Latex Balloon Degradation Differs Based on Environment

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ABSTRACT

Anthropogenic pollution, particularly litter, has detrimental consequences for the environment. Polluted latex balloons are a form of litter that can have deleterious effects on the ecosystem it degrades in, such as posing a hazard to wildlife or leaching chemicals into the environment. These harmful effects can be better understood through studying how balloons degrade in the environment. This project aimed to quantify the degradation of latex balloons in different environments by assessing discoloration, fragmentation, and changes in elasticity (relationship between stress of the material with regard to applied strain). Latex balloons in four treatments (Control, Air, Water, and Soil) were placed on the rooftop of Loyola Science Center for three weeks and assessed with an ordinal scale for discoloration and fragmentation. Control balloons were kept in the laboratory away from environmental conditions. In addition, I measured changes in elasticity using a force transducer to measure strain of balloons when stretched to various lengths. Soil Treatment balloons were placed on soil in a glass aquarium, Air Treatment were pinned to branches of a tree, and Water Treatment balloons were suspended off of the bottom of a glass aquarium filled with water. All measures of degradation were compared to balloons within a Control Treatment. I found that balloons in the Water Treatment did not degrade as quickly as the Air or Soil Treatments. This can negatively impact the function of aquatic ecosystems by threatening wildlife. This also calls for better waste management in coastal zones.

INTRODUCTION

Anthropogenic pollution is the damage to the biosphere caused directly by human activity (Arihilam and Arihilam 2019). Anthropogenic pollution has macroscopic and serious effects. For example, urban runoff can cause eutrophication, in which coastal zones are depleted of oxygen and become inhospitable to the native wildlife (Xu et al. 2019). Anthropogenic pollution has been increasingly prominent since the Industrial Revolution (Rhind 2009). Further, litter is a form of pollution where a physical, structural material, typically a waste product, is placed within the environment and this may have environmental consequences as an introduced material to the environment.

Balloon pollution is a type of litter pollution that can add chemicals to the environment and threaten wildlife. A polluted balloon is an unnatural, anthropogenic material and thus, investigation of its negative effects is warranted. Despite a report that claimed latex balloon releases are harmless to wildlife and the environment (Burchette 1989), certain organizations and research groups are concerned with balloon pollution's threat to wildlife. Animals may ingest or become entangled in balloons or ribbons, which leads to a premature death by starvation, choking, or strangulation (Roman et al. 2019; Don't Let Go 2022). In fact, balloons have been classified among the top five deadliest types of debris (O'Hara et al. 2018; Wilcox et al. 2016; Joynes 2018). For example, Walde et al. (2007) reported a desert tortoise (*Gopherus agassizii*) consuming 108 cm of balloon ribbon. Also, Lavers et al. (2018) reported balloons becoming lodged in the esophagus and gizzard of shearwaters, and the potential for latex to accumulate in the digestive tracts of red-eared sliders (*Trachemys scripta elegans*) (Irwin 2012).

Degradability is an important metric for measuring the environmental impact of latex balloon pollution because it quantifies the permanent changes in a polymer's physical and chemical properties (Gilmour and Lavers 2021). When considering this multifaceted phenomenon in light of organismal and ecological health, macroscopic changes will reduce wildlife risks like entanglement or ingestion (Gilmour and Lavers 2021). Degradation is an irreversible chemical process that affects physical parameters of a polymer—such as color chain conformation, weight, and flexibility throughout degradation and also contributes to the mixture of substances that arises when polymer-based materials degrade in the environment (Lambert et al. 2014; Lambert et al. 2013; Venkatachalam et al. 2012). Degrading latex has the potential to leach carcinogenic nitrosamines (Altkofer et al. 2005; Proksch 2001) and zinc (Lambert et al. 2014; Councell et al. 2004) into the soil and atmosphere (Lambert et al. 2014) at the nano-size range (Lambert et al. 2013).

