	0.3268	0.353	0.354
0.385	0.276	0.22	0.334	0.3170	0.3125	0.331	0.340
0.378	0.281	0.22	0.323	0.3060	0.3014	0.308	0.326
0.365	0.287	0.225	0.311	0.2990	0.2970	0.285	0.310
0.349	0.293	0.233	0.299	0.2930	0.2970	0.261	0.291
0.331	0.301	0.248	0.284	0.2910	0.2992	0.243	0.275
0.317	0.311	0.269	0.269	0.2900	0.3014	0.23	0.263
0.306	0.324	0.293	0.254	0.2930	0.3059	0.222	0.255
0.299	0.336	0.32	0.242	0.3000	0.3103	0.22	0.250
0.293	0.345	0.346	0.232	0.3110	0.3180	0.222	0.245
0.291	0.348	0.371	0.225	0.3230	0.3257	0.228	0.241
0.29	0.342	0.391	0.22	0.3380	0.3346	0.238	0.236
0.293	0.33	0.407	0.216	0.3540	0.3467	0.256	0.237
0.3	0.312	0.413	0.213	0.3700	0.3611	0.279	0.246
0.311	0.296	0.413	0.212	0.3800	0.3732	0.305	0.266
0.323	0.283	0.405	0.217	0.3860	0.3821	0.333	0.295
0.338	0.273	0.389	0.229	0.3840	0.3832	0.358	0.325
0.354	0.269	0.371	0.251	0.3750	0.3743	0.381	0.355
0.37	0.269	0.353	0.279	0.3610	0.3600	0.398	0.381
0.38	0.271	0.331	0.307	0.3450	0.3401	0.411	0.400

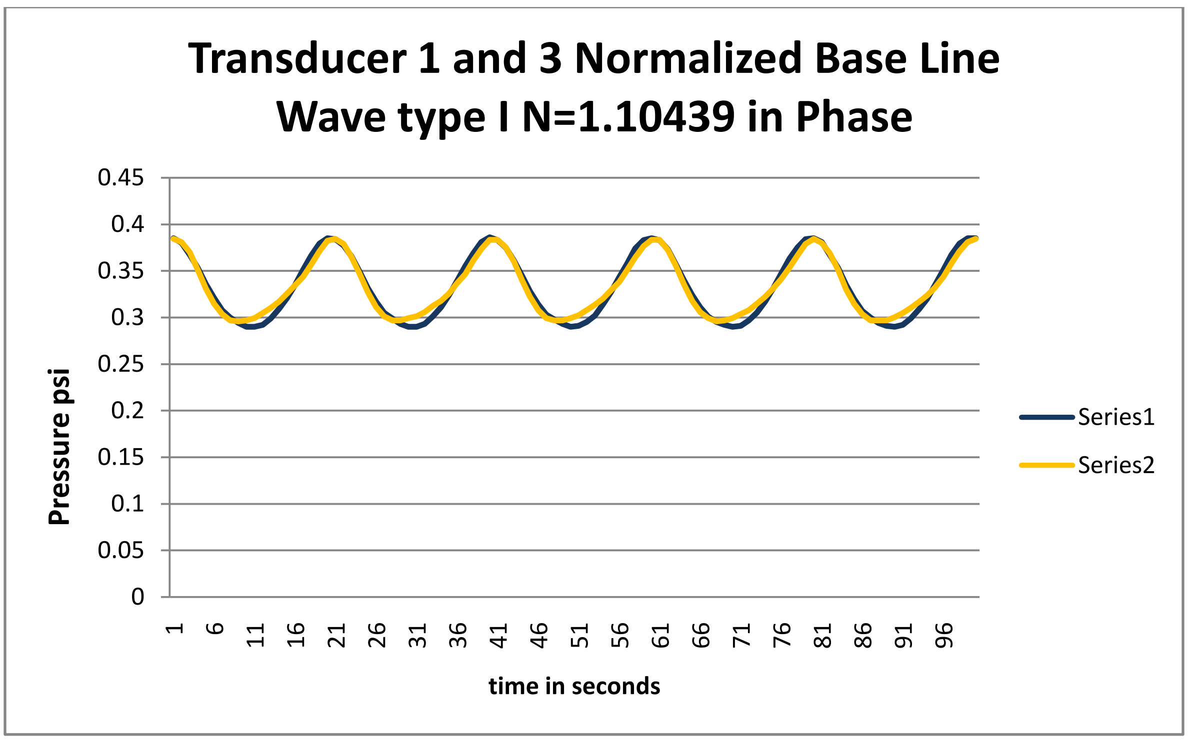
B11	B13	B21	B23	B11F3	B13F1N	B21F3	B23F1N
0.386	0.273	0.308	0.333	0.3280	0.3224	0.416	0.403
0.384	0.277	0.285	0.352	0.3140	0.3092	0.409	0.397
0.375	0.281	0.261	0.362	0.3030	0.3003	0.397	0.383
0.361	0.288	0.243	0.36	0.2980	0.2970	0.38	0.372
0.345	0.295	0.23	0.35	0.2930	0.2970	0.362	0.361
0.328	0.303	0.222	0.339	0.2910	0.2992	0.342	0.349
0.314	0.314	0.22	0.328	0.2910	0.3025	0.32	0.334
0.303	0.327	0.222	0.318	0.2940	0.3081	0.297	0.318
0.298	0.338	0.228	0.305	0.3010	0.3136	0.273	0.302
0.293	0.346	0.238	0.293	0.3120	0.3191	0.252	0.284
0.291	0.347	0.256	0.278	0.3270	0.3279	0.236	0.269
0.291	0.339	0.279	0.261	0.3420	0.3379	0.226	0.258
0.294	0.326	0.305	0.247	0.3580	0.3500	0.22	0.251
0.301	0.308	0.333	0.236	0.3740	0.3644	0.22	0.247
0.312	0.292	0.358	0.229	0.3840	0.3754	0.225	0.243
0.327	0.28	0.381	0.224	0.3860	0.3832	0.232	0.240
0.342	0.272	0.398	0.22	0.3830	0.3832	0.246	0.236
0.358	0.269	0.411	0.216	0.3730	0.3721	0.266	0.240
0.374	0.269	0.416	0.212	0.3570	0.3556	0.291	0.253
0.384	0.271	0.409	0.213	0.3410	0.3346	0.317	0.277
0.386	0.274	0.397	0.221	0.3240	0.3180	0.343	0.307
0.383	0.279	0.38	0.239	0.3110	0.3059	0.367	0.339
0.373	0.284	0.362	0.265	0.3010	0.2981	0.389	0.368
0.357	0.289	0.342	0.292	0.2950	0.2959	0.403	0.391
0.341	0.297	0.32	0.319	0.2930	0.2970	0.414	0.403
0.324	0.306	0.297	0.342	0.2910	0.3003	0.414	0.401
0.311	0.317	0.273	0.359	0.2910	0.3036	0.405	0.391
0.301	0.33	0.252	0.362	0.2970	0.3081	0.389	0.379
0.295	0.34	0.236	0.356	0.3040	0.3147	0.374	0.368
0.293	0.347	0.226	0.344	0.3170	0.3213	0.355	0.357
0.291	0.347	0.22	0.334	0.3300	0.3302	0.333	0.342
0.291	0.337	0.22	0.324	0.3460	0.3412	0.311	0.328
0.297	0.322	0.225	0.313	0.3630	0.3533	0.285	0.311
0.304	0.303	0.232	0.3	0.3760	0.3666	0.262	0.293
0.317	0.288	0.246	0.285	0.3840	0.3787	0.245	0.276
0.33	0.277	0.266	0.271	0.3850	0.3832	0.231	0.264
0.346	0.27	0.291	0.255	0.3800	0.3798	0.224	0.254
0.363	0.268	0.317	0.241	0.3680	0.3688	0.22	0.250
0.376	0.269	0.343	0.232	0.3530	0.3500	0.221	0.245
0.384	0.272	0.367	0.225	0.3360	0.3313	0.226	0.241
0.385	0.275	0.389	0.222	0.3210	0.3147	0.237	0.237
0.38	0.279	0.403	0.218	0.3090	0.3036	0.254	0.237

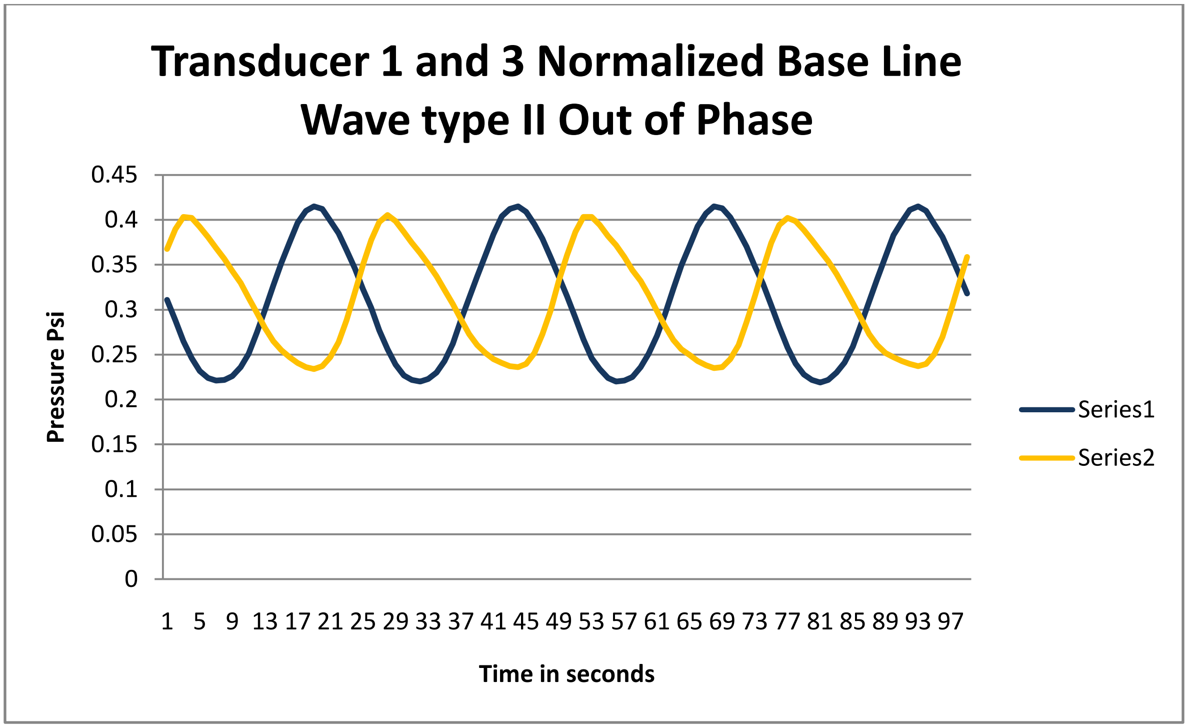
B11	B13	B21	B23	B11F3	B13F1N	B21F3	B23F1N
0.368	0.285	0.414	0.215	0.3000	0.2970	0.276	0.245
0.353	0.291	0.414	0.212	0.2940	0.2970	0.302	0.263
0.336	0.299	0.405	0.215	0.2910	0.2992	0.329	0.291
0.321	0.309	0.389	0.227	0.2900	0.3014	0.353	0.322
0.309	0.32	0.374	0.249	0.2930	0.3048	0.375	0.352
0.3	0.332	0.355	0.276	0.2990	0.3103	0.396	0.379
0.294	0.343	0.333	0.304	0.3070	0.3147	0.408	0.399
0.291	0.347	0.311	0.33	0.3190	0.3224	0.415	0.404
0.29	0.344	0.285	0.351	0.3330	0.3324	0.411	0.399
0.293	0.334	0.262	0.362	0.3500	0.3434	0.395	0.385
0.299	0.317	0.245	0.36	0.3650	0.3567	0.385	0.374
0.307	0.3	0.231	0.351	0.3790	0.3710	0.365	0.362
0.319	0.285	0.224	0.34	0.3850	0.3810	0.345	0.348
0.333	0.275	0.22	0.33	0.3850	0.3832	0.323	0.335
0.35	0.269	0.221	0.32	0.3780	0.3776	0.299	0.320
0.365	0.269	0.226	0.307	0.3650	0.3644	0.275	0.303
0.379	0.271	0.237	0.294	0.3500	0.3456	0.254	0.285
0.385	0.273	0.254	0.279	0.3330	0.3257	0.238	0.270
0.385	0.276	0.276	0.263	0.3170	0.3125	0.227	0.260
0.378	0.281	0.302	0.248	0.3060	0.3014	0.222	0.252
0.365	0.285	0.329	0.237	0.0340	0.0303	0.0691	0.058
0.35	0.292	0.353	0.228	61.606	61.645	57.837	57.887
0.333	0.301	0.375	0.224				
0.317	0.311	0.396	0.22				
0.306	0.323	0.408	0.216				
0.299	0.336	0.415	0.213				
0.293	0.345	0.411	0.213				
0.291	0.347	0.395	0.22				
0.291	0.342	0.385	0.236				
0.293	0.33	0.365	0.261				
0.3	0.313	0.345	0.289				
0.31	0.295	0.323	0.316				
0.323	0.283	0.299	0.34				
0.337	0.273	0.275	0.358				
0.0339 3	0.0273 5	0.0686	0.0525				
66.145	59.913	62.054	55.805				

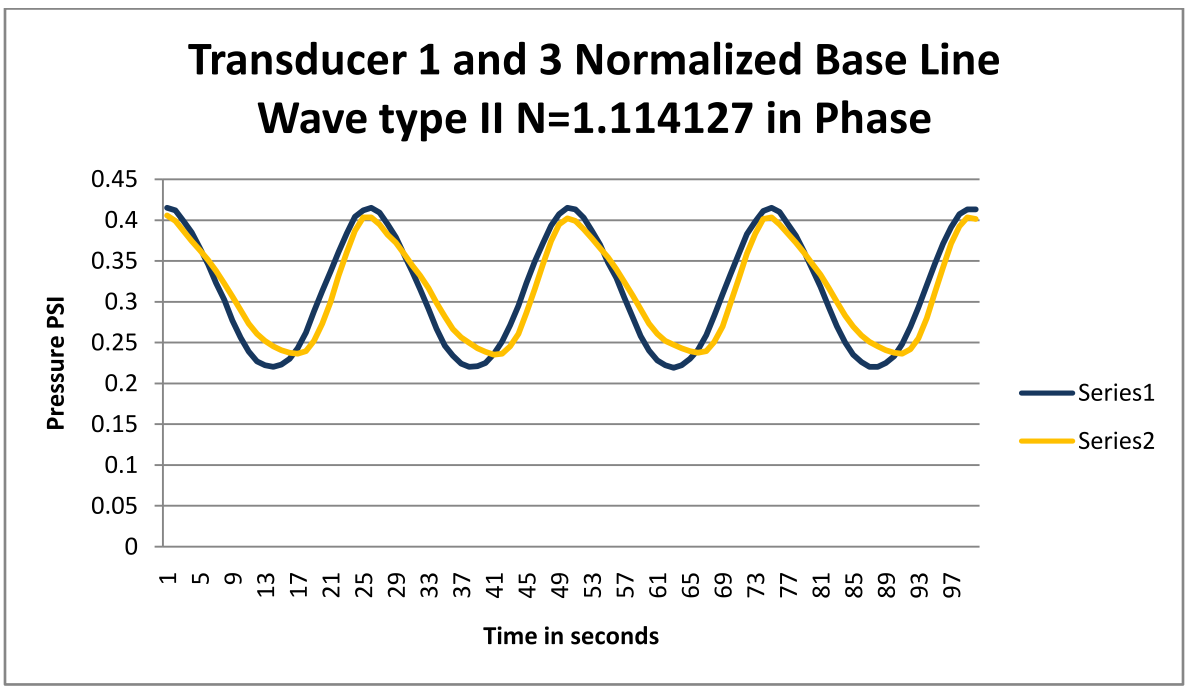
APPENDIX B. WAVE ENERGY TABLE DATA AND WAVE ENERGY GRAPHS

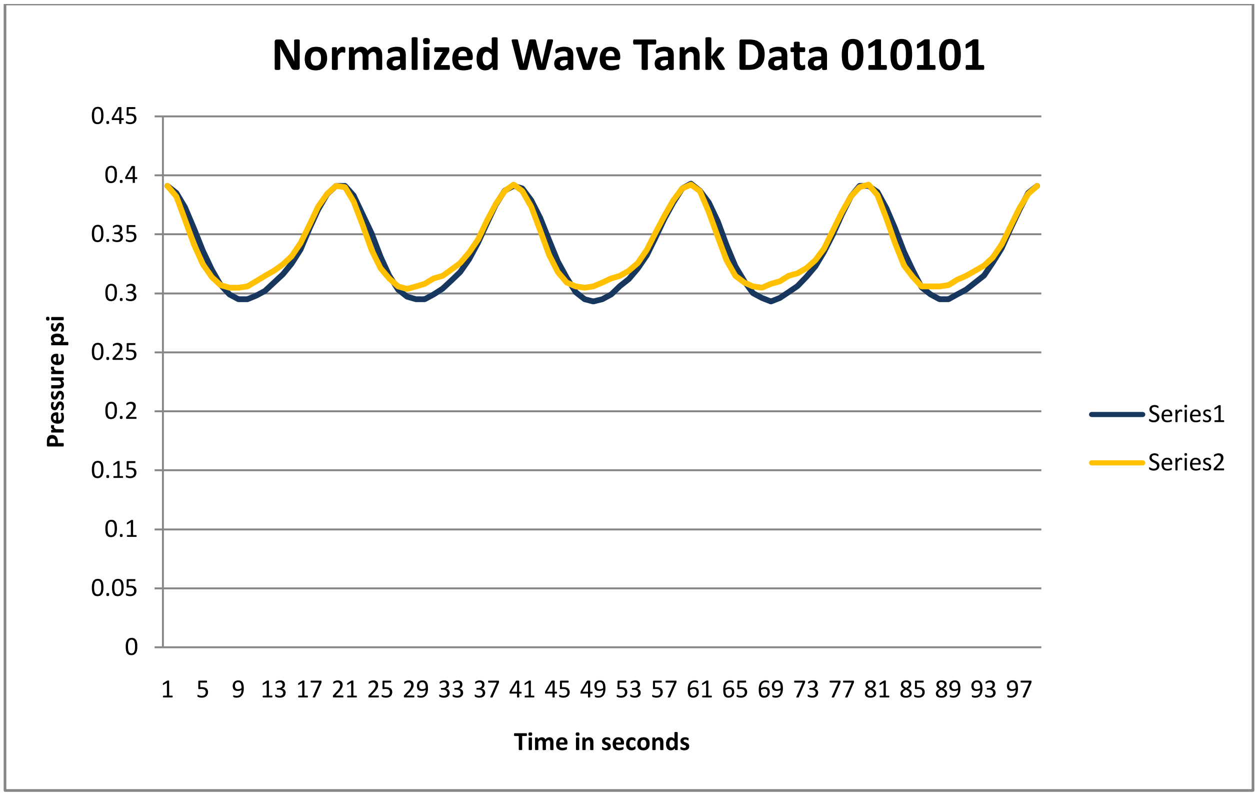
This appendix contains table data for all readings. Data is ordered sequentially by file name with file name 010101 indicating wave type 1, run number 1, and 1/3 plant biomass used, 010103 would indicate wave type 1, run number 1, and 3/3 plant biomass, the full amount, where total plant biomass is 34.382kg.   The second part of this appendix shows graphs of all data for wave energy reduction comparison series 1 represents transducer 1 data showing the wave energy before encountering plant biomass and series 2 represents the wave energy as shown by transducer 3 after encountering plant biomass. The difference between Data was normalized and fit as described in appendix A.