Latex balloons clearly degrade into chemicals that negatively affect the environment, but studying their exact impact remains complex and multifaceted. What exactly makes a latex balloon degrade? Gilmour and Lavers (2021) claim that latex balloon degradation pathways include water absorption, biothermal heat, and UV exposure. However, the variation of these changes make it difficult to generally quantify balloon degradation in a way that addresses harm to wildlife in different environments (Gilmour and Lavers 2021).

Observing physical changes in a degrading balloon over time can give insight to its environmental impact. As a balloon degrades, the chemical construct of the material may change, and this may affect the physical properties of that balloon material. This change in properties can be visually observed by color change, fragmentation of the balloon, or measured with physical tests using metrics like stress, strain, and elasticity.

Among the physical properties of an object, a material will have its own stress-strain curve, otherwise known as Young’s Modulus of Elasticity (Serway and Jewett 2018). This curve is determined by observing the stress a material undergoes in response to a given strain, the change in length over initial length (Serway and Jewett 2018). These two metrics are proportional to a certain point, the elastic limit, according to Hooke's law (Serway and Jewett 2018). If a material is stretched along one axis, the material will pull back a predictable amount in order to maintain its original shape. After the elastic limit, a reduced stress leads to lowered elasticity. The material as been stretched so much that it can no longer pull back to its original shape (Serway and Jewett 2018).

Physical or chemical changes in latex can be evidenced by stress-strain curves that differ from non-degraded latex. Irwin (2012) found that latex balloons degrade more slowly in water and retain their elasticity beyond five months. Furthermore, Irwin (2012) noted how exposure to air makes a balloon quickly lose elasticity. Thus, the objective of my project was to quantify degradation of post-release latex balloons in different environments using (a) visual metrics and (b) stress/strain curves. Specifically, I quantified degradation of latex balloons in Air, Soil, and Water.

METHODS

I ran a three-week experiment from 20 July to 9 August 2021 to observe the degradation of balloons in three environmental conditions. Latex balloons were cut into individual 26-cm^2 pieces. Balloon pieces (n = 20 for each treatment) were randomly assorted to one of four treatments (Control, Air, Soil, or Water) and uniquely labeled to track individual balloon degradation. Control balloons were held in a drawer in a climate-controlled lab where they were not subjected to any environmental factors (e.g., rain or UV-light). Experimental trials in Air, Water, and Soil were exposed to environmental conditions atop the roof of the Loyola Science

Center at the University of Scranton in Scranton, Pennsylvania. The roof was exposed to full sun and was not shaded or protected from any weather conditions.

The Soil Treatment was conducted in two terrariums filled with an inch of soil from a Northeastern Pennsylvanian deciduous woodland. Latex balloons were anchored onto the surface of the soil with paperclips so they would not blow away (Fig. 1a). The Water Treatment featured a mix of rainwater and tap water in terrariums. Latex balloons were tied with fishing wire and weighed down with watch glasses so that they were suspended in water (Fig 1b). Finally, the Air Treatment featured latex balloons fastened to the branches of a potted Norfolk Pine Tree (*Araucaria heterophylla*) surrounded by tulling as an extra barricade from wildlife and reduce the probability of balloons becoming loose and blowing away (Fig. 1c). All balloon pieces attached to the tree were suspended between 4 – 5 feet off of the ground.

<u>Data Collection:</u>

Each week, I took a picture of each balloon. These were then rated for discoloration and fragmentation on an ordinal scale (see Table 1 and Table 2) developed using photos from similar studies that observed latex balloon degradation (Gilmour and Lavers 2021; Balloons Blow 2022). Balloons were rated 0-5 on the Discoloration Ordinal Scale (Table 1) based on the amount of the balloon that had retained original color. Balloons were rated 0-5 on the Fragmentation Ordinal Scale (Table 2) based on the number and connectivity of the fragments. After three weeks, the ordinal scale experiment was terminated. Balloons were left out until 2 September 2021 to investigate any further changes.

Each latex balloon was cut into 22.5 x 36.5 mm pieces (Fig. 2a) that were clamped between two alligator clips and sandpaper squares for grip. One alligator clip was held in the same position, while the other was attached by a string to force plates on a force transducer. The force transducer was moved (2-5 cm) on a vertical axis to induce strain (change in length divided by initial length) on the balloon. Force was recorded by the force transducer and used to estimate stress (change in force over area) and elasticity (stress divided strain).

Data Analysis

I used a Chi-square Test for ordinal data (discoloration and fragmentation) and grouped categories that had low sample sizes (expected frequencies less than 1, and no more than 20% of categories with an expected frequency less than 5) in order to meet the assumptions of the Chi-square Test. The Chi-square Test determined if there was an association between Treatment and the degree of degradation for both the discoloration and fragmentation scales. I used an analysis of variance (ANOVA) to determine if elasticity differed between treatments. I used an analysis of covariance (ANCOVA) to determine if stress differed among treatments while strain was set as a covariate (this was to account for the fact that not all balloons were strained the same). Prior to running ANOVA or ANCOVA statistical tests, I tested the assumptions of normality and equal variances. If it did not meet these assumptions, then the data were transformed or a non-parametric Kruskal-Wallace test was used in place of the parametric test. I calculated all Chi-square Tests by hand and used R statistical software to perform ANOVA and ANCOVA tests. All *P*-values were compared to an alpha-level of 0.05 to determine significance.

RESULTS

I made some general observations while collecting ordinal data. There were differential water retention patterns between balloons in the Air and Soil Treatments: balloons in the Air Treatment had a spotted pattern, while balloons in the Soil Treatment had a pattern of wide, concentric circles. I noticed green buildup and the development of a slimy film only on the surface of latex balloons in the Water Treatment. The film did not rub off easily. Additionally, I observed that latex balloons in the Soil Treatment were the only treatment that became stiff.

Discoloration

There was an association between discoloration and treatment on Day 6 (χ^2 = 28.10, df = 4, P < 0.001, Fig. 3a), Day 13 (χ^2= 29.56, df = 4, P < 0.001, Fig. 3b), and Day 20 (χ^2= 32.00, df = 6, P < 0.001, Fig. 3c). Balloons in the Water Treatment discolored less than balloons in the Air and Soil Treatments (Fig. 3).

Fragmentation

There was an association between fragmentation and treatment on Day 6, (χ^2= 6.72, df = 2, 0.050 > P > 0.025, Fig. 4a), Day 13 (χ^2= 19.29, df = 2, P <0.001, Fig. 4b), and Day 20 (χ^2= 39.79, df = 4, P <0.001, Fig. 4c). Balloons in the Water Treatment fragmented less than balloons in the Air and Soil Treatments.

Stress and Strain

Although not significant, elasticity slightly differed between treatments (W = 6.29, df = 3, P = 0.098; see Fig. 5). Elasticity was lowest in Soil Treatments, and highest in the Air and Control Treatments. Further, stress differed between treatments when controlling for strain ($F_{3,43}$ = 4.17, P = 0.011, see Fig. 6). Soil and Water Treatments responded with a higher stress than Air and Control Treatments.

DISCUSSION

This project aimed to determine the difference between latex balloon degradation in air, soil, and water. While I aimed to simulate natural environments as best as possible, the setup of the experiment meant that balloons were held stationary in positions parallel to the ground (Soil treatment) or perpendicular to the ground (Air and Water treatments), whereas polluted balloons will move around in environments more freely. Additionally, balloons were subject to different temperatures in each treatment given the experimental setup. Regardless, this variation in balloon position among treatments may actually reflect the differences in position that a balloon may settle in natural environments. For example, in a water environment, a balloon may be held suspended in the water column and temperature would naturally be lower than a terrestrial or aerial environment.

Ultimately, I found that balloon degradation differed depending on the environment. Balloons lost color, became more fragmented, and lost elasticity different depending on if they were in the air, on the soil, or within water. These findings point to both macroscopic and microscopic properties of degrading balloons that are valuable in assessing the ecological impact of balloon and where conservation efforts should be directed. Balloons degrade faster in air and on soil than they do in water, which means that it is especially important to assess the effects of balloon pollution on aquatic ecosystems.