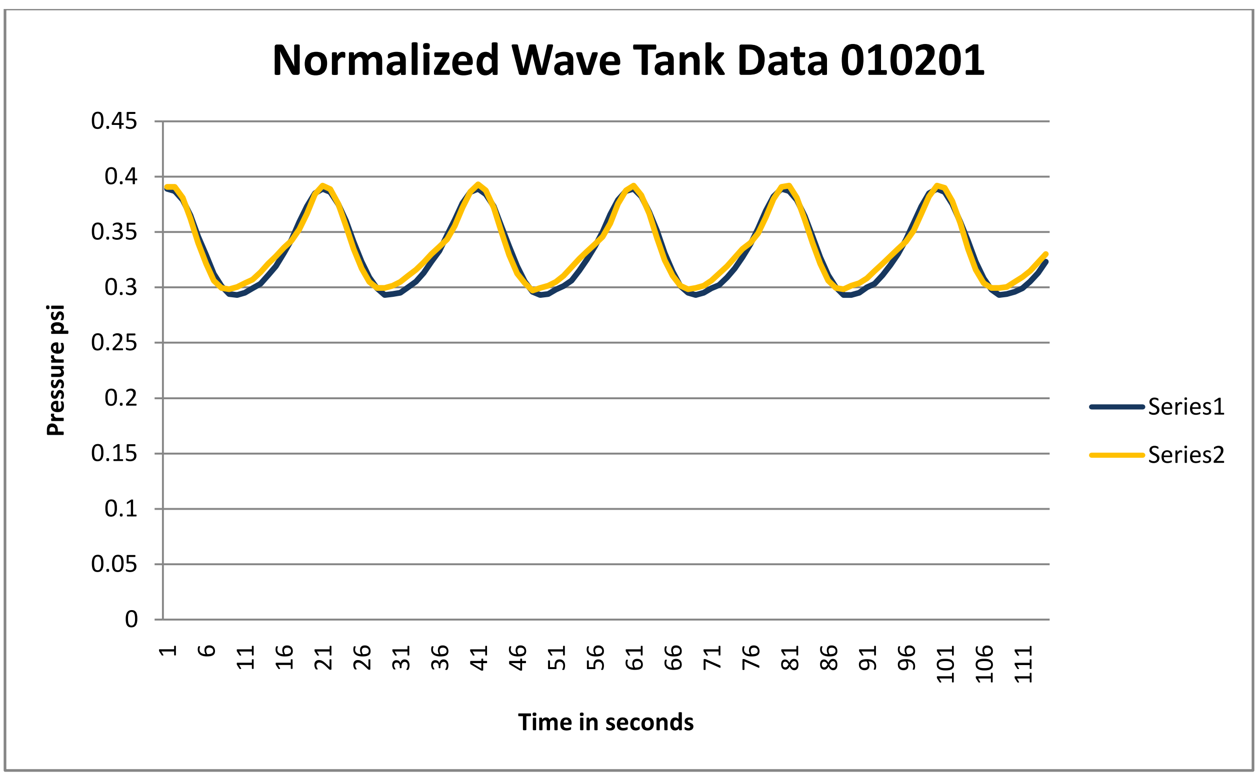

Transducer 1 and 3 Normalized Base Line Wave type I N=1.10439 Out of Phase
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

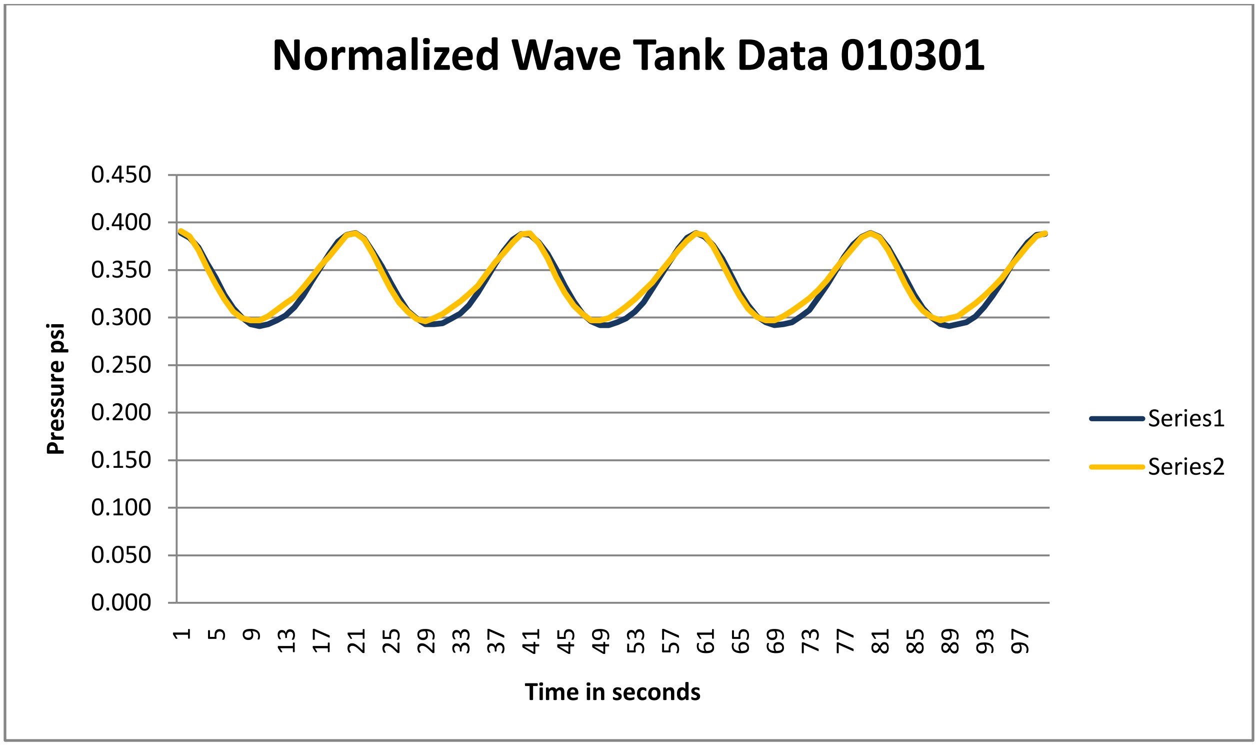

Transducer 1 and 3 Normalized Base Line Wave type I N=1.10439 in Phase
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96
time in seconds
Series1
Series2

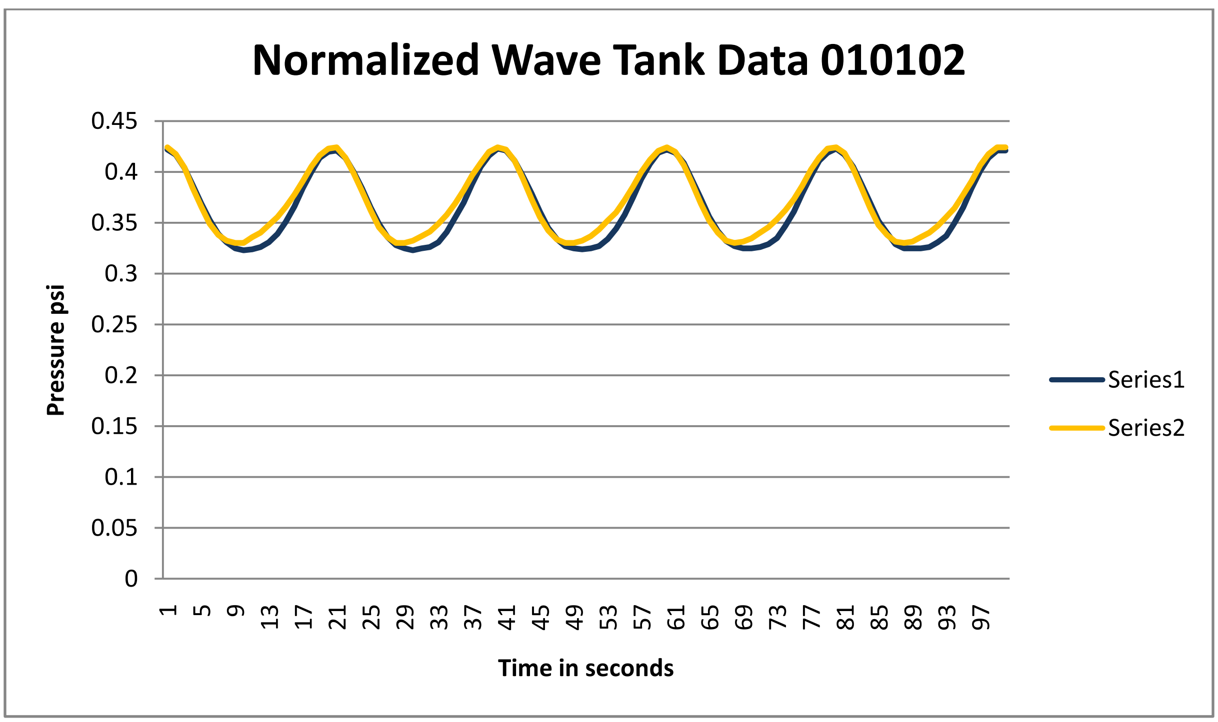

Transducer 1 and 3 Normalized Base Line
Wave type II Out of Phase
Pressure Psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

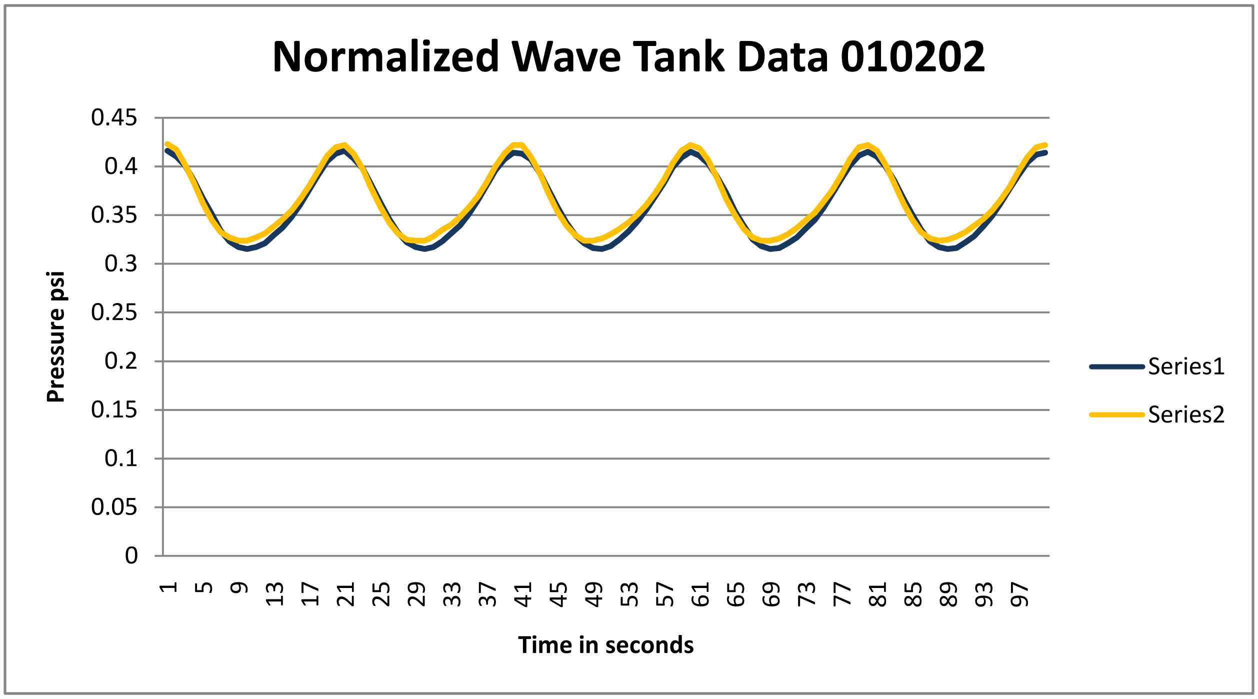

Transducer 1 and 3 Normalized Base Line
Wave type II N=1.114127 in Phase
Pressure PSI
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

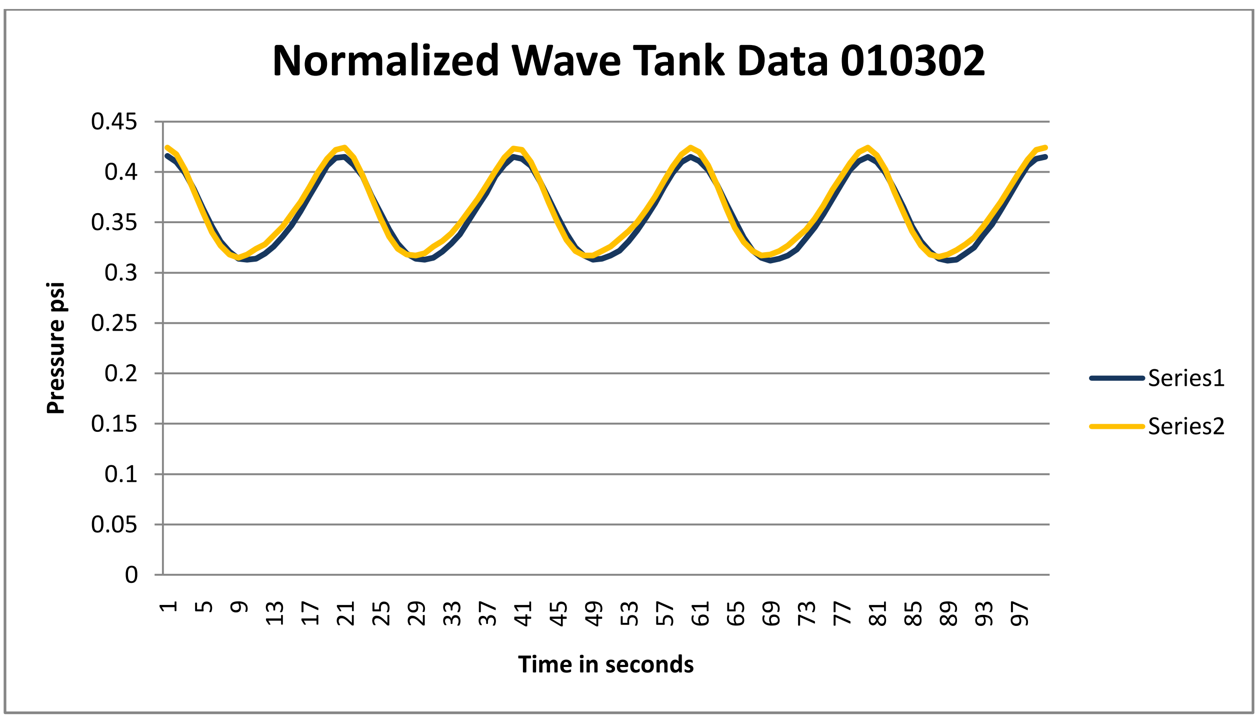

Normalized Wave Tank Data 010101
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

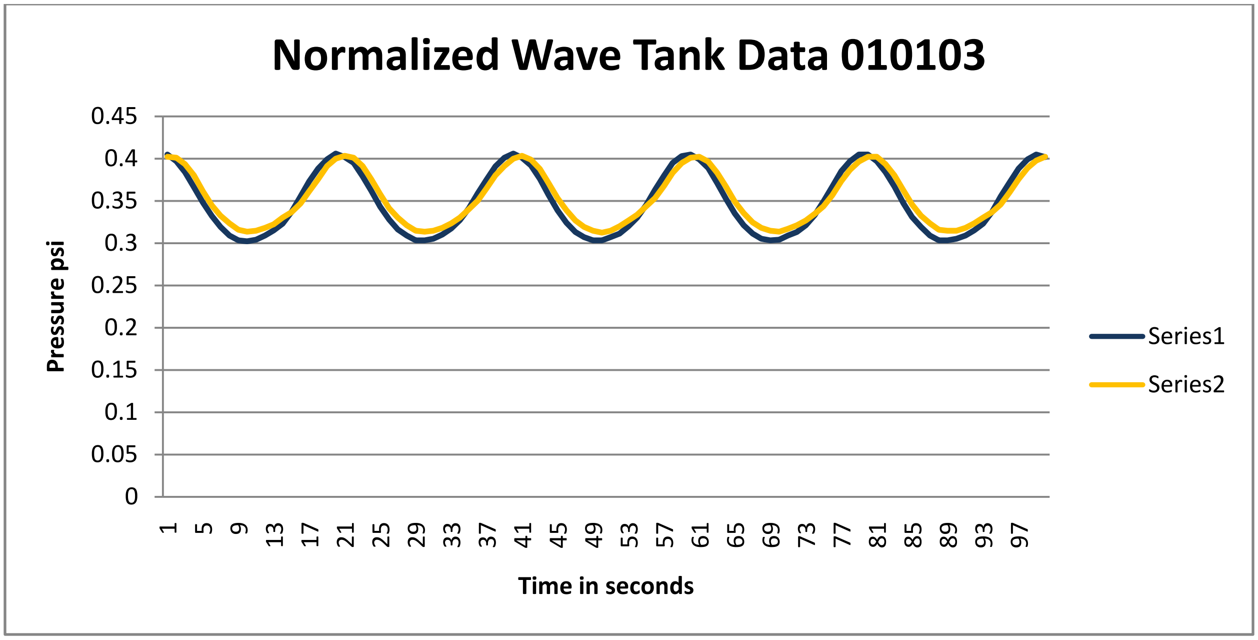

Normalized Wave Tank Data 010201
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111
Time in seconds
Series1
Series2

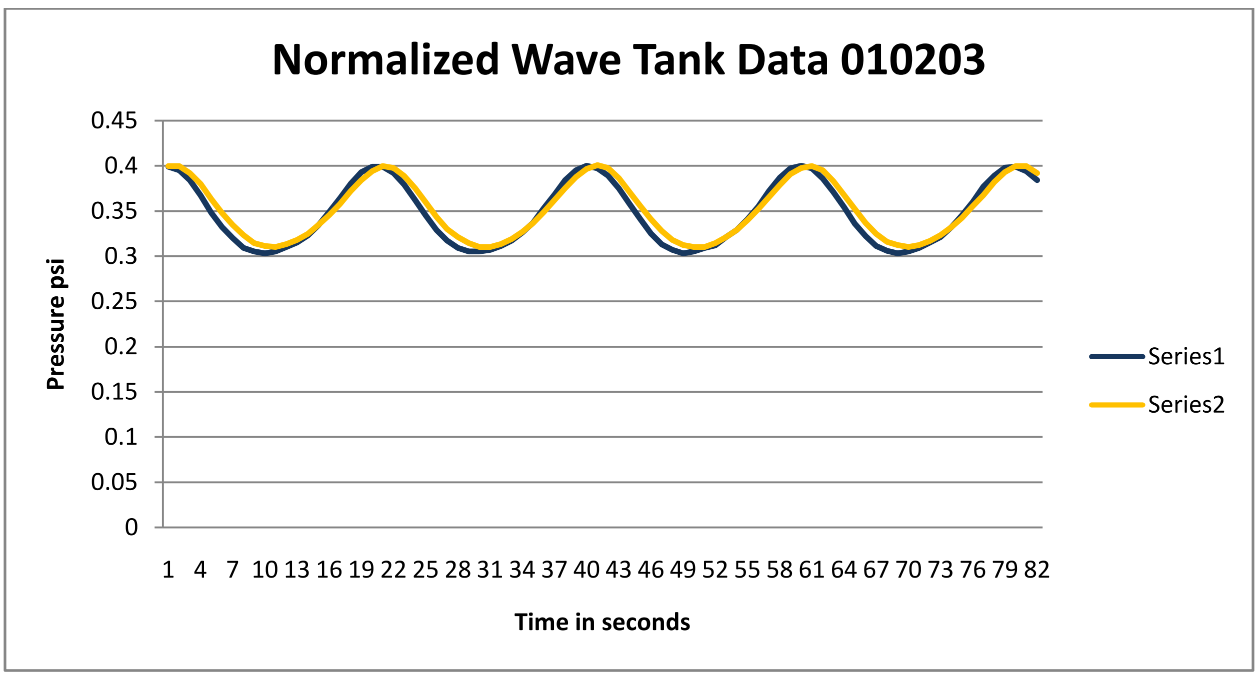

Normalized Wave Tank Data 010301
Pressure psi
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

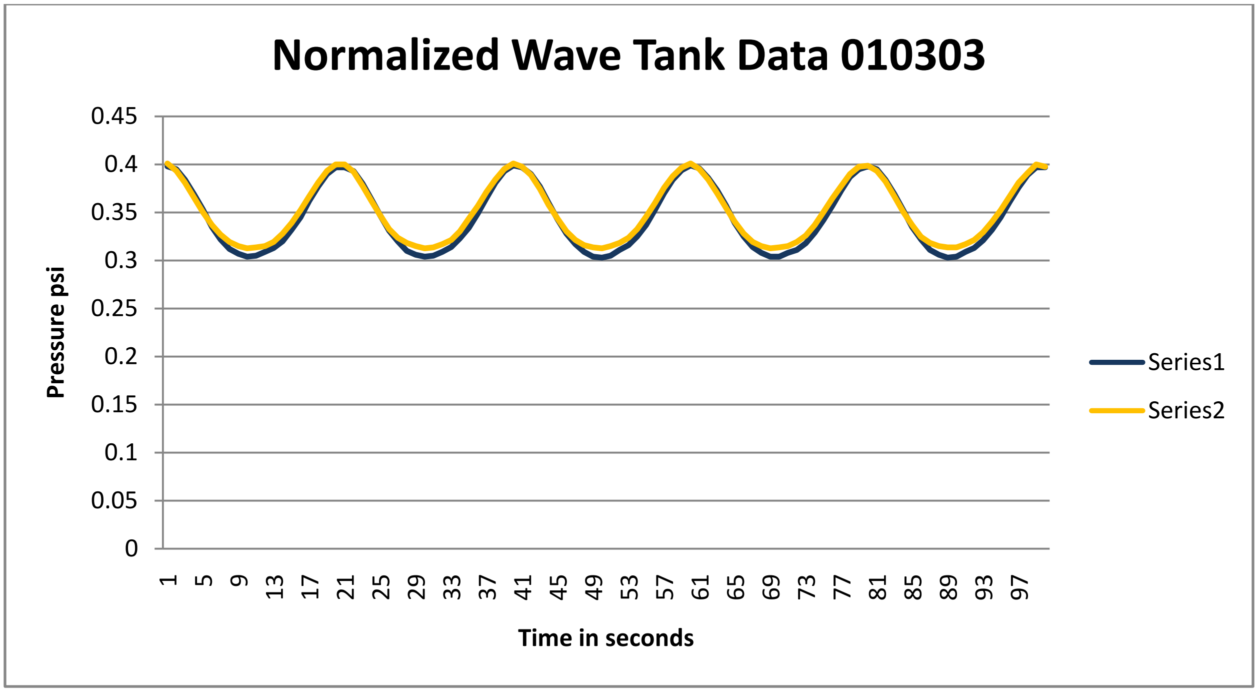

Normalized Wave Tank Data 010102
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

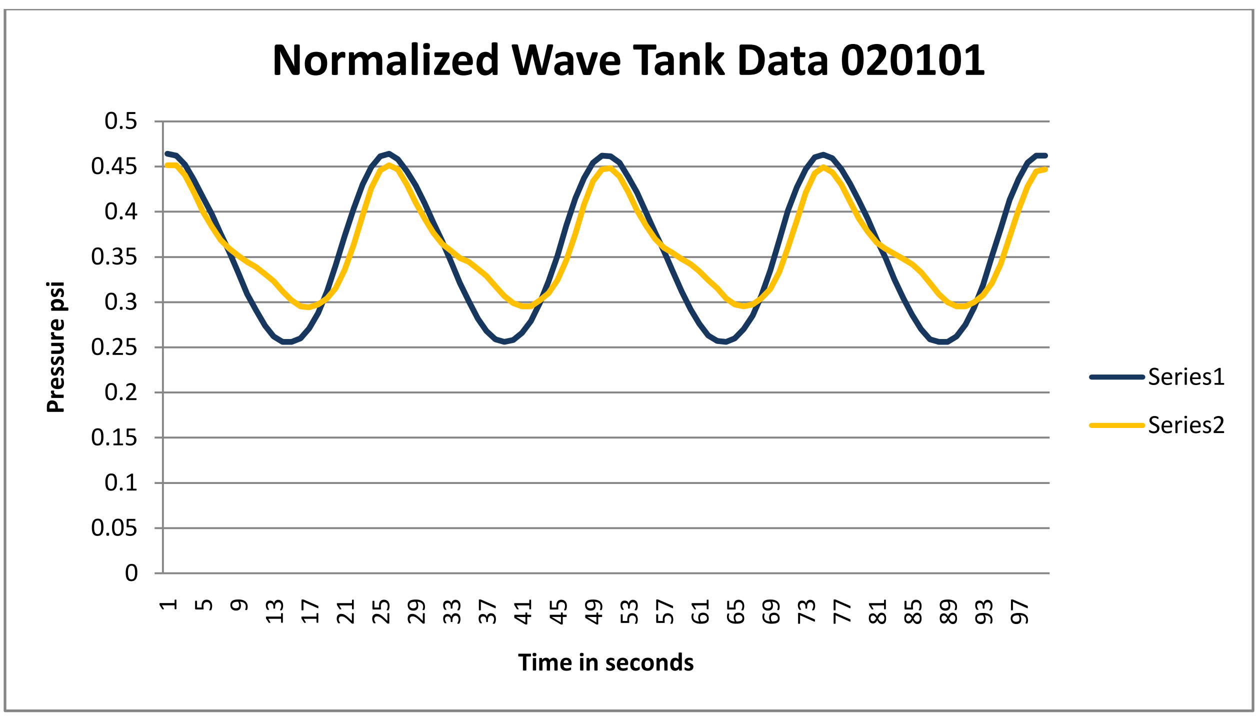

Normalized Wave Tank Data 010202
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2