Macroscopic visual changes, in this case fragmentation and discoloration, occurred more quickly in balloons degrading in soil or air (suspended in a tree). It is noteworthy that balloons mostly did not fragment past the first ranking. Although physical changes are occurring, the relatively low degradation rankings suggest that latex balloons do not degrade on a macroscopic scale within the three-week time period in which this study was carried out. For at least three weeks, the balloon will still pose a threat of ingestion or entanglement to wildlife that interacts with it.

Despite the absence of macroscopic degradation, the differences that do preside in ordinal scale degradation do provide insight as to how balloons might degrade differently in different environments. By Day 6, balloons in the Air Treatment had become most discolored and balloons in the Air Treatment and the Soil Treatment mostly ranked a 1 or 2 in discoloration. Balloons in the Water Treatments largely retained their color. These trends continued into Day 13. By Day 20, Air and Soil Treatments reached a “three” discoloration, whereas the Water Treatment remained largely unchanged. By Day 6, only a few balloons in the Air and Soil Treatments had fragmented. These trends continued into Day 13. By Day 20, balloons in the Air and Soil Treatments fragmented more than balloons in the Water Treatment. Furthermore, microscopic physical changes may evade visual detection. Balloons from Soil and Water Treatments responded more than Air and Control Treatments to a certain strain, which suggests a loss in elasticity, particularly in the Soil Treatments. This points towards chemical changes in the structure of latex as it was affected by environmental conditions. This strong trend follows the changes we see in ordinal scale data. Balloons in the Water Treatment trended towards elasticity retention while also displaying the fewest visual changes. A balloon polluted in an aquatic environment is subject to different environmental factors than a balloon polluted on land. Such factors include less UV light, more biofouling, and less heat buildup (Andrady 1989). Andrady (1989) observed biofouling—the buildup of undesirable biological matter on a surface—on latex balloons in seawater (Bixler and Bhushan 2012). The development of this opaque biofilm can restrict the amount of light that reaches the latex and thus reduces the heat buildup in the balloon (Andrady 1989). Exposure to UV light results in chain scission and bond cleavage, which break up the latex polymer (Manaila et al. 2018). Balloons degrade less in water as a result of less UV light and more biofouling on the balloon's surface (Andrady 1989).

Balloons do not degrade much in any environment. However, balloons appear to degrade even less in water, where most balloon pollution can be expected given the majority of the planet's surface covered in water. Marine debris overall is a pressing conservation concern. *Procellariformes* (seabirds like petrels and shearwater) have a 20.4% mortality rate from ingesting a *single* debris item (obstruction of digestive tract) and balloons are the highest-risk debris item (Roman et al. 2019). While all marine debris has the potential to harm wildlife, balloons have been identified as among the top five "deadliest" (Wilcox et al. 2016). The most lethal threats that marine debris poses to marine taxa like seabirds, sea turtles, and marine mammals are entanglement and ingestion, but experts push for policy changes to lessen the threat (Wilcox et al. 2016).

The findings of this study can help better understand global balloon pollution in that we can understand the differential threats a balloon poses in different environments. However, there is much to be studied about balloon pollution. Despite the irreversible changes that do occur, more degradation does not equate to less adversary environmental impact. Leached chemicals can potentially have a biomagnified effect on the environment, in which through a food-web contaminants to increase in concentration, such as the DDT increasing 28.7 times in concentration from plankton to fish (Drouillard 2008; Evans 1991). Additionally, an undegraded balloon would be easier to remove from the environment because the majority of it is in one piece. Every factor of an organism's environment affects how suitable the environment is for that organism, and the chemical and physical threats posed by degrading balloons may alter the

Habitat Suitability Index, which combines all environmental variables on a species' vital rates and hence survival (United States Environmental Protection Agency 2016)

The problem of balloon pollution is a large-scale conservation issue with several solutions. First, there is a need to continue to quantify balloon degradation. Studies can be carried out in more varied environments, such as different temperatures or types of water. Different balloons, such as mylar can be analyzed. At the societal level, we can aim to fix the waste mismanagement that leaves pollution on coastal zones (Ferreria et al. 2021), especially since the chemistry of latex permits easy recycling (Venkatachalam et al. 2012). We can focus on modifying policies and knowledge that regulate the current balloon industry. Science-informed policy will take into account all the factors involved in balloon pollution and guide towards solving a multifaceted conservation issue.

Asides from the physics and chemistry of degrading balloons, it is also important to understand the geographical global patterns of balloon pollution. Toward this end, I developed a mobile app for this purpose called F.L.O.A.T. (Flying Litter Operations App Tracker; free to download on all Android devices), which uses citizen science to record instances of balloon pollution. Collected data would be used to construct maps that depict global patterns of balloon pollution and gather information about the nature of polluted balloons. This is one way that we can gather more information about balloon pollution and act accordingly by directing conservation efforts towards areas that suffer more from balloon pollution. Understanding and managing balloon pollution will add to the understanding and mitigation of litter and anthropogenic pollution.

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TABLES AND FIGURES

Table 1. Ordinal scale used to measure discoloration of balloons. Bottom right picture depicts a balloon rated a 1. Bottom left picture depicts a balloon rated a 3.

Ordinal Scale	Description of Discoloration
0	Indistinguishable from the Control Treatment balloons.
1	Any slight difference in original color.
2	Discoloration of at least a quarter of the balloon, but discoloration is spotty.
3	Discoloration of at least a quarter of the balloon, and discoloration patches are connected.
4	Few black spots along the balloon.
5	No original color remaining on the balloon.

Table 2. Ordinal scale used to measure fragmentation of balloons. Bottom right picture depicts a balloon rated a 1. Bottom left picture depicts a balloon rated a 2.

Ordinal Scale	**Description of Fragmentation**
0	Balloon fully intact.
1	Any shape or textural alteration.
2	At least one clear fragment present on balloon.
3	Two to three clear fragments present on balloon.
4	More than three clear fragments present on balloon.
5	The balloon is in multiple pieces.

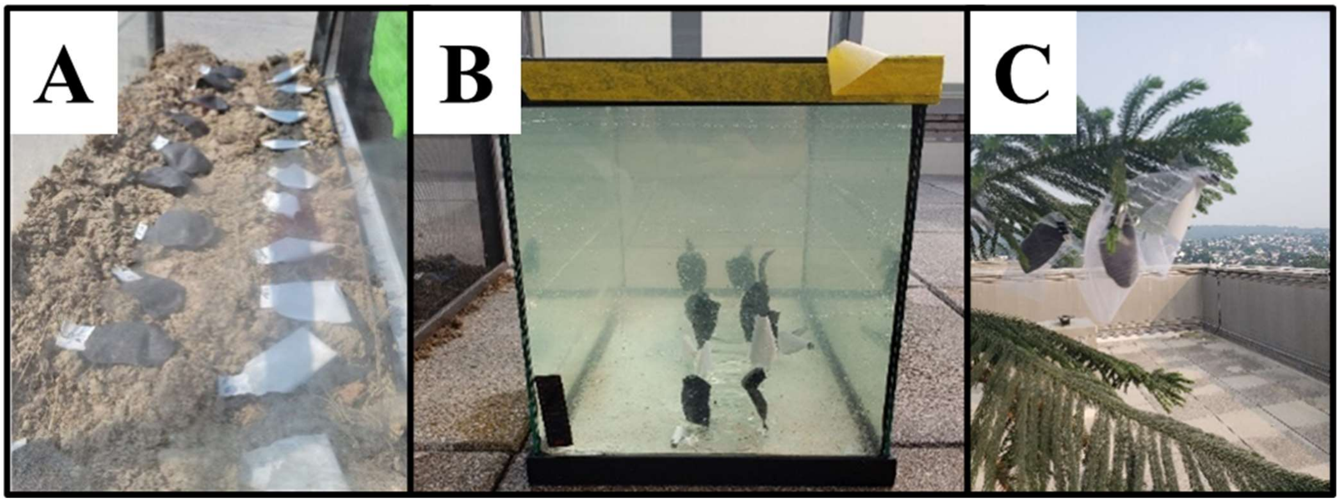

Figure 1: (A) Latex balloons (left row) were anchored to soil with paperclips in a terrarium, (B) were anchored to the floor of a water-filled terrarium with fishing wire and watch glasses, and (C) were clipped to branches of a Norfolk Pine and encased by tulle.