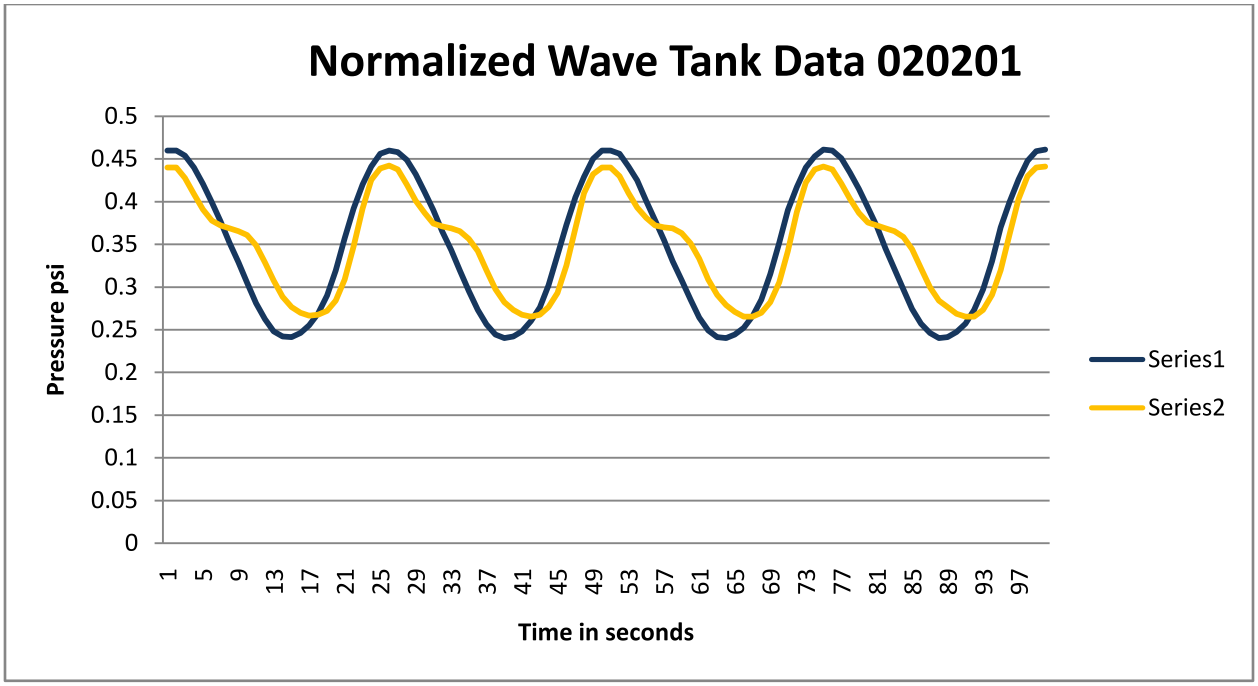

Normalized Wave Tank Data 010302
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 010103
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

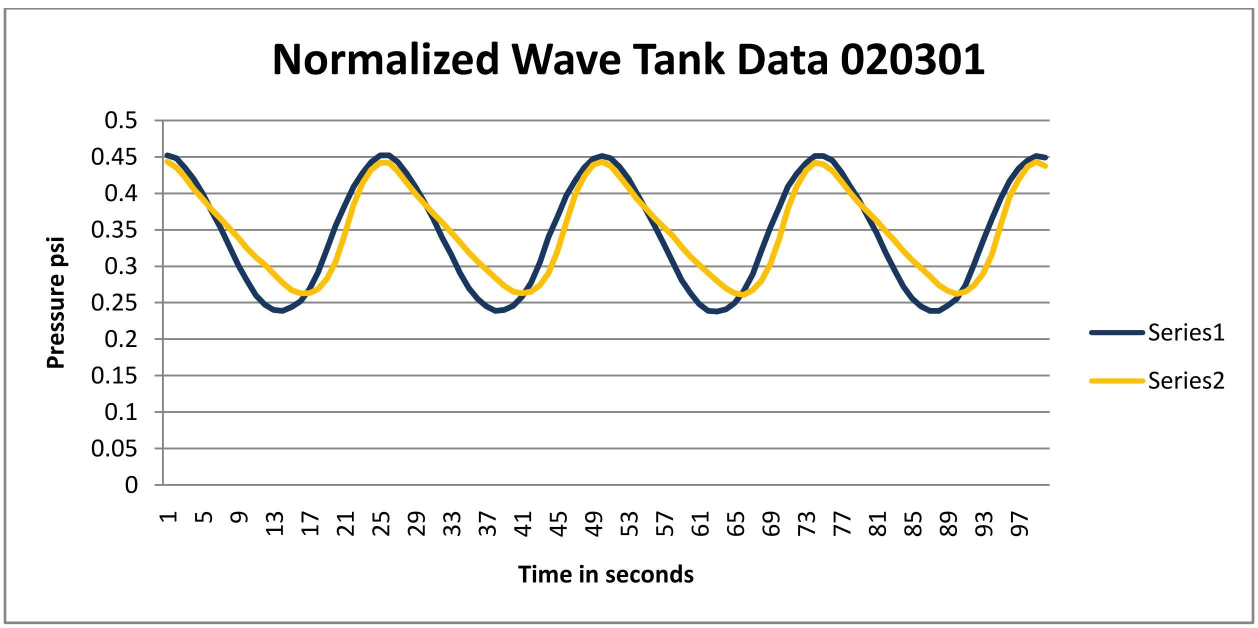

Normalized Wave Tank Data 010203
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82
Time in seconds
Series1
Series2


Normalized Wave Tank Data 010303
Pressure psi
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

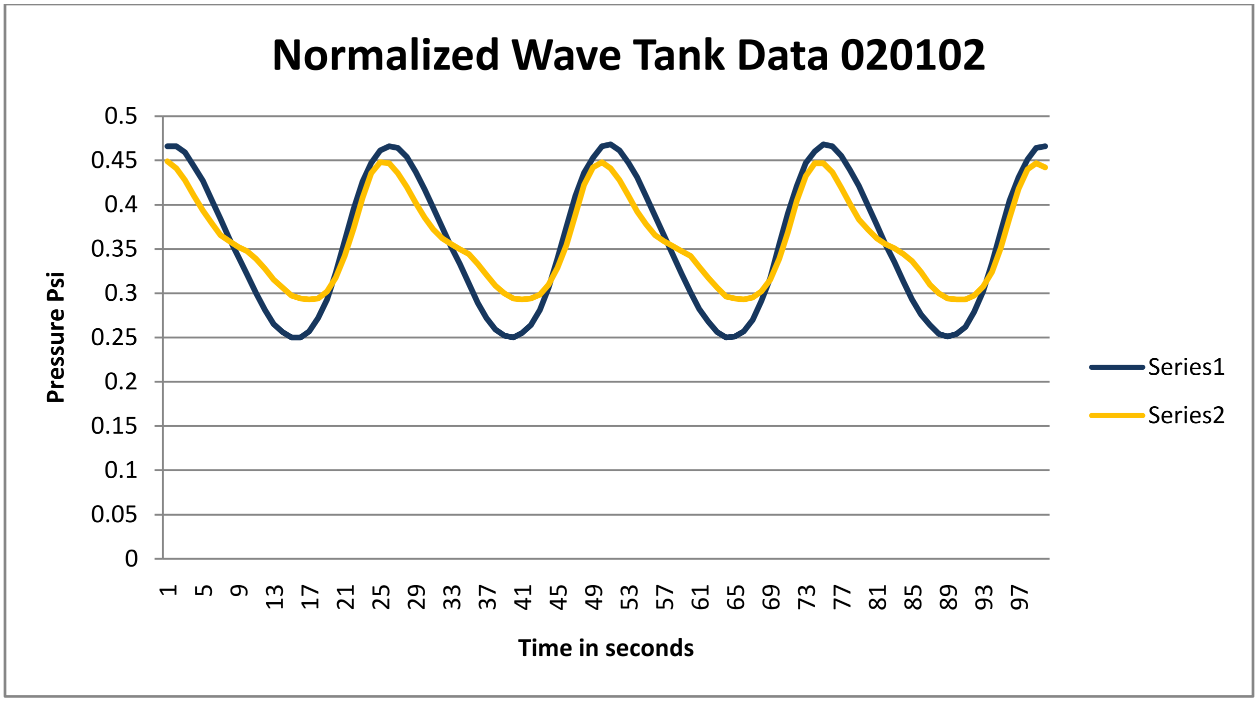

Normalized Wave Tank Data 020101
Pressure psi
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2

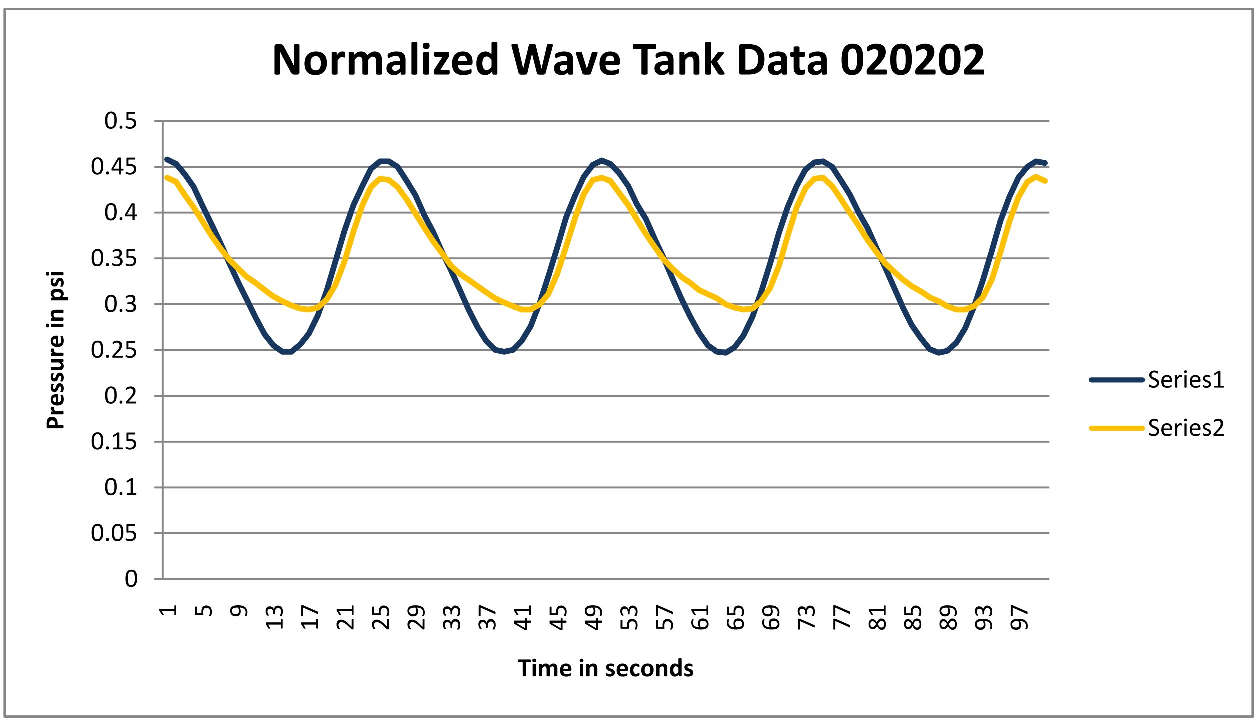


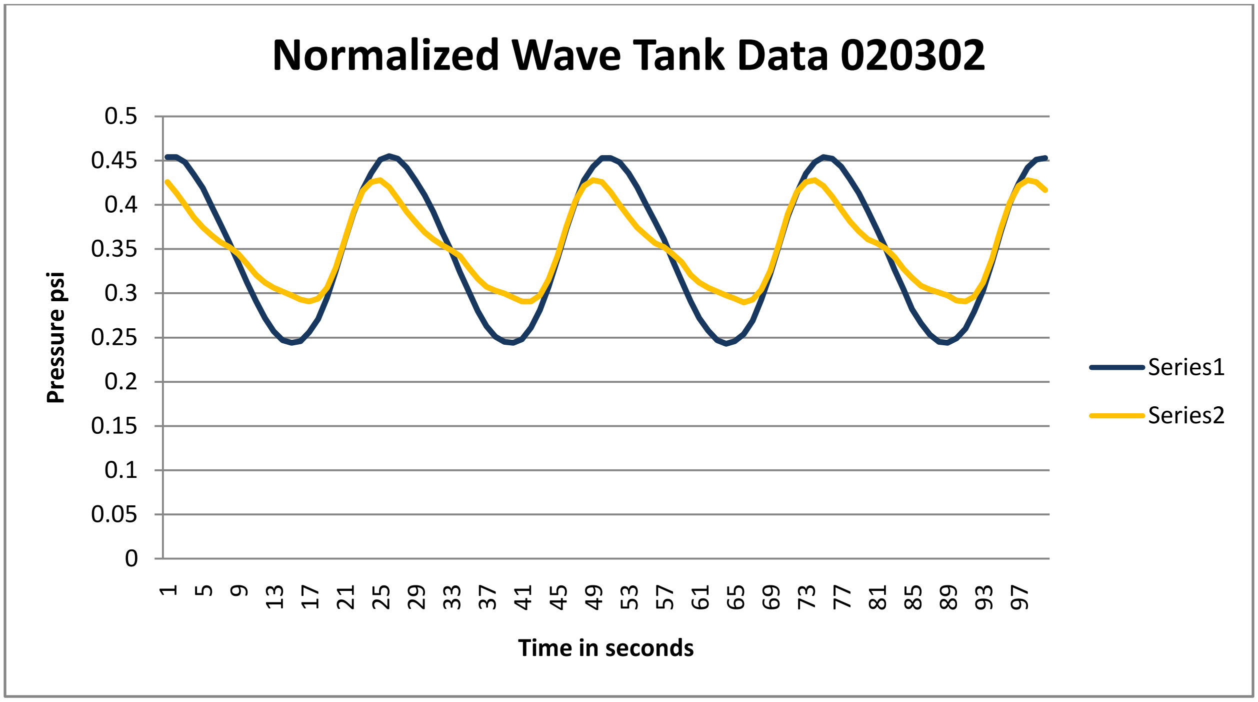
Normalized Wave Tank Data 020201
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2

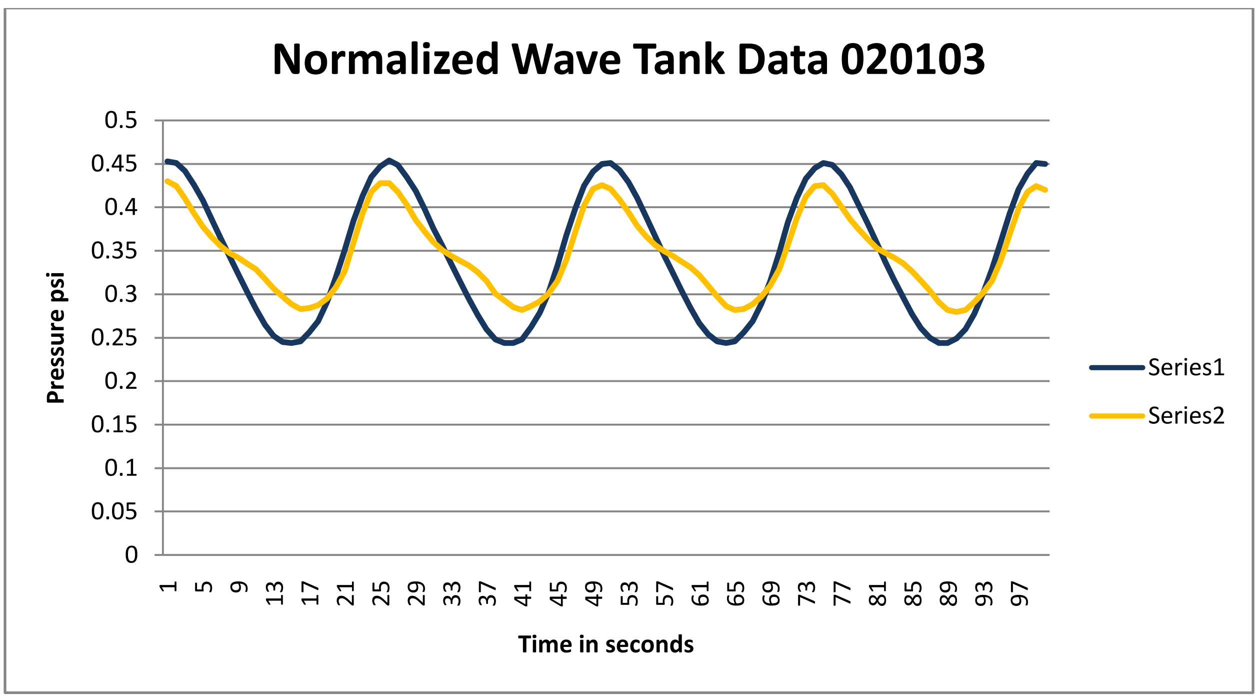


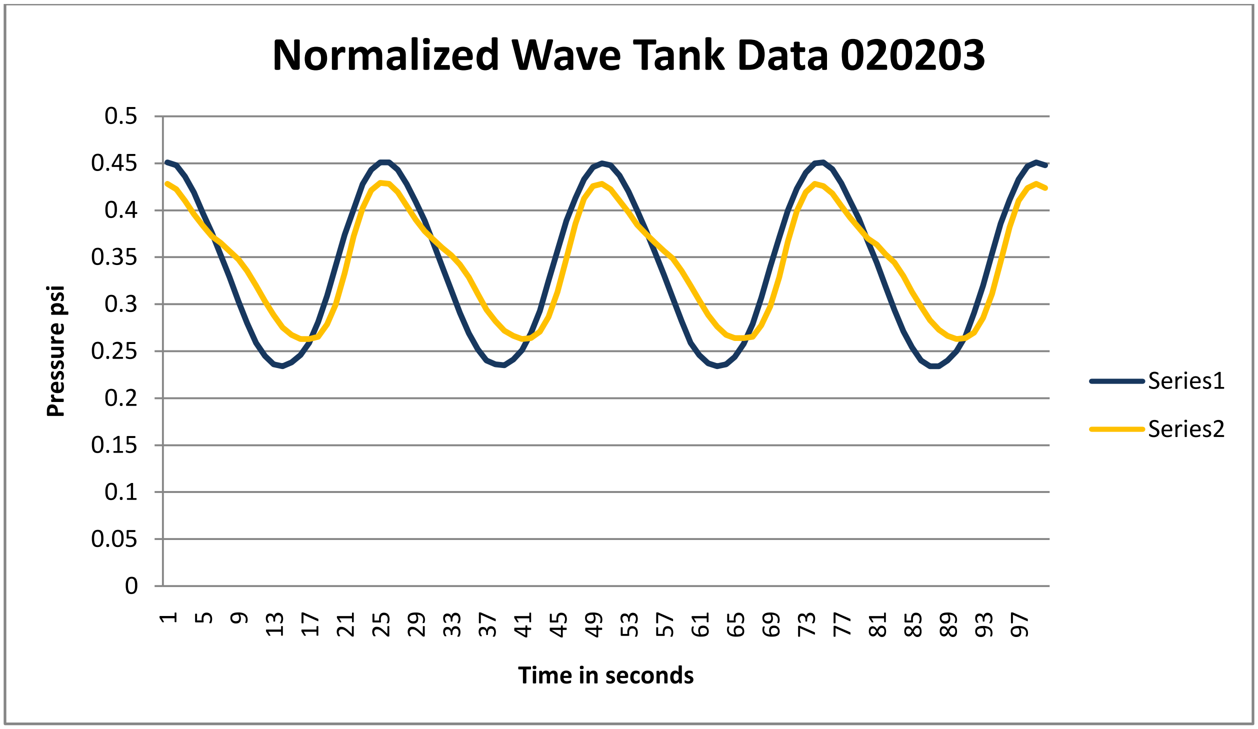
Normalized Wave Tank Data 020301
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2

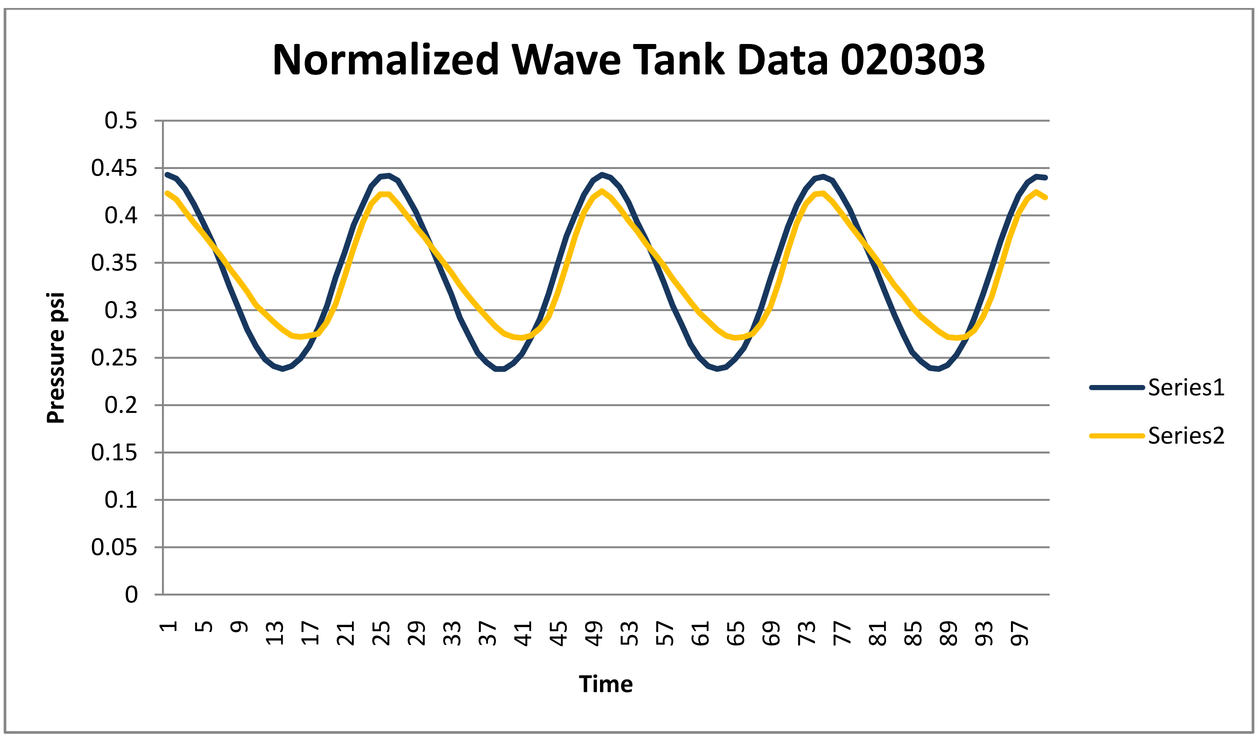

Normalized Wave Tank Data 020102
Pressure Psi
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 020202
Pressure in psi
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 020302
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 020103
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pressure psi
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 020203
Pressure psi
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time in seconds
Series1
Series2


Normalized Wave Tank Data 020303
Pressure psi
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97
Time
Series1
Series2

APPENDIX C. ANOVA ANALYSIS OF VARIANCE IN WATER HYACINTH DATA

This appendix contains analysis of variance in *Eichhornia crassipes* Data. Wave tank energy reduction data, plant size data, and plant sample weight was compared.

ANOVA calculations result in an F statistic which is an indication of the amount of overlap between data distributions. As the F Statistic gets smaller, approaching zero the similarity between the groups tested increases. As the F Statistic gets larger similarities between groups becomes smaller.

$$F = \frac{\text{Experimental Variance} + \text{Error Variance}}{\text{Error Variance}},$$

This is the conceptual basis of the F statistic where error variance is the sampling error within groups of data. An F Chart with tabulated values was used to locate the critical value and if the F is below the critical value then we fail to reject the null hypothesis.

ANOVA: Plant Length of Random Water Hyacinth Sampling of 78 Plants

ANOVA statistical analysis outcomes, test done at 22:47 on 6-APR-2013

H0: U1 = U2 = U3; HA: H0 not true, significant difference in width

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	32.75	2	16.37	2.612
Error	470.1	75	6.268	
Total	502.9	77		

Group A: Number of items= 28
4.00 5.50 6.00 7.00 7.50 7.50 8.00 8.50 8.50 9.00 9.00 9.00 10.2 10.5 10.5 11.0 11.2 11.5 11.5 12.0 12.0 12.0 12.5 12.5 12.5 13.0 13.0 13.0

Mean = 9.95
95% confidence interval for Mean: 9.004 thru 10.89
Standard Deviation = 2.51
Hi = 13.0 Low = 4.00
Median = 10.5
Average Absolute Deviation from Median = 2.07

Group B: Number of items= 25
2.50 5.00 5.50 6.50 7.50 8.00 8.00 8.00 8.00 8.00 8.50 8.50 8.50 8.50 9.00 9.00 9.50 9.50 9.75 10.0 10.0 10.0 10.0 12.0 13.0

Mean = 8.51
95% confidence interval for Mean: 7.513 thru 9.507
Standard Deviation = 2.13
Hi = 13.0 Low = 2.50
Median = 8.50
Average Absolute Deviation from Median = 1.45

Group C: Number of items= 25
3.00 4.00 4.50 5.00 5.00 7.00 7.00 7.50 8.00 8.50 8.50 8.50 9.00 9.50 9.50 10.0 10.0 10.0 11.0 11.0 11.0 12.0 12.0 12.0 14.0

Mean = 8.70
95% confidence interval for Mean: 7.703 thru 9.697

Standard Deviation = 2.82
Hi = 14.0 Low = 3.00
Median = 9.00
Average Absolute Deviation from Median = 2.22

$F(2, 75) = 2.612$, $p>.05$, F table critical value = 3.183

F of $2.612 < 3.183$ so we fail to reject the null hypothesis that there is no significant difference between the plant samples to a probability factor, P, > .05 significance level.

ANOVA: Plant Width of Random Water Hyacinth Sampling of 78 Plants

ANOVA statistical analysis outcomes, test done at 00:26 on 7-APR-2013

H0: U1 = U2 = U3; HA: H0 not true, significant difference in width

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	33.72	2	16.86	1.965
Error	643.4	75	8.578	
Total	677.1	77		

Group A: Number of items= 28
2.50 2.50 2.50 2.75 3.00 3.25 3.50 3.50 3.50 3.50 3.50 4.00 4.25 5.00 5.00 5.00 5.25 5.50 6.00 6.00 6.00 6.00 7.00 7.50 8.00 8.00 10.0 11.0

Mean = 5.12
95% confidence interval for Mean: 4.022 thru 6.228
Standard Deviation = 2.25
Hi = 11.0 Low = 2.50
Median = 5.00
Average Absolute Deviation from Median = 1.75

Group B: Number of items= 25
2.00 3.00 3.50 3.50 4.00 4.25 4.50 4.75 5.00 5.00 6.00 6.00 6.00 7.00 7.00 7.50 7.50 8.00 8.00 8.50 9.50 9.50 10.5 12.0 14.0

Mean = 6.66
95% confidence interval for Mean: 5.493 thru 7.827
Standard Deviation = 2.92
Hi = 14.0 Low = 2.00
Median = 6.00
Average Absolute Deviation from Median = 2.30

Group C: Number of items= 25
1.50 1.50 2.50 3.00 3.00 3.50 4.00 4.00 4.00 4.00 4.50 5.00 5.00 5.00 6.00 7.50 7.50 8.00 8.50 9.00 10.0 10.0 12.0 13.0 14.0

Mean = 6.24
95% confidence interval for Mean: 5.073 thru 7.407
Standard Deviation = 3.54
Hi = 14.0 Low = 1.50

Median = 5.00
Average Absolute Deviation from Median = 2.80

$F(2, 75) = 1.965$, $p<.05$, F table critical value = 3.183

F of $1.965 < 3.183$, so we fail to reject the null hypothesis. There is no significant difference in the mean diameters between the plant samples to a probability factor, P, $>.05$ significance level.

ANOVA: Plant Mass of Random Water Hyacinth Sampling of 19 Plants

ANOVA statistical analysis outcomes, test done at 23:58 on 6-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	380.4	2	190.2	1.4424E-02
Error	2.1097E+05	16	1.3186E+04	
Total	2.1135E+05	18		

Group A: Number of items= 6
158. 234. 244. 336. 405. 438.

Mean = 302.
95% confidence interval for Mean: 203.1 thru 401.8
Standard Deviation = 108.
Hi = 438. Low = 158.
Median = 290.
Average Absolute Deviation from Median = 90.3

Group B: Number of items= 7
126. 233. 239. 279. 336. 356. 492.

Mean = 295.
95% confidence interval for Mean: 202.5 thru 386.5
Standard Deviation = 116.
Hi = 492. Low = 126.
Median = 279.
Average Absolute Deviation from Median = 83.7

Group C: Number of items= 6
153. 211. 235. 372. 414. 443.

Mean = 305.
95% confidence interval for Mean: 205.4 thru 404.1
Standard Deviation = 120.
Hi = 443. Low = 153.
Median = 303.
Average Absolute Deviation from Median = 105.

$F(2, 16) = 1.4424E\text{-}02$, $p<.05$, F table critical value = 3.634

F of 1.4424E-02 << 3.183 so we fail to reject the null hypothesis that there is no significant difference between the mass of the plant samples to a probability factor, $P > .05$ significance level so there is no significant difference between the mass of the plant samples.

APPENDIX D. WATER HYACINTH WAVE ENERGY REDUCTION TRANSDUCER ANALYSIS

This appendix contains analysis of variance data for analysis of base line and biomass mitigated wave pressure variations between the three pressure transducers leveled and aligned in series in the wave tank for readings as pictured below. Differences between sensors showed inaccuracies in base line readings that were corrected with mathematical normalization factors computed from division of sums. Variations after normalization of wave test runs with biomass in place show the wave energy attenuation effects of the floating plants biomass as its weight and drag absorb wave energy thereby reducing wave height which is seen as variation in pressures across transducer 2 and 3 which are underneath the mat of vegetation and immediately to the rear of it respectively.

Two pressure transducers were used to measure the change in wave energy as the change in pressure as the water wave moved between them. Two different wave heights and frequencies were used for this test. The first, wave type 1, was a lower energy wave set to a frequency of .5291 hertz and a span of .05 meters +/- .009 meters with a wave height of .0889 meters +/- .009 meters. The second wave, type 2, was a higher energy wave with a frequency of .4258 hertz and a span of .1397 meters +/- .009 meters with a wave height of .135 meters +/- .009 meters. The wave energy data from these sensors was cataloged by a Campbell Scientific data logger model CR 23X which was programmed in CR Basic to record transducer data at a sampling rate of .1 seconds, 10 hertz and take 2048 data collections per wave tank analysis run.

For this ANOVA analysis there are 3 to 4 groups used for all runs Group A represents transducer 1, Group B shows analysis of data from transducer 2, Group C shows analysis of data from transducer 3, and Group D shows analysis of variance in normalized data from transducer 3. Variance in normalized data from transducer 3 is of interest as this data was graphed with data from transducer 1 for analysis of the reduction in wave energy by plant biomass as waves passed from transducer 1 to transducer 3 after passing underneath plant biomass. Variation throughout the data in these ANOVA tables shows statistical analysis of the differences in wave energies induced by the energy attenuating effects of the floating vegetation being analyzed.

Data is ordered sequentially by file name with file name 010101 indicating wave type 1, run number 1, and 1/3 plant biomass used, 010103 would indicate wave type 1, run number 1, and 3/3 plant biomass, the full amount, where total plant biomass is 34.382kg.

ANOVA calculations result in an F statistic which is an indication of the amount of overlap between data distributions. As the F Statistic gets smaller, approaching zero the similarity between the groups tested increases. As the F Statistic gets larger similarities between groups becomes smaller.

$$F = \frac{\text{Experimental Variance + Error Variance}}{\text{Error Variance}},$$

This is the conceptual basis of the F statistic where error variance is the sampling error within groups of data. An F Chart with tabulated values was used to locate the critical value and if the F is below the critical value then we fail to reject the null hypothesis.

Example Heading and Explanation:

ANOVA: 010101

01-wave type 1, Run number 1, 1/3 plant biomass = 010101

ANOVA: Analysis of variance in Baseline data of Wave Type I, Druck Pressure Transducers 1, 2, and 3, of MTS 407

ANOVA statistical analysis outcomes, test done at 23:41 on 7-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	5.6177E-02	2	2.8089E-02	26.70
Error	0.1041	99	1.0519E-03	
Total	0.1603	101		

Assuming the null hypothesis, this result’s probability is lower than .0001.

Group A: Number of items= 34
0.290 0.290 0.292 0.293 0.294 0.299 0.299 0.300 0.305 0.308 0.309 0.317 0.321 0.321 0.331 0.331 0.335 0.336 0.347 0.349 0.351 0.353 0.364 0.365 0.366 0.367 0.376 0.377 0.379 0.380 0.384 0.384 0.385 0.385

Mean = 0.33774
95% confidence interval for Mean: 0.3267 thru 0.3488
Standard Deviation = 3.385E-02
High = 0.3850 Low = 0.2900
Median = 0.3355
Average Absolute Deviation from Median = 2.979E-02

Group B: Number of items= 34
0.306 0.306 0.307 0.308 0.309 0.310 0.314 0.315 0.316 0.321 0.325 0.328 0.330 0.339 0.342 0.347 0.350 0.361 0.362 0.367 0.369 0.373 0.381 0.382 0.385 0.385 0.393 0.395 0.397 0.399 0.401 0.403 0.403 0.403

Mean = 0.35388
95% confidence interval for Mean: 0.3428 thru 0.3649
Standard Deviation = 3.562E-02
High = 0.4030 Low = 0.3060
Median = 0.3555
Average Absolute Deviation from Median = 3.194E-02

Group C: Number of items= 34
0.268 0.269 0.269 0.269 0.269 0.270 0.271 0.271 0.275 0.275 0.276 0.277 0.279 0.281
0.285 0.286 0.287 0.292 0.295 0.300 0.300 0.303 0.309 0.311 0.318 0.320 0.323 0.332
0.335 0.336 0.343 0.345 0.346 0.348

Mean = 0.29803
95% confidence interval for Mean: 0.2870 thru 0.3091
Standard Deviation = 2.722E-02
High = 0.3480 Low = 0.2680
Median = 0.2895
Average Absolute Deviation from Median = 2.291E-02

ANOVA: Analysis of variance in Baseline data of Wave Type II, Druck Pressure Transducers 1, 2, and 3, of MTS 407

ANOVA statistical analysis outcomes, test done at 00:04 on 8-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	6.5611E-02	2	3.2806E-02	10.51
Error	0.7776	249	3.1228E-03	
Total	0.8432	251		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 84
0.219 0.220 0.220 0.221 0.221 0.222 0.222 0.222 0.222 0.223 0.224 0.224 0.225 0.226
0.227 0.228 0.230 0.230 0.232 0.234 0.236 0.236 0.239 0.240 0.241 0.243 0.246 0.246
0.251 0.251 0.256 0.258 0.262 0.265 0.267 0.271 0.275 0.277 0.281 0.288 0.288 0.291
0.295 0.300 0.302 0.305 0.311 0.313 0.315 0.323 0.323 0.327 0.329 0.337 0.337 0.346
0.348 0.349 0.352 0.358 0.361 0.366 0.370 0.371 0.375 0.379 0.384 0.385 0.387 0.393
0.395 0.397 0.399 0.403 0.404 0.407 0.409 0.410 0.412 0.412 0.413 0.415 0.415 0.415

Mean = 0.30413
95% confidence interval for Mean: 0.2921 thru 0.3161
Standard Deviation = 6.920E-02
High = 0.4150 Low = 0.2190
Median = 0.2930
Average Absolute Deviation from Median = 6.127E-02

Group B: Number of items= 84
0.275 0.276 0.276 0.276 0.276 0.277 0.278 0.279 0.279 0.280 0.281 0.281 0.282 0.283
0.283 0.284 0.285 0.285 0.286 0.287 0.288 0.289 0.291 0.291 0.291 0.291 0.293 0.293
0.296 0.296 0.298 0.299 0.299 0.301 0.301 0.303 0.304 0.306 0.307 0.310 0.310 0.313
0.316 0.317 0.318 0.320 0.320 0.322 0.328 0.330 0.330 0.334 0.338 0.338 0.339 0.343
0.346 0.347 0.350 0.352 0.357 0.358 0.363 0.363 0.367 0.367 0.372 0.377 0.378 0.378
0.380 0.384 0.387 0.392 0.393 0.393 0.393 0.397 0.397 0.399 0.399 0.400 0.401 0.401

Mean = 0.32575
95% confidence interval for Mean: 0.3137 thru 0.3378
Standard Deviation = 4.197E-02
High = 0.4010 Low = 0.2750
Median = 0.3145
Average Absolute Deviation from Median = 3.577E-02

Group C: Number of items= 84
0.210 0.211 0.212 0.212 0.212 0.213 0.213 0.214 0.215 0.216 0.216 0.218 0.220 0.220
0.222 0.222 0.224 0.226 0.226 0.229 0.230 0.234 0.234 0.237 0.238 0.239 0.245 0.245
0.251 0.253 0.257 0.259 0.260 0.266 0.268 0.269 0.275 0.281 0.283 0.284 0.287 0.289
0.291 0.296 0.298 0.298 0.303 0.305 0.308 0.309 0.310 0.314 0.315 0.318 0.320 0.322
0.324 0.326 0.328 0.330 0.331 0.334 0.336 0.336 0.339 0.339 0.342 0.343 0.347 0.347
0.349 0.350 0.352 0.354 0.354 0.357 0.358 0.358 0.361 0.361 0.362 0.362 0.362 0.364

Mean = 0.28629
95% confidence interval for Mean: 0.2743 thru 0.2983
Standard Deviation = 5.309E-02
High = 0.3640 Low = 0.2100
Median = 0.2900
Average Absolute Deviation from Median = 4.736E-02

ANOVA: 010101

01-wave type 1, Run number 1, 1/3 plant biomass = 010101

ANOVA statistical analysis outcomes, test done at 18:41 on 8-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1239	3	4.1310E-02	35.03
Error	0.4387	372	1.1794E-03	
Total	0.5627	375		

Assuming the null hypothesis, this result's probability is lower than .0001

Group A: Number of items= 94
0.293 0.293 0.295 0.295 0.295 0.295 0.295 0.295 0.295 0.295 0.296 0.296 0.297 0.298
0.299 0.299 0.299 0.299 0.299 0.300 0.301 0.301 0.302 0.303 0.303 0.304 0.305 0.306
0.306 0.307 0.309 0.310 0.311 0.312 0.313 0.314 0.315 0.316 0.318 0.319 0.320 0.321
0.323 0.323 0.325 0.327 0.329 0.331 0.332 0.335 0.335 0.336 0.337 0.341 0.343 0.345
0.347 0.350 0.351 0.355 0.355 0.355 0.359 0.361 0.363 0.364 0.366 0.367 0.367 0.371
0.372 0.373 0.375 0.377 0.377 0.379 0.382 0.382 0.383 0.384 0.385 0.386 0.387 0.387
0.389 0.389 0.390 0.391 0.391 0.391 0.391 0.391 0.391 0.393

Mean = 0.33695
95% confidence interval for Mean: 0.3300 thru 0.3439
Standard Deviation = 3.511E-02
High = 0.3930 Low = 0.2930
Median = 0.3300
Average Absolute Deviation from Median = 3.118E-02

Group B: Number of items= 94
0.301 0.301 0.301 0.301 0.301 0.303 0.303 0.303 0.304 0.304 0.305 0.306 0.306 0.308
0.308 0.310 0.310 0.311 0.312 0.313 0.314 0.315 0.317 0.318 0.318 0.320 0.322 0.323
0.326 0.326 0.327 0.330 0.331 0.331 0.332 0.332 0.336 0.336 0.339 0.342 0.342 0.345
0.345 0.348 0.348 0.352 0.354 0.355 0.357 0.360 0.360 0.361 0.365 0.367 0.369 0.373
0.373 0.378 0.379 0.379 0.380 0.382 0.385 0.387 0.391 0.391 0.395 0.395 0.396 0.399
0.402 0.402 0.403 0.405 0.406 0.408 0.409 0.409 0.411 0.413 0.414 0.415 0.415 0.417
0.417 0.419 0.419 0.419 0.419 0.421 0.421 0.421 0.421 0.421

Mean = 0.35834
95% confidence interval for Mean: 0.3514 thru 0.3653
Standard Deviation = 4.211E-02
High = 0.4210 Low = 0.3010
Median = 0.3545
Average Absolute Deviation from Median = 3.749E-02

Group C: Number of items= 94
0.275 0.276 0.276 0.276 0.276 0.277 0.277 0.277 0.277 0.277 0.277 0.277 0.277 0.278
0.279 0.279 0.280 0.280 0.280 0.281 0.281 0.281 0.283 0.283 0.283 0.284 0.284 0.285
0.285 0.285 0.285 0.285 0.287 0.288 0.288 0.289 0.289 0.290 0.291 0.291 0.292 0.294
0.294 0.295 0.295 0.297 0.297 0.298 0.300 0.301 0.303 0.305 0.305 0.306 0.308 0.309
0.310 0.313 0.315 0.318 0.320 0.320 0.320 0.324 0.324 0.327 0.328 0.329 0.331 0.334
0.334 0.334 0.338 0.338 0.340 0.342 0.343 0.346 0.346 0.346 0.347 0.348 0.350 0.350
0.350 0.352 0.353 0.353 0.353 0.354 0.354 0.355 0.355 0.355

Mean = 0.30763
95% confidence interval for Mean: 0.3007 thru 0.3146
Standard Deviation = 2.777E-02
High = 0.3550 Low = 0.2750
Median = 0.2975
Average Absolute Deviation from Median = 2.395E-02

Group D: Number of items= 94
0.304 0.305 0.305 0.305 0.305 0.306 0.306 0.306 0.306 0.306 0.306 0.306 0.306 0.307
0.308 0.308 0.309 0.309 0.309 0.310 0.310 0.310 0.313 0.313 0.313 0.314 0.314 0.315
0.315 0.315 0.315 0.315 0.317 0.318 0.318 0.319 0.319 0.320 0.321 0.321 0.322 0.325
0.325 0.326 0.326 0.328 0.328 0.329 0.331 0.332 0.335 0.337 0.337 0.338 0.340 0.341
0.342 0.346 0.348 0.351 0.353 0.353 0.353 0.358 0.358 0.361 0.362 0.363 0.366 0.369
0.369 0.369 0.373 0.373 0.375 0.378 0.379 0.382 0.382 0.382 0.383 0.384 0.387 0.387
0.387 0.389 0.390 0.390 0.390 0.391 0.391 0.392 0.392 0.392

Mean = 0.33973
95% confidence interval for Mean: 0.3328 thru 0.3467
Standard Deviation = 3.067E-02
High = 0.3920 Low = 0.3037
Median = 0.3285
Average Absolute Deviation from Median = 2.645E-02

ANOVA: 010201

ANOVA statistical analysis outcomes, test done at 18:47 on 8-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1274	3	4.2479E-02	33.44
Error	0.4725	372	1.2703E-03	
Total	0.6000	375		

Assuming the null hypothesis, this result’s probability is lower than .0001

Group A: Number of items= 94
0.293 0.293 0.293 0.293 0.293 0.293 0.294 0.294 0.294 0.295 0.295 0.295 0.295 0.295
0.296 0.298 0.299 0.299 0.299 0.300 0.300 0.300 0.301 0.301 0.301 0.302 0.303 0.303
0.305 0.305 0.306 0.309 0.309 0.311 0.311 0.312 0.313 0.314 0.315 0.317 0.319 0.319
0.323 0.323 0.325 0.327 0.327 0.329 0.331 0.331 0.333 0.337 0.337 0.339 0.341 0.343
0.346 0.346 0.347 0.350 0.351 0.353 0.355 0.359 0.360 0.361 0.364 0.365 0.366 0.368
0.369 0.369 0.373 0.373 0.375 0.376 0.379 0.379 0.379 0.382 0.382 0.382 0.384 0.385
0.386 0.386 0.387 0.387 0.387 0.389 0.389 0.389 0.389 0.389

Mean = 0.33494
95% confidence interval for Mean: 0.3277 thru 0.3422
Standard Deviation = 3.442E-02
High = 0.3890 Low = 0.2930
Median = 0.3280
Average Absolute Deviation from Median = 3.053E-02

Group B: Number of items= 94
0.294 0.295 0.295 0.295 0.295 0.296 0.296 0.297 0.297 0.297 0.299 0.300 0.301 0.301
0.301 0.304 0.305 0.307 0.308 0.308 0.309 0.310 0.313 0.313 0.315 0.318 0.318 0.320
0.322 0.323 0.326 0.326 0.328 0.328 0.331 0.331 0.334 0.334 0.337 0.339 0.340 0.344
0.344 0.345 0.348 0.352 0.352 0.352 0.356 0.359 0.360 0.362 0.365 0.366 0.369 0.373
0.373 0.379 0.379 0.379 0.380 0.384 0.386 0.388 0.393 0.393 0.397 0.397 0.398 0.401
0.403 0.404 0.405 0.409 0.409 0.412 0.412 0.413 0.415 0.416 0.418 0.419 0.419 0.420
0.421 0.421 0.422 0.423 0.424 0.424 0.425 0.426 0.426 0.426

Mean = 0.35736
95% confidence interval for Mean: 0.3501 thru 0.3646
Standard Deviation = 4.566E-02
High = 0.4260 Low = 0.2940
Median = 0.3520
Average Absolute Deviation from Median = 4.053E-02

Group C: Number of items= 94
0.269 0.270 0.270 0.271 0.271 0.271 0.271 0.271 0.272 0.272 0.273 0.273 0.273 0.273
0.273 0.275 0.275 0.276 0.276 0.276 0.277 0.277 0.277 0.278 0.281 0.281 0.281 0.281
0.283 0.283 0.284 0.286 0.287 0.288 0.289 0.289 0.291 0.291 0.292 0.294 0.295 0.296
0.297 0.297 0.298 0.299 0.301 0.303 0.303 0.303 0.304 0.305 0.307 0.308 0.308 0.308
0.310 0.311 0.312 0.313 0.316 0.316 0.317 0.319 0.322 0.322 0.324 0.327 0.328 0.328
0.329 0.332 0.332 0.337 0.337 0.340 0.340 0.344 0.344 0.345 0.345 0.347 0.348 0.350
0.351 0.351 0.352 0.354 0.354 0.354 0.355 0.355 0.355 0.356

Mean = 0.30580
95% confidence interval for Mean: 0.2986 thru 0.3130
Standard Deviation = 2.857E-02
High = 0.3560 Low = 0.2690
Median = 0.3020
Average Absolute Deviation from Median = 2.444E-02

Group D: Number of items= 94
0.297 0.298 0.298 0.299 0.299 0.299 0.299 0.299 0.300 0.300 0.301 0.301 0.301 0.301
0.301 0.304 0.304 0.305 0.305 0.305 0.306 0.306 0.306 0.307 0.310 0.310 0.310 0.310
0.313 0.313 0.314 0.316 0.317 0.318 0.319 0.319 0.321 0.321 0.322 0.325 0.326 0.327
0.328 0.328 0.329 0.330 0.332 0.335 0.335 0.335 0.336 0.337 0.339 0.340 0.340 0.340
0.342 0.343 0.345 0.346 0.349 0.349 0.350 0.352 0.356 0.356 0.358 0.361 0.362 0.362
0.363 0.367 0.367 0.372 0.372 0.375 0.375 0.380 0.380 0.381 0.381 0.383 0.384 0.387
0.388 0.388 0.389 0.391 0.391 0.391 0.392 0.392 0.392 0.393

Mean = 0.33770
95% confidence interval for Mean: 0.3305 thru 0.3449
Standard Deviation = 3.155E-02
High = 0.3931 Low = 0.2971
Median = 0.3335
Average Absolute Deviation from Median = 2.699E-02

ANOVA: 010301

ANOVA statistical analysis outcomes, test done at 14:03 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1198	3	3.9921E-02	37.32
Error	0.3980	372	1.0698E-03	
Total	0.5177	375		

Assuming the null hypothesis, this result’s probability is lower than .0001.

Group A: Number of items= 94
0.291 0.292 0.292 0.292 0.293 0.293 0.293 0.293 0.293 0.294 0.295 0.295 0.295 0.295
0.296 0.297 0.299 0.299 0.299 0.300 0.300 0.301 0.301 0.302 0.304 0.304 0.306 0.307
0.308 0.309 0.310 0.311 0.313 0.313 0.316 0.317 0.319 0.321 0.321 0.323 0.324 0.324
0.326 0.327 0.330 0.333 0.334 0.334 0.337 0.338 0.341 0.342 0.342 0.345 0.345 0.348
0.349 0.351 0.353 0.354 0.356 0.357 0.358 0.359 0.362 0.364 0.364 0.367 0.367 0.369
0.370 0.373 0.374 0.374 0.376 0.376 0.377 0.379 0.380 0.382 0.383 0.384 0.384 0.385
0.385 0.385 0.386 0.387 0.387 0.388 0.389 0.389 0.389 0.389

Mean = 0.33695
95% confidence interval for Mean: 0.3303 thru 0.3436
Standard Deviation = 3.426E-02
High = 0.3890 Low = 0.2910
Median = 0.3340
Average Absolute Deviation from Median = 3.056E-02

Group B: Number of items= 94
0.304 0.304 0.304 0.304 0.304 0.305 0.305 0.306 0.306 0.307 0.307 0.308 0.308 0.308
0.308 0.310 0.310 0.311 0.312 0.312 0.314 0.315 0.316 0.317 0.318 0.319 0.320 0.321
0.321 0.324 0.325 0.326 0.326 0.328 0.330 0.330 0.333 0.333 0.336 0.336 0.339 0.339
0.339 0.342 0.344 0.344 0.346 0.347 0.350 0.350 0.352 0.355 0.356 0.360 0.360 0.360
0.363 0.366 0.366 0.369 0.371 0.373 0.376 0.377 0.379 0.381 0.382 0.382 0.385 0.386
0.389 0.391 0.391 0.394 0.395 0.397 0.397 0.399 0.399 0.402 0.403 0.405 0.405 0.407
0.407 0.408 0.409 0.409 0.409 0.410 0.410 0.411 0.411 0.411

Mean = 0.35254
95% confidence interval for Mean: 0.3459 thru 0.3592
Standard Deviation = 3.728E-02
High = 0.4110 Low = 0.3040
Median = 0.3465
Average Absolute Deviation from Median = 3.288E-02

Group C: Number of items= 94
0.268 0.269 0.269 0.269 0.269 0.269 0.269 0.269 0.269 0.270 0.271 0.271 0.271 0.272
0.273 0.273 0.273 0.273 0.275 0.275 0.276 0.277 0.277 0.277 0.278 0.279 0.280 0.281
0.281 0.282 0.283 0.284 0.284 0.285 0.286 0.287 0.289 0.289 0.290 0.291 0.291 0.292
0.292 0.294 0.295 0.297 0.298 0.299 0.299 0.300 0.302 0.303 0.305 0.307 0.307 0.307
0.308 0.310 0.310 0.313 0.315 0.316 0.318 0.318 0.319 0.321 0.323 0.324 0.324 0.326
0.328 0.328 0.330 0.332 0.333 0.336 0.336 0.338 0.339 0.339 0.340 0.342 0.343 0.345
0.346 0.348 0.349 0.350 0.350 0.351 0.352 0.352 0.352 0.354

Mean = 0.30339
95% confidence interval for Mean: 0.2968 thru 0.3100
Standard Deviation = 2.780E-02
High = 0.3540 Low = 0.2680
Median = 0.2985
Average Absolute Deviation from Median = 2.399E-02

Group D: Number of items= 94
0.296 0.297 0.297 0.297 0.297 0.297 0.297 0.297 0.297 0.298 0.299 0.299 0.299 0.300
0.301 0.301 0.301 0.301 0.304 0.304 0.305 0.306 0.306 0.306 0.307 0.308 0.309 0.310
0.310 0.311 0.313 0.314 0.314 0.315 0.316 0.317 0.319 0.319 0.320 0.321 0.321 0.322
0.322 0.325 0.326 0.328 0.329 0.330 0.330 0.331 0.334 0.335 0.337 0.339 0.339 0.339
0.340 0.342 0.342 0.346 0.348 0.349 0.351 0.351 0.352 0.354 0.357 0.358 0.358 0.360
0.362 0.362 0.364 0.367 0.368 0.371 0.371 0.373 0.374 0.374 0.375 0.378 0.379 0.381
0.382 0.384 0.385 0.387 0.387 0.388 0.389 0.389 0.389 0.391

Mean = 0.33505
95% confidence interval for Mean: 0.3284 thru 0.3417
Standard Deviation = 3.070E-02
High = 0.3909 Low = 0.2960
Median = 0.3296
Average Absolute Deviation from Median = 2.649E-02

ANOVA: 010102

ANOVA statistical analysis outcomes, test done at 14:17 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1133	3	3.7775E-02	35.06
Error	0.4009	372	1.0776E-03	
Total	0.5142	375		

Assuming the null hypothesis, this result's probability is lower than .0001

Group A: Number of items= 94
0.323 0.323 0.323 0.323 0.324 0.324 0.325 0.325 0.325 0.325 0.325 0.325 0.325 0.325
0.326 0.326 0.326 0.327 0.327 0.327 0.328 0.329 0.329 0.331 0.331 0.331 0.332 0.334
0.334 0.335 0.336 0.337 0.339 0.339 0.341 0.342 0.344 0.345 0.347 0.347 0.349 0.351
0.353 0.355 0.356 0.358 0.361 0.361 0.363 0.365 0.366 0.369 0.370 0.374 0.375 0.379
0.379 0.379 0.384 0.384 0.387 0.388 0.388 0.392 0.393 0.396 0.396 0.397 0.400 0.400
0.404 0.405 0.405 0.408 0.409 0.411 0.411 0.411 0.414 0.414 0.416 0.417 0.417 0.419
0.419 0.419 0.420 0.420 0.421 0.421 0.422 0.422 0.423 0.423

Mean = 0.36669
95% confidence interval for Mean: 0.3600 thru 0.3733
Standard Deviation = 3.615E-02
High = 0.4230 Low = 0.3230
Median = 0.3610
Average Absolute Deviation from Median = 3.237E-02

Group B: Number of items= 94
0.340 0.340 0.340 0.340 0.341 0.342 0.342 0.342 0.342 0.342 0.343 0.344 0.344 0.344
0.345 0.346 0.347 0.347 0.348 0.348 0.350 0.350 0.350 0.352 0.352 0.354 0.355 0.356
0.356 0.357 0.358 0.360 0.360 0.360 0.362 0.364 0.364 0.365 0.366 0.369 0.369 0.370
0.372 0.372 0.373 0.375 0.377 0.377 0.378 0.379 0.382 0.382 0.383 0.385 0.387 0.387
0.390 0.392 0.392 0.393 0.395 0.397 0.397 0.398 0.401 0.402 0.405 0.406 0.407 0.410
0.411 0.413 0.414 0.414 0.417 0.418 0.419 0.421 0.423 0.424 0.426 0.427 0.428 0.428
0.429 0.430 0.431 0.432 0.433 0.433 0.433 0.434 0.434 0.434

Mean = 0.38155
95% confidence interval for Mean: 0.3749 thru 0.3882
Standard Deviation = 3.174E-02
High = 0.4340 Low = 0.3400
Median = 0.3770
Average Absolute Deviation from Median = 2.762E-02

Group C: Number of items= 94
0.299 0.299 0.299 0.299 0.299 0.299 0.299 0.299 0.299 0.300 0.301 0.301 0.301 0.301
0.301 0.302 0.303 0.303 0.304 0.304 0.305 0.305 0.306 0.307 0.307 0.308 0.308 0.308
0.309 0.310 0.311 0.313 0.313 0.313 0.315 0.316 0.316 0.318 0.319 0.319 0.320 0.320
0.322 0.322 0.324 0.326 0.328 0.328 0.329 0.331 0.331 0.334 0.334 0.334 0.337 0.338
0.340 0.342 0.345 0.346 0.348 0.349 0.351 0.352 0.353 0.354 0.356 0.359 0.361 0.362
0.364 0.366 0.367 0.368 0.368 0.370 0.372 0.373 0.375 0.375 0.377 0.378 0.380 0.380
0.380 0.381 0.382 0.382 0.383 0.384 0.384 0.384 0.384 0.384

Mean = 0.33463
95% confidence interval for Mean: 0.3280 thru 0.3413
Standard Deviation = 2.999E-02
High = 0.3840 Low = 0.2990
Median = 0.3280
Average Absolute Deviation from Median = 2.612E-02

Group D: Number of items= 94
0.330 0.330 0.330 0.330 0.330 0.330 0.330 0.330 0.330 0.331 0.332 0.332 0.332 0.332
0.332 0.334 0.335 0.335 0.336 0.336 0.337 0.337 0.338 0.339 0.339 0.340 0.340 0.340
0.341 0.342 0.343 0.346 0.346 0.346 0.348 0.349 0.349 0.351 0.352 0.352 0.353 0.353
0.356 0.356 0.358 0.360 0.362 0.362 0.363 0.366 0.366 0.369 0.369 0.369 0.372 0.373
0.375 0.378 0.381 0.382 0.384 0.385 0.388 0.389 0.390 0.391 0.393 0.396 0.399 0.400
0.402 0.404 0.405 0.406 0.406 0.409 0.411 0.412 0.414 0.414 0.416 0.417 0.420 0.420
0.420 0.421 0.422 0.422 0.423 0.424 0.424 0.424 0.424 0.424

Mean = 0.36954
95% confidence interval for Mean: 0.3629 thru 0.3762
Standard Deviation = 3.311E-02
High = 0.4241 Low = 0.3302
Median = 0.3622
Average Absolute Deviation from Median = 2.884E-02

ANOVA: 010202

ANOVA statistical analysis outcomes, test done at 14:28 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1090	3	3.6333E-02	30.34
Error	0.4455	372	1.1975E-03	
Total	0.5545	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.315 0.315 0.315 0.315 0.315 0.316 0.316 0.316 0.317 0.317 0.317 0.317 0.318 0.318
0.319 0.321 0.321 0.321 0.321 0.322 0.323 0.323 0.325 0.325 0.326 0.327 0.329 0.329
0.331 0.332 0.333 0.334 0.336 0.336 0.337 0.339 0.339 0.342 0.343 0.345 0.345 0.346
0.348 0.351 0.351 0.354 0.355 0.357 0.358 0.358 0.361 0.363 0.365 0.367 0.369 0.371
0.372 0.373 0.376 0.376 0.380 0.381 0.383 0.385 0.387 0.389 0.389 0.391 0.393 0.396
0.398 0.399 0.400 0.401 0.401 0.402 0.403 0.405 0.407 0.407 0.408 0.409 0.410 0.410
0.411 0.411 0.412 0.413 0.413 0.414 0.415 0.415 0.416 0.416

Mean = 0.36055
95% confidence interval for Mean: 0.3535 thru 0.3676
Standard Deviation = 3.561E-02
High = 0.4160 Low = 0.3150
Median = 0.3560
Average Absolute Deviation from Median = 3.170E-02

Group B: Number of items= 94
0.330 0.330 0.331 0.331 0.331 0.331 0.331 0.331 0.331 0.332 0.334 0.334 0.334 0.334
0.334 0.335 0.336 0.337 0.337 0.338 0.339 0.339 0.340 0.340 0.342 0.342 0.344 0.345
0.346 0.347 0.348 0.348 0.348 0.351 0.352 0.354 0.355 0.357 0.357 0.358 0.362 0.362
0.365 0.366 0.366 0.367 0.369 0.371 0.371 0.374 0.377 0.377 0.380 0.381 0.383 0.385
0.387 0.388 0.389 0.391 0.393 0.395 0.395 0.398 0.399 0.402 0.404 0.405 0.408 0.409
0.409 0.409 0.412 0.413 0.415 0.417 0.417 0.421 0.421 0.423 0.425 0.426 0.428 0.428
0.430 0.430 0.432 0.432 0.433 0.433 0.434 0.434 0.435 0.435

Mean = 0.37580
95% confidence interval for Mean: 0.3688 thru 0.3828
Standard Deviation = 3.601E-02
High = 0.4350 Low = 0.3300
Median = 0.3700
Average Absolute Deviation from Median = 3.173E-02

Group C: Number of items= 94
0.293 0.293 0.293 0.293 0.293 0.293 0.293 0.293 0.293 0.293 0.294 0.295 0.295 0.295
0.296 0.296 0.296 0.296 0.297 0.298 0.299 0.299 0.300 0.300 0.300 0.301 0.303 0.304
0.304 0.304 0.305 0.305 0.306 0.307 0.308 0.310 0.310 0.311 0.312 0.312 0.313 0.315
0.316 0.317 0.317 0.319 0.320 0.321 0.324 0.325 0.326 0.328 0.328 0.332 0.332 0.332
0.334 0.337 0.337 0.340 0.342 0.344 0.347 0.347 0.350 0.351 0.352 0.355 0.356 0.358
0.360 0.362 0.364 0.365 0.368 0.368 0.369 0.371 0.372 0.374 0.374 0.377 0.377 0.378
0.379 0.379 0.380 0.380 0.382 0.382 0.382 0.382 0.383 0.383

Mean = 0.32972
95% confidence interval for Mean: 0.3227 thru 0.3367
Standard Deviation = 3.166E-02
High = 0.3830 Low = 0.2930
Median = 0.3205
Average Absolute Deviation from Median = 2.749E-02

Group D: Number of items= 94
0.324 0.324 0.324 0.324 0.324 0.324 0.324 0.324 0.324 0.324 0.325 0.326 0.326 0.326
0.327 0.327 0.327 0.327 0.328 0.329 0.330 0.330 0.331 0.331 0.331 0.332 0.335 0.336
0.336 0.336 0.337 0.337 0.338 0.339 0.340 0.342 0.342 0.343 0.345 0.345 0.346 0.348
0.349 0.350 0.350 0.352 0.353 0.354 0.358 0.359 0.360 0.362 0.362 0.367 0.367 0.367
0.369 0.372 0.372 0.375 0.378 0.380 0.383 0.383 0.387 0.388 0.389 0.392 0.393 0.395
0.398 0.400 0.402 0.403 0.406 0.406 0.408 0.410 0.411 0.413 0.413 0.416 0.416 0.417
0.419 0.419 0.420 0.420 0.422 0.422 0.422 0.422 0.423 0.423

Mean = 0.36413
95% confidence interval for Mean: 0.3571 thru 0.3711
Standard Deviation = 3.497E-02
High = 0.4230 Low = 0.3236
Median = 0.3539
Average Absolute Deviation from Median = 3.036E-02

ANOVA: 010302

ANOVA statistical analysis outcomes, test done at 14:30 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1095	3	3.6504E-02	27.33
Error	0.4969	372	1.3358E-03	
Total	0.6064	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.312 0.312 0.313 0.313 0.313 0.314 0.314 0.314 0.314 0.314 0.314 0.315 0.315 0.315
0.317 0.317 0.317 0.318 0.319 0.319 0.321 0.321 0.322 0.322 0.323 0.324 0.325 0.326
0.329 0.329 0.331 0.331 0.334 0.334 0.335 0.336 0.338 0.339 0.342 0.343 0.344 0.345
0.346 0.347 0.352 0.352 0.355 0.356 0.358 0.358 0.360 0.361 0.364 0.366 0.369 0.369
0.373 0.373 0.374 0.376 0.377 0.379 0.383 0.385 0.387 0.388 0.388 0.391 0.391 0.396
0.396 0.399 0.399 0.399 0.402 0.402 0.402 0.406 0.406 0.407 0.407 0.410 0.410 0.410
0.411 0.411 0.411 0.413 0.414 0.415 0.415 0.415 0.415 0.416

Mean = 0.35913
95% confidence interval for Mean: 0.3517 thru 0.3665
Standard Deviation = 3.662E-02
High = 0.4160 Low = 0.3120
Median = 0.3555
Average Absolute Deviation from Median = 3.264E-02

Group B: Number of items= 94
0.325 0.326 0.326 0.326 0.326 0.326 0.326 0.326 0.326 0.328 0.328 0.328 0.329 0.329
0.331 0.331 0.332 0.332 0.333 0.334 0.336 0.336 0.337 0.339 0.339 0.340 0.340 0.341
0.344 0.344 0.347 0.348 0.349 0.349 0.351 0.352 0.353 0.356 0.358 0.358 0.360 0.360
0.362 0.363 0.366 0.369 0.369 0.372 0.372 0.374 0.375 0.379 0.380 0.381 0.382 0.385
0.385 0.385 0.389 0.392 0.393 0.396 0.397 0.399 0.399 0.403 0.403 0.403 0.405 0.408
0.409 0.412 0.412 0.413 0.416 0.417 0.418 0.421 0.421 0.424 0.426 0.427 0.428 0.428
0.430 0.431 0.433 0.433 0.434 0.434 0.436 0.436 0.436 0.436

Mean = 0.37449
95% confidence interval for Mean: 0.3671 thru 0.3819
Standard Deviation = 3.783E-02
High = 0.4360 Low = 0.3250
Median = 0.3705
Average Absolute Deviation from Median = 3.334E-02

Group C: Number of items= 94
0.285 0.285 0.287 0.287 0.287 0.287 0.288 0.288 0.288 0.288 0.288 0.289 0.290 0.291
0.291 0.291 0.291 0.291 0.293 0.293 0.295 0.295 0.296 0.296 0.297 0.297 0.299 0.299
0.300 0.301 0.302 0.303 0.303 0.304 0.305 0.307 0.308 0.309 0.310 0.310 0.312 0.313
0.313 0.316 0.317 0.317 0.320 0.321 0.324 0.326 0.327 0.328 0.330 0.330 0.332 0.335
0.335 0.338 0.340 0.340 0.344 0.345 0.348 0.350 0.350 0.350 0.354 0.354 0.357 0.359
0.362 0.363 0.364 0.367 0.368 0.368 0.370 0.371 0.374 0.375 0.375 0.378 0.378 0.378
0.379 0.380 0.381 0.382 0.382 0.383 0.384 0.384 0.384 0.384

Mean = 0.32822
95% confidence interval for Mean: 0.3208 thru 0.3356
Standard Deviation = 3.404E-02
High = 0.3840 Low = 0.2850
Median = 0.3205
Average Absolute Deviation from Median = 2.988E-02

Group D: Number of items= 94
0.315 0.315 0.317 0.317 0.317 0.317 0.318 0.318 0.318 0.318 0.318 0.319 0.320 0.321
0.321 0.321 0.321 0.321 0.324 0.324 0.326 0.326 0.327 0.327 0.328 0.328 0.330 0.330
0.331 0.332 0.334 0.335 0.335 0.336 0.337 0.339 0.340 0.341 0.342 0.342 0.345 0.346
0.346 0.349 0.350 0.350 0.353 0.354 0.358 0.360 0.361 0.362 0.364 0.364 0.367 0.370
0.370 0.373 0.375 0.375 0.380 0.381 0.384 0.387 0.387 0.387 0.391 0.391 0.394 0.396
0.400 0.401 0.402 0.405 0.406 0.406 0.409 0.410 0.413 0.414 0.414 0.417 0.417 0.417
0.419 0.420 0.421 0.422 0.422 0.423 0.424 0.424 0.424 0.424

Mean = 0.36247
95% confidence interval for Mean: 0.3551 thru 0.3699
Standard Deviation = 3.759E-02
High = 0.4241 Low = 0.3147
Median = 0.3539
Average Absolute Deviation from Median = 3.300E-02

ANOVA: 010103

ANOVA statistical analysis outcomes, test done at 13:50 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1042	3	3.4722E-02	36.18
Error	0.3570	372	9.5961E-04	
Total	0.4611	375		

Assuming the null hypothesis, this result’s probability is lower than .0001.

Group A: Number of items= 94
0.302 0.303 0.303 0.303 0.303 0.303 0.303 0.303 0.303 0.304 0.304 0.305 0.305 0.305
0.307 0.307 0.307 0.309 0.309 0.309 0.309 0.310 0.311 0.311 0.311 0.313 0.313 0.313
0.315 0.316 0.317 0.319 0.320 0.321 0.321 0.321 0.321 0.323 0.324 0.327 0.328 0.330
0.332 0.333 0.333 0.335 0.335 0.337 0.339 0.341 0.343 0.345 0.348 0.349 0.349 0.352
0.353 0.355 0.357 0.359 0.362 0.363 0.366 0.367 0.367 0.371 0.372 0.373 0.375 0.376
0.379 0.380 0.384 0.384 0.385 0.388 0.389 0.391 0.392 0.395 0.395 0.397 0.397 0.399
0.399 0.401 0.401 0.402 0.403 0.403 0.405 0.405 0.406 0.406

Mean = 0.34536
95% confidence interval for Mean: 0.3391 thru 0.3516
Standard Deviation = 3.577E-02
High = 0.4060 Low = 0.3020
Median = 0.3360
Average Absolute Deviation from Median = 3.134E-02

Group B: Number of items= 94
0.328 0.328 0.328 0.328 0.329 0.330 0.330 0.330 0.330 0.331 0.331 0.331 0.332 0.334
0.334 0.334 0.334 0.336 0.336 0.337 0.338 0.338 0.339 0.339 0.341 0.342 0.342 0.344
0.344 0.345 0.345 0.347 0.348 0.349 0.350 0.352 0.352 0.352 0.352 0.355 0.356 0.358
0.358 0.358 0.361 0.361 0.363 0.364 0.365 0.366 0.367 0.369 0.370 0.371 0.373 0.374
0.375 0.377 0.377 0.379 0.380 0.382 0.382 0.385 0.385 0.386 0.387 0.390 0.390 0.393
0.393 0.395 0.395 0.396 0.398 0.399 0.399 0.401 0.401 0.401 0.403 0.403 0.404 0.405
0.405 0.406 0.406 0.407 0.407 0.407 0.407 0.407 0.407 0.408

Mean = 0.36603
95% confidence interval for Mean: 0.3597 thru 0.3723
Standard Deviation = 2.750E-02
High = 0.4080 Low = 0.3280
Median = 0.3635
Average Absolute Deviation from Median = 2.433E-02

Group C: Number of items= 94
0.283 0.284 0.284 0.284 0.285 0.285 0.285 0.285 0.285 0.285 0.285 0.286 0.286 0.288
0.288 0.288 0.288 0.289 0.290 0.291 0.291 0.292 0.293 0.293 0.294 0.295 0.296 0.296
0.297 0.299 0.299 0.299 0.301 0.302 0.304 0.304 0.304 0.305 0.307 0.308 0.309 0.310
0.311 0.312 0.313 0.314 0.316 0.316 0.317 0.320 0.320 0.320 0.324 0.324 0.327 0.327
0.330 0.331 0.332 0.333 0.334 0.336 0.338 0.340 0.340 0.344 0.344 0.347 0.347 0.347
0.348 0.349 0.351 0.354 0.354 0.354 0.356 0.357 0.357 0.359 0.359 0.360 0.361 0.362
0.362 0.363 0.363 0.363 0.363 0.364 0.364 0.364 0.365 0.365

Mean = 0.32067
95% confidence interval for Mean: 0.3144 thru 0.3270
Standard Deviation = 2.850E-02
High = 0.3650 Low = 0.2830
Median = 0.3160
Average Absolute Deviation from Median = 2.518E-02

Group D: Number of items= 94
0.313 0.314 0.314 0.314 0.315 0.315 0.315 0.315 0.315 0.315 0.315 0.316 0.316 0.318
0.318 0.318 0.318 0.319 0.320 0.321 0.321 0.322 0.324 0.324 0.325 0.326 0.327 0.327
0.328 0.330 0.330 0.330 0.332 0.334 0.336 0.336 0.336 0.337 0.339 0.340 0.341 0.342
0.343 0.345 0.346 0.347 0.349 0.349 0.350 0.353 0.353 0.353 0.358 0.358 0.361 0.361
0.364 0.366 0.367 0.368 0.369 0.371 0.373 0.375 0.375 0.380 0.380 0.383 0.383 0.383
0.384 0.385 0.388 0.391 0.391 0.391 0.393 0.394 0.394 0.396 0.396 0.398 0.399 0.400
0.400 0.401 0.401 0.401 0.401 0.402 0.402 0.402 0.403 0.403

Mean = 0.35413
95% confidence interval for Mean: 0.3478 thru 0.3604
Standard Deviation = 3.147E-02
High = 0.4031 Low = 0.3125
Median = 0.3490
Average Absolute Deviation from Median = 2.781E-02

ANOVA: 010203

ANOVA statistical analysis outcomes, test done at 14:35 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1042	3	3.4741E-02	34.72
Error	0.3722	372	1.0006E-03	
Total	0.4764	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.303 0.303 0.303 0.303 0.305 0.305 0.305 0.305 0.305 0.305 0.306 0.306 0.306 0.307
0.307 0.309 0.309 0.309 0.309 0.309 0.310 0.311 0.311 0.311 0.312 0.313 0.315 0.315
0.315 0.317 0.317 0.320 0.321 0.321 0.321 0.322 0.322 0.323 0.325 0.326 0.329 0.329
0.331 0.332 0.332 0.334 0.335 0.336 0.337 0.341 0.341 0.344 0.345 0.345 0.348 0.349
0.353 0.353 0.354 0.355 0.358 0.360 0.360 0.362 0.364 0.367 0.368 0.371 0.371 0.372
0.375 0.376 0.377 0.379 0.380 0.384 0.384 0.386 0.387 0.389 0.390 0.392 0.393 0.395
0.395 0.397 0.397 0.397 0.398 0.399 0.399 0.399 0.400 0.400

Mean = 0.34373
95% confidence interval for Mean: 0.3373 thru 0.3501
Standard Deviation = 3.332E-02
High = 0.4000 Low = 0.3030
Median = 0.3355
Average Absolute Deviation from Median = 2.907E-02

Group B: Number of items= 94
0.323 0.323 0.324 0.324 0.324 0.324 0.324 0.324 0.324 0.325 0.326 0.326 0.326 0.326
0.327 0.327 0.328 0.328 0.328 0.328 0.330 0.330 0.331 0.332 0.332 0.333 0.334 0.335
0.336 0.338 0.338 0.339 0.339 0.340 0.342 0.344 0.344 0.346 0.348 0.348 0.348 0.351
0.352 0.353 0.356 0.356 0.359 0.360 0.362 0.363 0.366 0.366 0.369 0.370 0.372 0.372
0.375 0.375 0.379 0.379 0.382 0.383 0.385 0.386 0.388 0.389 0.393 0.393 0.395 0.396
0.399 0.399 0.400 0.401 0.403 0.404 0.405 0.406 0.406 0.409 0.409 0.409 0.410 0.411
0.411 0.413 0.413 0.414 0.414 0.414 0.414 0.414 0.414 0.415

Mean = 0.36434
95% confidence interval for Mean: 0.3579 thru 0.3708
Standard Deviation = 3.290E-02
High = 0.4150 Low = 0.3230
Median = 0.3595
Average Absolute Deviation from Median = 2.938E-02

Group C: Number of items= 94
0.281 0.281 0.281 0.281 0.281 0.281 0.282 0.282 0.283 0.283 0.283 0.284 0.284 0.285
0.285 0.285 0.286 0.287 0.287 0.288 0.288 0.289 0.291 0.291 0.292 0.293 0.294 0.294
0.295 0.296 0.297 0.298 0.299 0.300 0.303 0.303 0.305 0.305 0.305 0.307 0.308 0.309
0.309 0.311 0.313 0.315 0.316 0.319 0.319 0.319 0.319 0.322 0.322 0.324 0.326 0.328
0.329 0.331 0.331 0.333 0.333 0.334 0.336 0.337 0.340 0.340 0.343 0.343 0.344 0.346
0.347 0.347 0.348 0.350 0.351 0.352 0.354 0.354 0.355 0.356 0.357 0.358 0.358 0.359
0.360 0.360 0.360 0.361 0.362 0.362 0.362 0.362 0.363 0.363

Mean = 0.31888
95% confidence interval for Mean: 0.3125 thru 0.3253
Standard Deviation = 2.855E-02
High = 0.3630 Low = 0.2810
Median = 0.3175
Average Absolute Deviation from Median = 2.535E-02

Group D: Number of items= 94
0.310 0.310 0.310 0.310 0.310 0.310 0.311 0.311 0.313 0.313 0.313 0.314 0.314 0.315
0.315 0.315 0.316 0.317 0.317 0.318 0.318 0.319 0.321 0.321 0.322 0.324 0.325 0.325
0.326 0.327 0.328 0.329 0.330 0.331 0.335 0.335 0.337 0.337 0.337 0.339 0.340 0.341
0.341 0.343 0.346 0.348 0.349 0.352 0.352 0.352 0.352 0.356 0.356 0.358 0.360 0.362
0.363 0.366 0.366 0.368 0.368 0.369 0.371 0.372 0.375 0.375 0.379 0.379 0.380 0.382
0.383 0.383 0.384 0.387 0.388 0.389 0.391 0.391 0.392 0.393 0.394 0.395 0.395 0.396
0.398 0.398 0.398 0.399 0.400 0.400 0.400 0.400 0.401 0.401

Mean = 0.35215
95% confidence interval for Mean: 0.3457 thru 0.3586
Standard Deviation = 3.153E-02
High = 0.4009 Low = 0.3103
Median = 0.3506
Average Absolute Deviation from Median = 2.800E-02

ANOVA: 010303

ANOVA statistical analysis outcomes, test done at 14:37 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1158	3	3.8616E-02	38.91
Error	0.3692	372	9.9238E-04	
Total	0.4850	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.303 0.303 0.304 0.304 0.304 0.304 0.304 0.304 0.305 0.305 0.305 0.306 0.306 0.307
0.308 0.308 0.309 0.309 0.309 0.310 0.311 0.311 0.311 0.312 0.313 0.314 0.314 0.316
0.317 0.318 0.320 0.320 0.322 0.322 0.323 0.325 0.325 0.328 0.329 0.331 0.332 0.334
0.335 0.335 0.337 0.339 0.342 0.343 0.345 0.347 0.349 0.352 0.353 0.353 0.357 0.357
0.357 0.360 0.362 0.364 0.365 0.369 0.369 0.370 0.373 0.373 0.374 0.377 0.377 0.380
0.381 0.384 0.384 0.384 0.386 0.387 0.388 0.390 0.390 0.393 0.393 0.394 0.395 0.395
0.395 0.396 0.397 0.397 0.397 0.397 0.398 0.398 0.399 0.399

Mean = 0.34677
95% confidence interval for Mean: 0.3404 thru 0.3532
Standard Deviation = 3.427E-02
High = 0.3990 Low = 0.3030
Median = 0.3425
Average Absolute Deviation from Median = 3.074E-02

Group B: Number of items= 94
0.323 0.323 0.323 0.324 0.324 0.324 0.324 0.325 0.325 0.326 0.326 0.326 0.326 0.327
0.328 0.328 0.328 0.330 0.331 0.331 0.332 0.334 0.334 0.334 0.336 0.336 0.337 0.338
0.340 0.340 0.342 0.342 0.344 0.346 0.346 0.347 0.350 0.350 0.352 0.353 0.354 0.355
0.356 0.358 0.359 0.361 0.363 0.363 0.364 0.366 0.367 0.369 0.370 0.371 0.374 0.374
0.377 0.379 0.379 0.380 0.381 0.383 0.383 0.387 0.387 0.389 0.391 0.393 0.393 0.394
0.395 0.395 0.398 0.399 0.401 0.401 0.403 0.403 0.405 0.406 0.407 0.407 0.408 0.409
0.409 0.409 0.410 0.411 0.411 0.411 0.411 0.411 0.411 0.412

Mean = 0.36509
95% confidence interval for Mean: 0.3587 thru 0.3715
Standard Deviation = 3.111E-02
High = 0.4120 Low = 0.3230
Median = 0.3630
Average Absolute Deviation from Median = 2.762E-02

Group C: Number of items= 94
0.283 0.283 0.283 0.283 0.283 0.284 0.284 0.284 0.284 0.284 0.285 0.285 0.285 0.285
0.285 0.285 0.285 0.286 0.286 0.287 0.288 0.288 0.288 0.289 0.289 0.289 0.289 0.291
0.291 0.291 0.293 0.293 0.294 0.295 0.296 0.297 0.297 0.299 0.299 0.301 0.301 0.303
0.305 0.305 0.307 0.308 0.311 0.311 0.313 0.314 0.315 0.317 0.317 0.319 0.321 0.323
0.324 0.326 0.328 0.330 0.330 0.331 0.332 0.335 0.336 0.339 0.340 0.342 0.342 0.342
0.345 0.345 0.348 0.348 0.351 0.352 0.353 0.354 0.355 0.356 0.356 0.356 0.358 0.358
0.359 0.360 0.360 0.361 0.362 0.362 0.362 0.363 0.363 0.363

Mean = 0.31663
95% confidence interval for Mean: 0.3102 thru 0.3230
Standard Deviation = 2.870E-02
High = 0.3630 Low = 0.2830
Median = 0.3110
Average Absolute Deviation from Median = 2.544E-02

Group D: Number of items= 94
0.313 0.313 0.313 0.313 0.313 0.314 0.314 0.314 0.314 0.314 0.315 0.315 0.315 0.315
0.315 0.315 0.315 0.316 0.316 0.317 0.318 0.318 0.318 0.319 0.319 0.319 0.319 0.321
0.321 0.321 0.324 0.324 0.325 0.326 0.327 0.328 0.328 0.330 0.330 0.332 0.332 0.335
0.337 0.337 0.339 0.340 0.343 0.343 0.346 0.347 0.348 0.350 0.350 0.352 0.354 0.357
0.358 0.360 0.362 0.364 0.364 0.366 0.367 0.370 0.371 0.374 0.375 0.378 0.378 0.378
0.381 0.381 0.384 0.384 0.388 0.389 0.390 0.391 0.392 0.393 0.393 0.393 0.395 0.395
0.396 0.398 0.398 0.399 0.400 0.400 0.400 0.401 0.401 0.401

Mean = 0.34966
95% confidence interval for Mean: 0.3433 thru 0.3561
Standard Deviation = 3.169E-02
High = 0.4009 Low = 0.3125
Median = 0.3434
Average Absolute Deviation from Median = 2.809E-02

ANOVA: 020101

02-wave type 2, Run number 1, 1/3 plant biomass = 020301

ANOVA statistical analysis outcomes, test done at 14:40 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1057	3	3.5225E-02	10.37
Error	1.263	372	3.3957E-03	
Total	1.369	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.256 0.256 0.256 0.256 0.256 0.257 0.258 0.258 0.259 0.259 0.260 0.260 0.262 0.263
0.266 0.266 0.266 0.268 0.270 0.271 0.274 0.276 0.279 0.279 0.279 0.282 0.285 0.288
0.291 0.292 0.297 0.299 0.299 0.301 0.307 0.309 0.312 0.312 0.318 0.321 0.323 0.327
0.332 0.334 0.335 0.341 0.341 0.344 0.351 0.355 0.356 0.359 0.363 0.367 0.368 0.373
0.376 0.377 0.385 0.388 0.391 0.397 0.399 0.401 0.403 0.409 0.415 0.416 0.421 0.421
0.427 0.429 0.430 0.435 0.437 0.438 0.443 0.445 0.447 0.449 0.452 0.454 0.454 0.458
0.458 0.459 0.460 0.461 0.461 0.462 0.462 0.463 0.464 0.464

Mean = 0.35216
95% confidence interval for Mean: 0.3403 thru 0.3640
Standard Deviation = 7.405E-02
High = 0.4640 Low = 0.2560
Median = 0.3425
Average Absolute Deviation from Median = 6.586E-02

Group B: Number of items= 94
0.303 0.303 0.304 0.304 0.304 0.304 0.304 0.304 0.305 0.306 0.306 0.307 0.307 0.307
0.308 0.308 0.308 0.309 0.310 0.310 0.311 0.312 0.312 0.314 0.314 0.315 0.317 0.318
0.318 0.319 0.323 0.323 0.324 0.326 0.328 0.330 0.333 0.334 0.334 0.337 0.342 0.342
0.344 0.344 0.349 0.352 0.353 0.354 0.358 0.359 0.365 0.366 0.366 0.368 0.375 0.377
0.379 0.381 0.383 0.385 0.393 0.393 0.394 0.395 0.403 0.404 0.406 0.409 0.415 0.415
0.419 0.420 0.426 0.426 0.430 0.432 0.437 0.438 0.441 0.442 0.448 0.450 0.450 0.457
0.458 0.458 0.458 0.464 0.464 0.467 0.468 0.468 0.469 0.470

Mean = 0.36800
95% confidence interval for Mean: 0.3562 thru 0.3798
Standard Deviation = 5.671E-02
High = 0.4700 Low = 0.3030
Median = 0.3535
Average Absolute Deviation from Median = 4.909E-02

Group C: Number of items= 94
0.264 0.265 0.265 0.265 0.265 0.265 0.267 0.267 0.267 0.267 0.267 0.268 0.271 0.271
0.272 0.273 0.273 0.273 0.274 0.275 0.278 0.279 0.280 0.283 0.283 0.283 0.285 0.290
0.291 0.291 0.293 0.293 0.295 0.297 0.299 0.300 0.301 0.302 0.304 0.305 0.307 0.309
0.309 0.311 0.312 0.312 0.313 0.313 0.315 0.318 0.318 0.320 0.322 0.323 0.326 0.326
0.327 0.331 0.332 0.336 0.337 0.338 0.340 0.344 0.345 0.351 0.352 0.355 0.359 0.360
0.366 0.368 0.368 0.370 0.378 0.378 0.382 0.386 0.386 0.387 0.389 0.394 0.394 0.395
0.400 0.401 0.401 0.402 0.403 0.403 0.405 0.405 0.405 0.407

Mean = 0.32383
95% confidence interval for Mean: 0.3120 thru 0.3356
Standard Deviation = 4.668E-02
High = 0.4070 Low = 0.2640
Median = 0.3130
Average Absolute Deviation from Median = 3.917E-02

Group D: Number of items= 94
0.294 0.295 0.295 0.295 0.295 0.295 0.297 0.297 0.297 0.297 0.297 0.299 0.302 0.302
0.303 0.304 0.304 0.304 0.305 0.306 0.310 0.311 0.312 0.315 0.315 0.315 0.318 0.323
0.324 0.324 0.326 0.326 0.329 0.331 0.333 0.334 0.335 0.336 0.339 0.340 0.342 0.344
0.344 0.346 0.348 0.348 0.349 0.349 0.351 0.354 0.354 0.357 0.359 0.360 0.363 0.363
0.364 0.369 0.370 0.374 0.375 0.377 0.379 0.383 0.384 0.391 0.392 0.396 0.400 0.401
0.408 0.410 0.410 0.412 0.421 0.421 0.426 0.430 0.430 0.431 0.433 0.439 0.439 0.440
0.446 0.447 0.447 0.448 0.449 0.449 0.451 0.451 0.451 0.453

Mean = 0.36079
95% confidence interval for Mean: 0.3490 thru 0.3726
Standard Deviation = 5.201E-02
High = 0.4534 Low = 0.2941
Median = 0.3487
Average Absolute Deviation from Median = 4.364E-02

ANOVA: 020201

ANOVA statistical analysis outcomes, test done at 14:46 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1270	3	4.2343E-02	11.33
Error	1.390	372	3.7365E-03	
Total	1.517	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.240 0.240 0.240 0.241 0.241 0.242 0.242 0.242 0.244 0.244 0.245 0.246 0.248 0.248
0.249 0.250 0.252 0.254 0.255 0.256 0.260 0.262 0.262 0.264 0.266 0.269 0.270 0.273
0.276 0.280 0.281 0.285 0.285 0.290 0.295 0.302 0.305 0.305 0.308 0.315 0.319 0.319
0.329 0.330 0.337 0.339 0.343 0.352 0.352 0.355 0.357 0.365 0.373 0.377 0.378 0.379
0.390 0.390 0.392 0.393 0.399 0.401 0.405 0.407 0.411 0.415 0.417 0.420 0.421 0.425
0.429 0.432 0.432 0.434 0.440 0.440 0.441 0.441 0.449 0.450 0.451 0.452 0.453 0.454
0.456 0.456 0.458 0.460 0.460 0.460 0.460 0.460 0.460 0.461

Mean = 0.34735
95% confidence interval for Mean: 0.3350 thru 0.3597
Standard Deviation = 8.070E-02
High = 0.4610 Low = 0.2400
Median = 0.3475
Average Absolute Deviation from Median = 7.314E-02

Group B: Number of items= 94
0.307 0.308 0.308 0.308 0.309 0.309 0.310 0.310 0.310 0.310 0.310 0.311 0.311 0.311
0.312 0.312 0.312 0.312 0.313 0.314 0.314 0.314 0.314 0.314 0.314 0.315 0.315 0.316
0.318 0.318 0.319 0.320 0.320 0.320 0.324 0.325 0.326 0.328 0.329 0.329 0.334 0.336
0.338 0.338 0.340 0.342 0.344 0.347 0.348 0.350 0.355 0.356 0.357 0.364 0.366 0.366
0.368 0.371 0.379 0.381 0.381 0.381 0.386 0.389 0.389 0.395 0.397 0.397 0.399 0.402
0.404 0.407 0.410 0.412 0.416 0.416 0.417 0.419 0.424 0.426 0.428 0.428 0.432 0.432
0.434 0.434 0.440 0.440 0.441 0.442 0.442 0.443 0.443 0.444

Mean = 0.36031
95% confidence interval for Mean: 0.3479 thru 0.3727
Standard Deviation = 4.783E-02
High = 0.4440 Low = 0.3070
Median = 0.3455
Average Absolute Deviation from Median = 4.178E-02

Group C: Number of items= 94
0.238 0.238 0.238 0.238 0.239 0.240 0.240 0.240 0.240 0.242 0.242 0.242 0.243 0.244
0.245 0.245 0.248 0.248 0.250 0.250 0.252 0.253 0.253 0.255 0.259 0.261 0.263 0.265
0.267 0.267 0.274 0.276 0.277 0.277 0.284 0.287 0.292 0.295 0.297 0.299 0.305 0.307
0.307 0.312 0.313 0.315 0.319 0.320 0.324 0.326 0.328 0.328 0.328 0.331 0.331 0.331
0.331 0.331 0.332 0.332 0.333 0.334 0.334 0.336 0.336 0.336 0.339 0.342 0.344 0.347
0.351 0.352 0.353 0.357 0.360 0.367 0.368 0.368 0.371 0.374 0.377 0.382 0.384 0.386
0.388 0.390 0.391 0.393 0.394 0.395 0.395 0.395 0.395 0.397

Mean = 0.31083
95% confidence interval for Mean: 0.2984 thru 0.3232
Standard Deviation = 5.236E-02
High = 0.3970 Low = 0.2380
Median = 0.3195
Average Absolute Deviation from Median = 4.528E-02

Group D: Number of items= 94
0.265 0.265 0.265 0.265 0.266 0.267 0.267 0.267 0.267 0.270 0.270 0.270 0.271 0.272
0.273 0.273 0.276 0.276 0.279 0.279 0.281 0.282 0.282 0.284 0.289 0.291 0.293 0.295
0.297 0.297 0.305 0.307 0.309 0.309 0.316 0.320 0.325 0.329 0.331 0.333 0.340 0.342
0.342 0.348 0.349 0.351 0.355 0.357 0.361 0.363 0.365 0.365 0.365 0.369 0.369 0.369
0.369 0.369 0.370 0.370 0.371 0.372 0.372 0.374 0.374 0.374 0.378 0.381 0.383 0.387
0.391 0.392 0.393 0.398 0.401 0.409 0.410 0.410 0.413 0.417 0.420 0.426 0.428 0.430
0.432 0.435 0.436 0.438 0.439 0.440 0.440 0.440 0.440 0.442

Mean = 0.34630
95% confidence interval for Mean: 0.3339 thru 0.3587
Standard Deviation = 5.834E-02
High = 0.4423 Low = 0.2652
Median = 0.3560
Average Absolute Deviation from Median = 5.044E-02

ANOVA: of 020301

ANOVA statistical analysis outcomes, test done at 15:05 on 8-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1217	3	4.0561E-02	10.82
Error	1.409	376	3.7486E-03	
Total	1.531	379		

Assuming the null hypothesis, this result's probability is lower than .0001

Group A: Number of items= 95
0.238 0.239 0.239 0.239 0.239 0.239 0.240 0.240 0.241 0.244 0.245 0.245 0.246 0.246
0.247 0.248 0.250 0.252 0.255 0.256 0.258 0.260 0.263 0.266 0.268 0.270 0.272 0.277
0.280 0.281 0.289 0.291 0.292 0.295 0.301 0.305 0.306 0.316 0.319 0.321 0.324 0.327
0.330 0.339 0.340 0.342 0.345 0.353 0.353 0.354 0.356 0.365 0.368 0.368 0.372 0.375
0.377 0.381 0.383 0.387 0.391 0.397 0.398 0.399 0.399 0.408 0.409 0.409 0.410 0.418
0.419 0.420 0.421 0.427 0.427 0.428 0.429 0.435 0.435 0.436 0.439 0.441 0.443 0.443
0.445 0.447 0.448 0.448 0.448 0.451 0.451 0.451 0.452 0.452 0.452

Mean = 0.34508
95% confidence interval for Mean: 0.3327 thru 0.3574
Standard Deviation = 7.653E-02
High = 0.4520 Low = 0.2380
Median = 0.3530
Average Absolute Deviation from Median = 6.842E-02

Group B: Number of items= 95
0.305 0.305 0.305 0.305 0.306 0.306 0.307 0.308 0.310 0.310 0.310 0.310 0.311 0.312
0.312 0.314 0.314 0.314 0.315 0.315 0.315 0.315 0.315 0.315 0.316 0.316 0.316 0.316
0.318 0.318 0.318 0.320 0.320 0.322 0.323 0.324 0.325 0.328 0.330 0.331 0.333 0.334
0.335 0.340 0.342 0.344 0.345 0.349 0.350 0.352 0.353 0.358 0.360 0.364 0.367 0.367
0.368 0.374 0.375 0.375 0.378 0.383 0.383 0.384 0.386 0.393 0.393 0.395 0.395 0.401
0.402 0.403 0.405 0.409 0.411 0.411 0.413 0.417 0.418 0.419 0.420 0.424 0.425 0.425
0.426 0.428 0.430 0.430 0.432 0.433 0.433 0.434 0.434 0.434 0.435

Mean = 0.35918
95% confidence interval for Mean: 0.3468 thru 0.3715
Standard Deviation = 4.561E-02
High = 0.4350 Low = 0.3050
Median = 0.3490
Average Absolute Deviation from Median = 4.039E-02

Group C: Number of items= 95
0.234 0.235 0.236 0.236 0.236 0.236 0.237 0.238 0.238 0.239 0.240 0.240 0.241 0.242
0.244 0.245 0.246 0.249 0.249 0.251 0.251 0.253 0.254 0.255 0.260 0.261 0.261 0.264
0.265 0.265 0.271 0.271 0.272 0.273 0.275 0.275 0.280 0.281 0.285 0.286 0.288 0.291
0.292 0.293 0.299 0.303 0.304 0.307 0.308 0.311 0.316 0.317 0.323 0.324 0.327 0.328
0.328 0.334 0.336 0.339 0.340 0.340 0.345 0.346 0.347 0.352 0.352 0.358 0.358 0.360
0.361 0.364 0.366 0.368 0.372 0.372 0.374 0.379 0.380 0.380 0.380 0.386 0.387 0.387
0.388 0.391 0.393 0.394 0.395 0.395 0.397 0.397 0.397 0.398 0.398

Mean = 0.31089
95% confidence interval for Mean: 0.2985 thru 0.3232
Standard Deviation = 5.611E-02
High = 0.3980 Low = 0.2340
Median = 0.3070
Average Absolute Deviation from Median = 4.998E-02

Group D: Number of items= 95
0.261 0.262 0.263 0.263 0.263 0.263 0.264 0.265 0.265 0.266 0.267 0.267 0.269 0.270
0.272 0.273 0.274 0.277 0.277 0.280 0.280 0.282 0.283 0.284 0.290 0.291 0.291 0.294
0.295 0.295 0.302 0.302 0.303 0.304 0.306 0.306 0.312 0.313 0.318 0.319 0.321 0.324
0.325 0.326 0.333 0.338 0.339 0.342 0.343 0.346 0.352 0.353 0.360 0.361 0.364 0.365
0.365 0.372 0.374 0.378 0.379 0.379 0.384 0.385 0.387 0.392 0.392 0.399 0.399 0.401
0.402 0.406 0.408 0.410 0.414 0.414 0.417 0.422 0.423 0.423 0.423 0.430 0.431 0.431
0.432 0.436 0.438 0.439 0.440 0.440 0.442 0.442 0.442 0.443 0.443

Mean = 0.34638
95% confidence interval for Mean: 0.3340 thru 0.3587
Standard Deviation = 6.252E-02
High = 0.4434 Low = 0.2607
Median = 0.3420
Average Absolute Deviation from Median = 5.568E-02

ANOVA: 020102

ANOVA statistical analysis outcomes, test done at 14:50 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1268	3	4.2263E-02	11.81
Error	1.331	372	3.5789E-03	
Total	1.458	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.250 0.250 0.250 0.250 0.251 0.251 0.252 0.254 0.254 0.255 0.256 0.256 0.257 0.257
0.259 0.262 0.264 0.264 0.265 0.268 0.270 0.272 0.272 0.276 0.281 0.281 0.282 0.289
0.291 0.293 0.293 0.300 0.301 0.306 0.311 0.313 0.317 0.321 0.322 0.323 0.333 0.335
0.339 0.341 0.344 0.352 0.355 0.355 0.359 0.361 0.365 0.374 0.375 0.377 0.384 0.387
0.390 0.395 0.396 0.399 0.405 0.409 0.410 0.414 0.417 0.421 0.421 0.426 0.427 0.431
0.436 0.437 0.439 0.439 0.443 0.447 0.447 0.447 0.453 0.454 0.455 0.455 0.459 0.460
0.461 0.461 0.464 0.466 0.466 0.466 0.466 0.466 0.468 0.468

Mean = 0.35595
95% confidence interval for Mean: 0.3438 thru 0.3681
Standard Deviation = 7.808E-02
High = 0.4680 Low = 0.2500
Median = 0.3550
Average Absolute Deviation from Median = 7.003E-02

Group B: Number of items= 94
0.303 0.304 0.304 0.304 0.304 0.305 0.305 0.305 0.305 0.307 0.307 0.307 0.307 0.308
0.309 0.310 0.310 0.310 0.312 0.313 0.314 0.315 0.315 0.317 0.318 0.318 0.319 0.322
0.326 0.326 0.328 0.328 0.330 0.331 0.334 0.336 0.338 0.340 0.343 0.344 0.344 0.346
0.352 0.354 0.354 0.355 0.359 0.362 0.365 0.366 0.369 0.371 0.377 0.379 0.379 0.381
0.387 0.391 0.392 0.393 0.397 0.400 0.405 0.407 0.408 0.412 0.417 0.418 0.419 0.422
0.430 0.432 0.433 0.434 0.438 0.440 0.443 0.445 0.448 0.452 0.453 0.456 0.456 0.458
0.461 0.462 0.463 0.464 0.464 0.466 0.467 0.467 0.468 0.468

Mean = 0.37266
95% confidence interval for Mean: 0.3605 thru 0.3848
Standard Deviation = 5.753E-02
High = 0.4680 Low = 0.3030
Median = 0.3605
Average Absolute Deviation from Median = 5.043E-02

Group C: Number of items= 94
0.262 0.263 0.263 0.263 0.263 0.264 0.264 0.264 0.264 0.264 0.265 0.266 0.267 0.267
0.267 0.268 0.269 0.271 0.271 0.272 0.275 0.275 0.277 0.278 0.278 0.279 0.283 0.283
0.285 0.285 0.288 0.294 0.295 0.296 0.296 0.299 0.304 0.304 0.307 0.307 0.309 0.312
0.312 0.314 0.316 0.317 0.318 0.319 0.319 0.320 0.322 0.322 0.325 0.325 0.328 0.328
0.331 0.334 0.334 0.335 0.339 0.340 0.344 0.346 0.349 0.352 0.352 0.353 0.360 0.361
0.363 0.366 0.368 0.368 0.376 0.377 0.379 0.382 0.384 0.384 0.388 0.391 0.391 0.392
0.396 0.396 0.397 0.399 0.401 0.401 0.401 0.402 0.402 0.403

Mean = 0.32285
95% confidence interval for Mean: 0.3107 thru 0.3350
Standard Deviation = 4.681E-02
High = 0.4030 Low = 0.2620
Median = 0.3185
Average Absolute Deviation from Median = 3.981E-02

Group D: Number of items= 94
0.292 0.293 0.293 0.293 0.293 0.294 0.294 0.294 0.294 0.294 0.295 0.296 0.297 0.297
0.297 0.299 0.300 0.302 0.302 0.303 0.306 0.306 0.309 0.310 0.310 0.311 0.315 0.315
0.318 0.318 0.321 0.328 0.329 0.330 0.330 0.333 0.339 0.339 0.342 0.342 0.344 0.348
0.348 0.350 0.352 0.353 0.354 0.355 0.355 0.357 0.359 0.359 0.362 0.362 0.365 0.365
0.369 0.372 0.372 0.373 0.378 0.379 0.383 0.385 0.389 0.392 0.392 0.393 0.401 0.402
0.404 0.408 0.410 0.410 0.419 0.420 0.422 0.426 0.428 0.428 0.432 0.436 0.436 0.437
0.441 0.441 0.442 0.445 0.447 0.447 0.447 0.448 0.448 0.449

Mean = 0.35970
95% confidence interval for Mean: 0.3476 thru 0.3718
Standard Deviation = 5.215E-02
High = 0.4490 Low = 0.2919
Median = 0.3548
Average Absolute Deviation from Median = 4.435E-02

ANOVA: 020202

ANOVA statistical analysis outcomes, test done at 14:53 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	9.9507E-02	3	3.3169E-02	10.66
Error	1.157	372	3.1114E-03	
Total	1.257	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.247 0.247 0.248 0.248 0.248 0.248 0.250 0.250 0.250 0.251 0.253 0.255 0.255 0.256
0.260 0.260 0.260 0.262 0.266 0.267 0.268 0.269 0.275 0.275 0.276 0.279 0.285 0.286
0.286 0.288 0.291 0.294 0.301 0.303 0.305 0.306 0.312 0.313 0.315 0.316 0.324 0.328
0.330 0.333 0.334 0.337 0.344 0.345 0.347 0.350 0.353 0.357 0.362 0.367 0.367 0.371
0.375 0.378 0.379 0.380 0.387 0.393 0.395 0.397 0.397 0.406 0.407 0.408 0.409 0.419
0.419 0.421 0.428 0.429 0.429 0.429 0.435 0.439 0.441 0.442 0.443 0.447 0.448 0.450
0.452 0.453 0.453 0.454 0.455 0.456 0.456 0.456 0.457 0.458

Mean = 0.34737
95% confidence interval for Mean: 0.3361 thru 0.3587
Standard Deviation = 7.367E-02
High = 0.4580 Low = 0.2470
Median = 0.3445
Average Absolute Deviation from Median = 6.537E-02

Group B: Number of items= 94
0.310 0.310 0.310 0.310 0.310 0.311 0.311 0.311 0.311 0.311 0.312 0.312 0.312 0.312
0.312 0.312 0.312 0.312 0.312 0.313 0.313 0.314 0.315 0.315 0.315 0.316 0.316 0.318
0.318 0.318 0.318 0.320 0.321 0.322 0.326 0.326 0.326 0.328 0.330 0.332 0.332 0.336
0.336 0.336 0.343 0.344 0.344 0.345 0.350 0.350 0.353 0.356 0.359 0.360 0.367 0.367
0.368 0.369 0.376 0.378 0.379 0.382 0.385 0.387 0.393 0.395 0.397 0.397 0.404 0.405
0.407 0.407 0.417 0.418 0.418 0.419 0.424 0.425 0.426 0.428 0.436 0.436 0.436 0.438
0.442 0.444 0.447 0.447 0.448 0.450 0.451 0.453 0.453 0.454

Mean = 0.36223
95% confidence interval for Mean: 0.3509 thru 0.3735
Standard Deviation = 5.002E-02
High = 0.4540 Low = 0.3100
Median = 0.3445
Average Absolute Deviation from Median = 4.300E-02

Group C: Number of items= 94
0.264 0.264 0.264 0.264 0.264 0.265 0.265 0.266 0.266 0.267 0.267 0.268 0.269 0.269
0.269 0.270 0.271 0.272 0.274 0.274 0.275 0.275 0.277 0.279 0.279 0.280 0.281 0.281
0.283 0.283 0.285 0.287 0.288 0.290 0.290 0.291 0.293 0.296 0.296 0.299 0.299 0.299
0.299 0.304 0.304 0.307 0.307 0.311 0.313 0.313 0.318 0.319 0.324 0.325 0.326 0.327
0.329 0.331 0.336 0.338 0.340 0.343 0.344 0.344 0.350 0.352 0.354 0.355 0.357 0.358
0.364 0.366 0.366 0.370 0.371 0.372 0.376 0.377 0.378 0.378 0.384 0.384 0.384 0.386
0.389 0.390 0.391 0.391 0.391 0.392 0.392 0.393 0.393 0.393

Mean = 0.31976
95% confidence interval for Mean: 0.3084 thru 0.3311
Standard Deviation = 4.489E-02
High = 0.3930 Low = 0.2640
Median = 0.3090
Average Absolute Deviation from Median = 3.935E-02

Group D: Number of items= 94
0.294 0.294 0.294 0.294 0.294 0.295 0.295 0.296 0.296 0.297 0.297 0.299 0.300 0.300
0.300 0.301 0.302 0.303 0.305 0.305 0.306 0.306 0.309 0.311 0.311 0.312 0.313 0.313
0.315 0.315 0.318 0.320 0.321 0.323 0.323 0.324 0.326 0.330 0.330 0.333 0.333 0.333
0.333 0.339 0.339 0.342 0.342 0.346 0.349 0.349 0.354 0.355 0.361 0.362 0.363 0.364
0.367 0.369 0.374 0.377 0.379 0.382 0.383 0.383 0.390 0.392 0.394 0.396 0.398 0.399
0.406 0.408 0.408 0.412 0.413 0.414 0.419 0.420 0.421 0.421 0.428 0.428 0.428 0.430
0.433 0.435 0.436 0.436 0.436 0.437 0.437 0.438 0.438 0.438

Mean = 0.35625
95% confidence interval for Mean: 0.3449 thru 0.3676
Standard Deviation = 5.001E-02
High = 0.4379 Low = 0.2941
Median = 0.3443
Average Absolute Deviation from Median = 4.384E-02

ANOVA: 020302

ANOVA statistical analysis outcomes, test done at 14:57 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1259	3	4.1953E-02	13.63
Error	1.145	372	3.0791E-03	
Total	1.271	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.243 0.244 0.244 0.245 0.245 0.245 0.246 0.246 0.247 0.247 0.248 0.250 0.250 0.251
0.256 0.257 0.258 0.261 0.262 0.263 0.263 0.271 0.272 0.272 0.279 0.280 0.281 0.284
0.291 0.291 0.295 0.300 0.302 0.307 0.311 0.312 0.314 0.321 0.324 0.325 0.334 0.337
0.339 0.345 0.345 0.348 0.357 0.359 0.361 0.361 0.365 0.369 0.373 0.377 0.378 0.381
0.387 0.391 0.392 0.393 0.398 0.400 0.403 0.406 0.406 0.411 0.417 0.418 0.419 0.420
0.427 0.427 0.428 0.429 0.434 0.436 0.436 0.440 0.440 0.442 0.443 0.447 0.448 0.448
0.451 0.451 0.452 0.452 0.453 0.453 0.454 0.454 0.455 0.455

Mean = 0.35051
95% confidence interval for Mean: 0.3393 thru 0.3618
Standard Deviation = 7.542E-02
High = 0.4550 Low = 0.2430
Median = 0.3580
Average Absolute Deviation from Median = 6.736E-02

Group B: Number of items= 94
0.307 0.307 0.307 0.307 0.307 0.307 0.307 0.307 0.307 0.308 0.308 0.308 0.309 0.310
0.310 0.310 0.310 0.310 0.310 0.312 0.312 0.312 0.314 0.314 0.316 0.316 0.317 0.319
0.320 0.320 0.322 0.323 0.326 0.326 0.329 0.330 0.331 0.332 0.336 0.336 0.338 0.339
0.344 0.346 0.346 0.348 0.352 0.354 0.356 0.358 0.361 0.364 0.369 0.370 0.371 0.372
0.379 0.381 0.382 0.383 0.388 0.391 0.393 0.396 0.401 0.403 0.404 0.405 0.410 0.412
0.414 0.417 0.422 0.423 0.424 0.425 0.429 0.431 0.432 0.433 0.438 0.438 0.440 0.441
0.444 0.444 0.445 0.446 0.448 0.448 0.449 0.449 0.450 0.450

Mean = 0.36505
95% confidence interval for Mean: 0.3538 thru 0.3763
Standard Deviation = 5.133E-02
High = 0.4500 Low = 0.3070
Median = 0.3530
Average Absolute Deviation from Median = 4.522E-02

Group C: Number of items= 94
0.261 0.261 0.261 0.261 0.262 0.262 0.263 0.263 0.264 0.265 0.265 0.265 0.267 0.267
0.267 0.269 0.269 0.269 0.270 0.271 0.272 0.272 0.274 0.275 0.275 0.275 0.276 0.276
0.279 0.280 0.283 0.283 0.284 0.284 0.288 0.288 0.292 0.295 0.295 0.297 0.299 0.302
0.307 0.307 0.308 0.309 0.311 0.313 0.316 0.318 0.318 0.321 0.323 0.324 0.324 0.326
0.328 0.328 0.331 0.331 0.336 0.336 0.337 0.339 0.340 0.341 0.346 0.347 0.351 0.352
0.352 0.356 0.359 0.359 0.363 0.364 0.365 0.366 0.371 0.372 0.373 0.375 0.376 0.377
0.378 0.380 0.382 0.382 0.382 0.384 0.384 0.384 0.384 0.384

Mean = 0.31560
95% confidence interval for Mean: 0.3043 thru 0.3268
Standard Deviation = 4.221E-02
High = 0.3840 Low = 0.2610
Median = 0.3120
Average Absolute Deviation from Median = 3.713E-02

Group D: Number of items= 94
0.291 0.291 0.291 0.291 0.292 0.292 0.293 0.293 0.294 0.295 0.295 0.295 0.297 0.297
0.297 0.300 0.300 0.300 0.301 0.302 0.303 0.303 0.305 0.306 0.306 0.306 0.307 0.307
0.311 0.312 0.315 0.315 0.316 0.316 0.321 0.321 0.325 0.329 0.329 0.331 0.333 0.336
0.342 0.342 0.343 0.344 0.346 0.349 0.352 0.354 0.354 0.358 0.360 0.361 0.361 0.363
0.365 0.365 0.369 0.369 0.374 0.374 0.375 0.378 0.379 0.380 0.385 0.387 0.391 0.392
0.392 0.397 0.400 0.400 0.404 0.406 0.407 0.408 0.413 0.414 0.416 0.418 0.419 0.420
0.421 0.423 0.426 0.426 0.426 0.428 0.428 0.428 0.428 0.428

Mean = 0.35161
95% confidence interval for Mean: 0.3404 thru 0.3629
Standard Deviation = 4.703E-02
High = 0.4278 Low = 0.2908
Median = 0.3476
Average Absolute Deviation from Median = 4.136E-02

ANOVA: 020103

ANOVA statistical analysis outcomes, test done at 15:04 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1123	3	3.7444E-02	11.63
Error	1.198	372	3.2192E-03	
Total	1.310	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.243 0.244 0.244 0.244 0.244 0.245 0.246 0.246 0.246 0.246 0.248 0.248 0.248 0.250
0.252 0.254 0.256 0.256 0.258 0.260 0.261 0.262 0.265 0.267 0.269 0.269 0.273 0.276
0.279 0.280 0.283 0.284 0.289 0.291 0.291 0.295 0.302 0.303 0.304 0.305 0.311 0.315
0.315 0.319 0.323 0.325 0.331 0.333 0.335 0.338 0.344 0.345 0.351 0.353 0.356 0.365
0.367 0.368 0.373 0.373 0.376 0.385 0.386 0.389 0.395 0.398 0.399 0.405 0.408 0.411
0.413 0.416 0.419 0.425 0.426 0.429 0.429 0.434 0.435 0.435 0.441 0.442 0.443 0.445
0.447 0.447 0.449 0.450 0.451 0.451 0.451 0.451 0.453 0.454

Mean = 0.33994
95% confidence interval for Mean: 0.3284 thru 0.3514
Standard Deviation = 7.445E-02
High = 0.4540 Low = 0.2430
Median = 0.3320
Average Absolute Deviation from Median = 6.621E-02

Group B: Number of items= 94
0.293 0.294 0.295 0.295 0.296 0.296 0.296 0.296 0.296 0.297 0.297 0.297 0.299 0.299
0.299 0.300 0.301 0.301 0.301 0.301 0.302 0.303 0.305 0.305 0.305 0.305 0.307 0.307
0.310 0.311 0.312 0.314 0.314 0.317 0.318 0.322 0.324 0.324 0.329 0.330 0.330 0.332
0.338 0.338 0.339 0.345 0.348 0.350 0.350 0.354 0.355 0.361 0.362 0.362 0.372 0.373
0.373 0.374 0.382 0.383 0.386 0.387 0.391 0.392 0.397 0.399 0.403 0.403 0.409 0.409
0.413 0.415 0.419 0.419 0.426 0.426 0.427 0.429 0.434 0.435 0.436 0.437 0.442 0.443
0.444 0.445 0.447 0.447 0.447 0.449 0.450 0.451 0.452 0.452

Mean = 0.35952
95% confidence interval for Mean: 0.3480 thru 0.3710
Standard Deviation = 5.577E-02
High = 0.4520 Low = 0.2930
Median = 0.3490
Average Absolute Deviation from Median = 4.924E-02

Group C: Number of items= 94
0.253 0.253 0.253 0.253 0.254 0.255 0.255 0.256 0.256 0.257 0.257 0.258 0.259 0.259
0.262 0.263 0.263 0.264 0.265 0.267 0.267 0.270 0.270 0.270 0.275 0.276 0.277 0.278
0.283 0.283 0.283 0.285 0.287 0.292 0.293 0.295 0.296 0.297 0.299 0.299 0.301 0.303
0.304 0.304 0.305 0.307 0.307 0.309 0.309 0.309 0.312 0.314 0.315 0.315 0.319 0.320
0.323 0.323 0.323 0.328 0.329 0.330 0.333 0.334 0.334 0.339 0.339 0.340 0.346 0.346
0.353 0.353 0.354 0.360 0.361 0.361 0.362 0.367 0.367 0.368 0.375 0.375 0.376 0.378
0.378 0.380 0.381 0.382 0.382 0.384 0.384 0.386 0.386 0.388

Mean = 0.31274
95% confidence interval for Mean: 0.3012 thru 0.3243
Standard Deviation = 4.341E-02
High = 0.3880 Low = 0.2530
Median = 0.3080
Average Absolute Deviation from Median = 3.683E-02

Group D: Number of items= 94
0.282 0.282 0.282 0.282 0.283 0.284 0.284 0.285 0.285 0.286 0.286 0.287 0.289 0.289
0.292 0.293 0.293 0.294 0.295 0.297 0.297 0.301 0.301 0.301 0.306 0.307 0.309 0.310
0.315 0.315 0.315 0.318 0.320 0.325 0.326 0.329 0.330 0.331 0.333 0.333 0.335 0.338
0.339 0.339 0.340 0.342 0.342 0.344 0.344 0.344 0.348 0.350 0.351 0.351 0.355 0.357
0.360 0.360 0.360 0.365 0.367 0.368 0.371 0.372 0.372 0.378 0.378 0.379 0.385 0.385
0.393 0.393 0.394 0.401 0.402 0.402 0.403 0.409 0.409 0.410 0.418 0.418 0.419 0.421
0.421 0.423 0.424 0.426 0.426 0.428 0.428 0.430 0.430 0.432

Mean = 0.34844
95% confidence interval for Mean: 0.3369 thru 0.3599
Standard Deviation = 4.837E-02
High = 0.4323 Low = 0.2819
Median = 0.3432
Average Absolute Deviation from Median = 4.103E-02

ANOVA: 020203

ANOVA statistical analysis outcomes, test done at 15:09 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	0.1046	3	3.4879E-02	9.854
Error	1.317	372	3.5397E-03	
Total	1.421	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.234 0.234 0.235 0.235 0.235 0.236 0.236 0.236 0.237 0.238 0.239 0.240 0.241 0.242
0.244 0.245 0.246 0.246 0.250 0.251 0.252 0.253 0.258 0.259 0.259 0.259 0.267 0.269
0.269 0.271 0.279 0.280 0.281 0.282 0.289 0.291 0.293 0.296 0.303 0.307 0.307 0.309
0.314 0.315 0.325 0.327 0.329 0.331 0.337 0.340 0.340 0.341 0.353 0.355 0.357 0.361
0.363 0.365 0.374 0.376 0.378 0.386 0.389 0.389 0.390 0.397 0.400 0.401 0.407 0.409
0.413 0.415 0.419 0.420 0.427 0.428 0.428 0.433 0.436 0.437 0.437 0.441 0.443 0.443
0.446 0.448 0.448 0.448 0.450 0.451 0.451 0.451 0.451 0.451

Mean = 0.33614
95% confidence interval for Mean: 0.3241 thru 0.3482
Standard Deviation = 7.766E-02
High = 0.4510 Low = 0.2340
Median = 0.3300
Average Absolute Deviation from Median = 6.927E-02

Group B: Number of items= 94
0.302 0.303 0.303 0.303 0.303 0.303 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304
0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.307 0.307 0.307
0.309 0.310 0.310 0.310 0.313 0.314 0.316 0.318 0.318 0.321 0.321 0.323 0.324 0.330
0.331 0.332 0.336 0.338 0.338 0.342 0.346 0.348 0.352 0.352 0.354 0.362 0.362 0.364
0.364 0.368 0.371 0.374 0.379 0.382 0.382 0.385 0.387 0.389 0.391 0.394 0.399 0.399
0.400 0.401 0.405 0.408 0.409 0.411 0.415 0.415 0.416 0.417 0.421 0.423 0.424 0.425
0.429 0.430 0.430 0.430 0.433 0.433 0.433 0.434 0.436 0.436

Mean = 0.35422
95% confidence interval for Mean: 0.3422 thru 0.3663
Standard Deviation = 4.824E-02
High = 0.4360 Low = 0.3020
Median = 0.3400
Average Absolute Deviation from Median = 4.280E-02

Group C: Number of items= 94
0.236 0.236 0.236 0.236 0.236 0.237 0.237 0.238 0.238 0.238 0.239 0.240 0.241 0.243
0.243 0.244 0.244 0.247 0.250 0.251 0.252 0.253 0.257 0.259 0.259 0.264 0.264 0.269
0.272 0.272 0.277 0.279 0.281 0.284 0.287 0.287 0.294 0.295 0.299 0.301 0.301 0.302
0.305 0.307 0.312 0.313 0.313 0.315 0.316 0.317 0.320 0.320 0.322 0.323 0.328 0.328
0.328 0.331 0.334 0.334 0.336 0.336 0.337 0.339 0.344 0.345 0.346 0.349 0.350 0.350
0.355 0.357 0.361 0.361 0.363 0.363 0.368 0.368 0.370 0.371 0.374 0.376 0.378 0.379
0.379 0.380 0.382 0.382 0.384 0.384 0.384 0.384 0.385 0.386

Mean = 0.30947
95% confidence interval for Mean: 0.2974 thru 0.3215
Standard Deviation = 5.088E-02
High = 0.3860 Low = 0.2360
Median = 0.3140
Average Absolute Deviation from Median = 4.419E-02

Group D: Number of items= 94
0.263 0.263 0.263 0.263 0.263 0.264 0.264 0.265 0.265 0.265 0.266 0.267 0.269 0.271
0.271 0.272 0.272 0.275 0.279 0.280 0.281 0.282 0.286 0.289 0.289 0.294 0.294 0.300
0.303 0.303 0.309 0.311 0.313 0.316 0.320 0.320 0.328 0.329 0.333 0.335 0.335 0.336
0.340 0.342 0.348 0.349 0.349 0.351 0.352 0.353 0.357 0.357 0.359 0.360 0.365 0.365
0.365 0.369 0.372 0.372 0.374 0.374 0.375 0.378 0.383 0.384 0.385 0.389 0.390 0.390
0.396 0.398 0.402 0.402 0.404 0.404 0.410 0.410 0.412 0.413 0.417 0.419 0.421 0.422
0.422 0.423 0.426 0.426 0.428 0.428 0.428 0.428 0.429 0.430

Mean = 0.34479
95% confidence interval for Mean: 0.3327 thru 0.3569
Standard Deviation = 5.668E-02
High = 0.4301 Low = 0.2629
Median = 0.3498
Average Absolute Deviation from Median = 4.923E-02

ANOVA: 020303

ANOVA statistical analysis outcomes, test done at 15:13 on 9-APR-2013

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	9.2467E-02	3	3.0822E-02	10.23
Error	1.120	372	3.0118E-03	
Total	1.213	375		

Assuming the null hypothesis, this result's probability is lower than .0001.

Group A: Number of items= 94
0.238 0.238 0.238 0.238 0.239 0.240 0.240 0.241 0.241 0.241 0.244 0.245 0.245 0.246
0.248 0.248 0.249 0.250 0.254 0.255 0.255 0.256 0.260 0.262 0.262 0.264 0.270 0.271
0.273 0.273 0.279 0.280 0.281 0.285 0.289 0.291 0.292 0.295 0.302 0.303 0.305 0.305
0.312 0.317 0.317 0.321 0.325 0.329 0.333 0.335 0.335 0.339 0.348 0.349 0.350 0.352
0.359 0.361 0.361 0.362 0.373 0.374 0.377 0.378 0.381 0.383 0.388 0.390 0.393 0.393
0.401 0.401 0.404 0.405 0.411 0.411 0.412 0.414 0.421 0.422 0.424 0.428 0.428 0.430
0.431 0.437 0.437 0.439 0.439 0.440 0.441 0.442 0.443 0.443

Mean = 0.33160
95% confidence interval for Mean: 0.3205 thru 0.3427
Standard Deviation = 7.086E-02
High = 0.4430 Low = 0.2380
Median = 0.3270
Average Absolute Deviation from Median = 6.302E-02

Group B: Number of items= 94
0.299 0.299 0.299 0.299 0.300 0.300 0.300 0.300 0.300 0.300 0.300 0.301 0.301 0.301
0.301 0.301 0.301 0.301 0.301 0.301 0.303 0.303 0.304 0.304 0.305 0.306 0.306 0.307
0.307 0.307 0.310 0.312 0.312 0.312 0.315 0.315 0.316 0.318 0.320 0.320 0.323 0.325
0.326 0.326 0.330 0.332 0.333 0.336 0.337 0.338 0.342 0.344 0.345 0.346 0.352 0.352
0.354 0.355 0.362 0.362 0.364 0.365 0.370 0.373 0.374 0.376 0.380 0.381 0.385 0.390
0.392 0.393 0.395 0.401 0.403 0.403 0.407 0.409 0.411 0.411 0.417 0.417 0.419 0.422
0.422 0.423 0.424 0.427 0.428 0.428 0.428 0.428 0.429 0.430

Mean = 0.34843
95% confidence interval for Mean: 0.3373 thru 0.3596
Standard Deviation = 4.630E-02
High = 0.4300 Low = 0.2990
Median = 0.3345
Average Absolute Deviation from Median = 3.987E-02

Group C: Number of items= 94
0.243 0.243 0.244 0.244 0.244 0.245 0.245 0.245 0.245 0.245 0.247 0.247 0.248 0.251
0.251 0.252 0.253 0.254 0.254 0.258 0.258 0.259 0.262 0.263 0.263 0.266 0.267 0.267
0.270 0.272 0.274 0.275 0.277 0.278 0.281 0.282 0.285 0.287 0.288 0.289 0.292 0.293
0.298 0.299 0.301 0.303 0.304 0.305 0.309 0.311 0.312 0.315 0.316 0.316 0.321 0.322
0.326 0.327 0.328 0.331 0.332 0.332 0.336 0.338 0.340 0.342 0.343 0.344 0.347 0.348
0.352 0.352 0.354 0.355 0.358 0.359 0.362 0.363 0.363 0.366 0.368 0.370 0.370 0.372
0.374 0.376 0.376 0.378 0.378 0.379 0.379 0.379 0.380 0.382

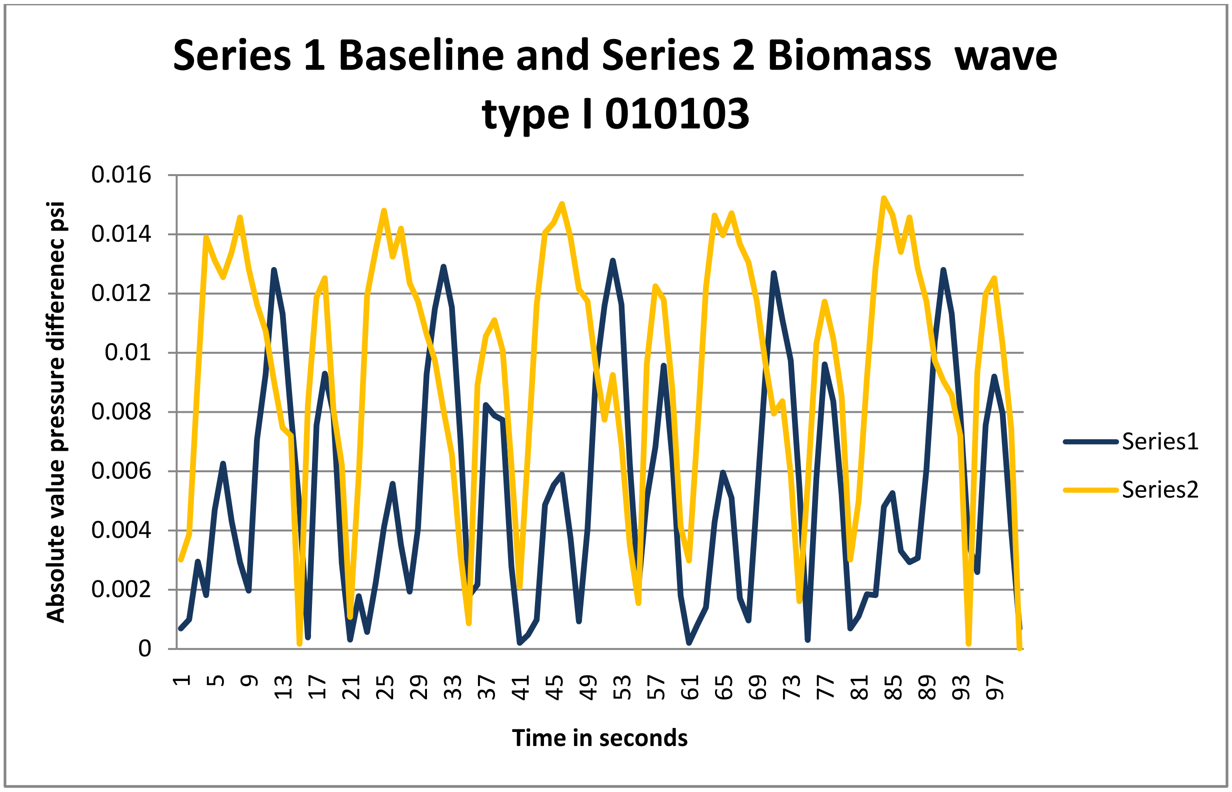
Mean = 0.30741
95% confidence interval for Mean: 0.2963 thru 0.3185
Standard Deviation = 4.667E-02
High = 0.3820 Low = 0.2430
Median = 0.3045
Average Absolute Deviation from Median = 4.122E-02

Group D: Number of items= 94
0.271 0.271 0.272 0.272 0.272 0.273 0.273 0.273 0.273 0.273 0.275 0.275 0.276 0.280
0.280 0.281 0.282 0.283 0.283 0.287 0.287 0.289 0.292 0.293 0.293 0.296 0.297 0.297
0.301 0.303 0.305 0.306 0.309 0.310 0.313 0.314 0.318 0.320 0.321 0.322 0.325 0.326
0.332 0.333 0.335 0.338 0.339 0.340 0.344 0.346 0.348 0.351 0.352 0.352 0.358 0.359
0.363 0.364 0.365 0.369 0.370 0.370 0.374 0.377 0.379 0.381 0.382 0.383 0.387 0.388
0.392 0.392 0.394 0.396 0.399 0.400 0.403 0.404 0.404 0.408 0.410 0.412 0.412 0.414
0.417 0.419 0.419 0.421 0.421 0.422 0.422 0.422 0.423 0.426

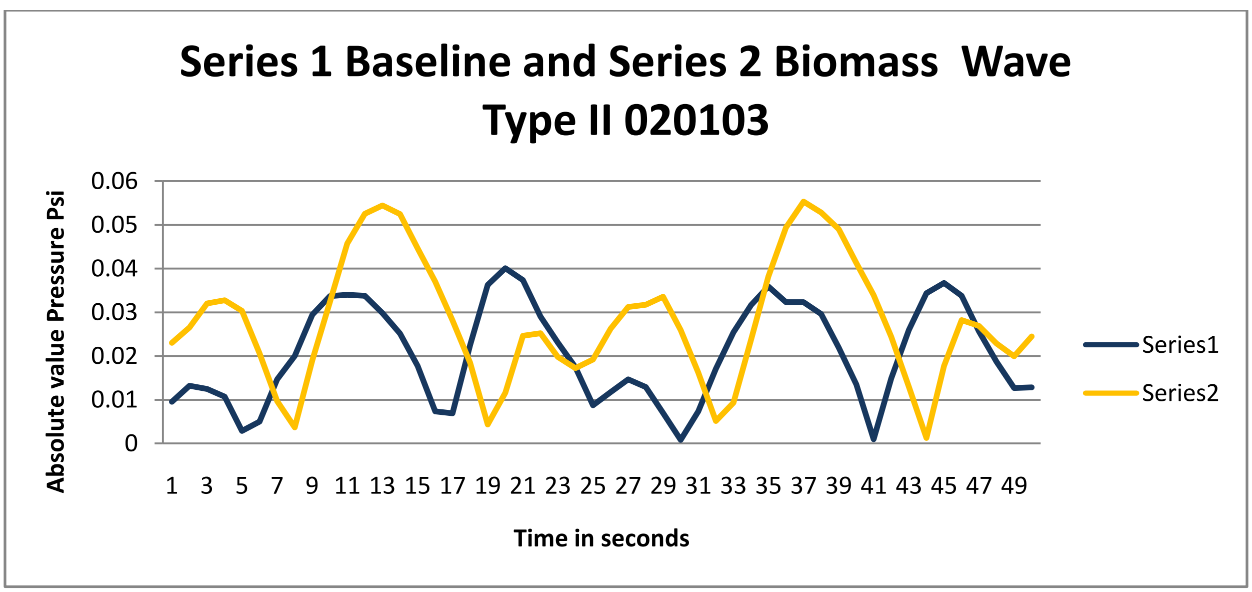
Mean = 0.34250
95% confidence interval for Mean: 0.3314 thru 0.3536
Standard Deviation = 5.200E-02
High = 0.4256 Low = 0.2707
Median = 0.3393
Average Absolute Deviation from Median = 4.593E-02

APPENDIX E: COMPARISON OF ABSOLUTE PRESSURE DIFFERENCE

This appendix contains graphing and values for the absolute in phase pressure difference of Transducer 1 – Transducer 3 baseline subtracted from Transducer 1 – Transducer 3 Biomass attenuated absolute values for Wave type I and Wave type II. The energy absorbed by the biomass is proportional to the difference in the absolute value of the pressure drop from transducer 1 to transducer 3 compared to the absolute value of the baseline (control, with no biomass in place) pressure drop as shown in this appendix.



Absolute in phase pressure difference between Transducer 1 – Transducer 3 baseline subtracted from the in phase pressure difference Transducer 1 – Transducer 3 Biomass attenuated = 6.312psi Wave I.



Absolute in phase pressure difference between Transducer 1 – Transducer 3 baseline subtracted from the in phase pressure difference Transducer 1 – Transducer 3 Biomass attenuated = 19.964psi Wave II.

VITA

Charles Malveaux has always had a passion for engineering and was excited to enter into the Masters Program in Biological Engineering at Louisiana State University. Having worked in industry before coming back to LSU for graduate studies he gained sufficient experience to apply the things which he has learned here to real world applications and is currently pursuing engineering consulting oppurtunities. Charles has begun extensive research into systems automation and remote sensing technologies and plans to continue his bioengineering research by pursuing a Docotorate of Philosophy in the newly forming Biological Engineering Phd. Program here at Louisiana State University.