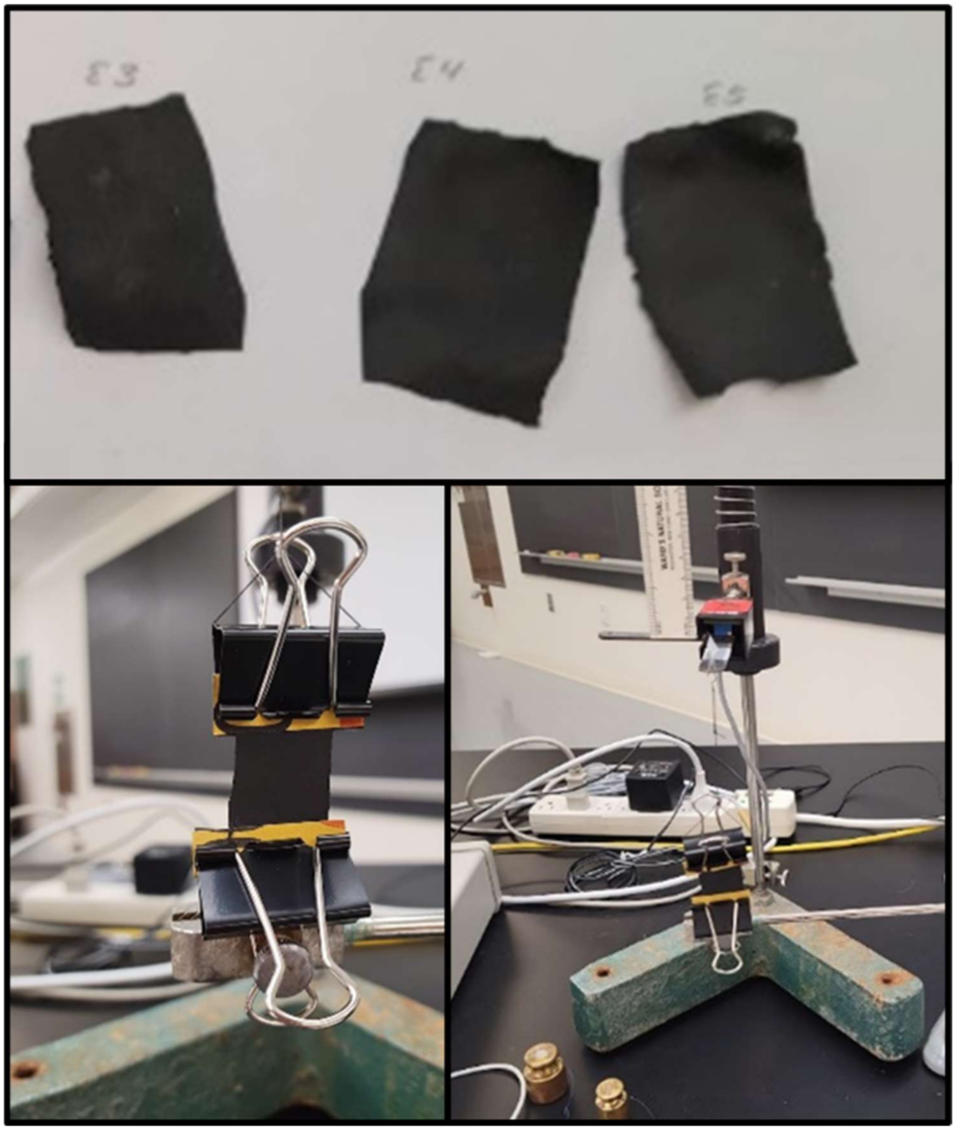

Figure 2: Balloons were cut into rectangles (top) and attached to the force transducer with paperclips, string, and sandpaper (below).

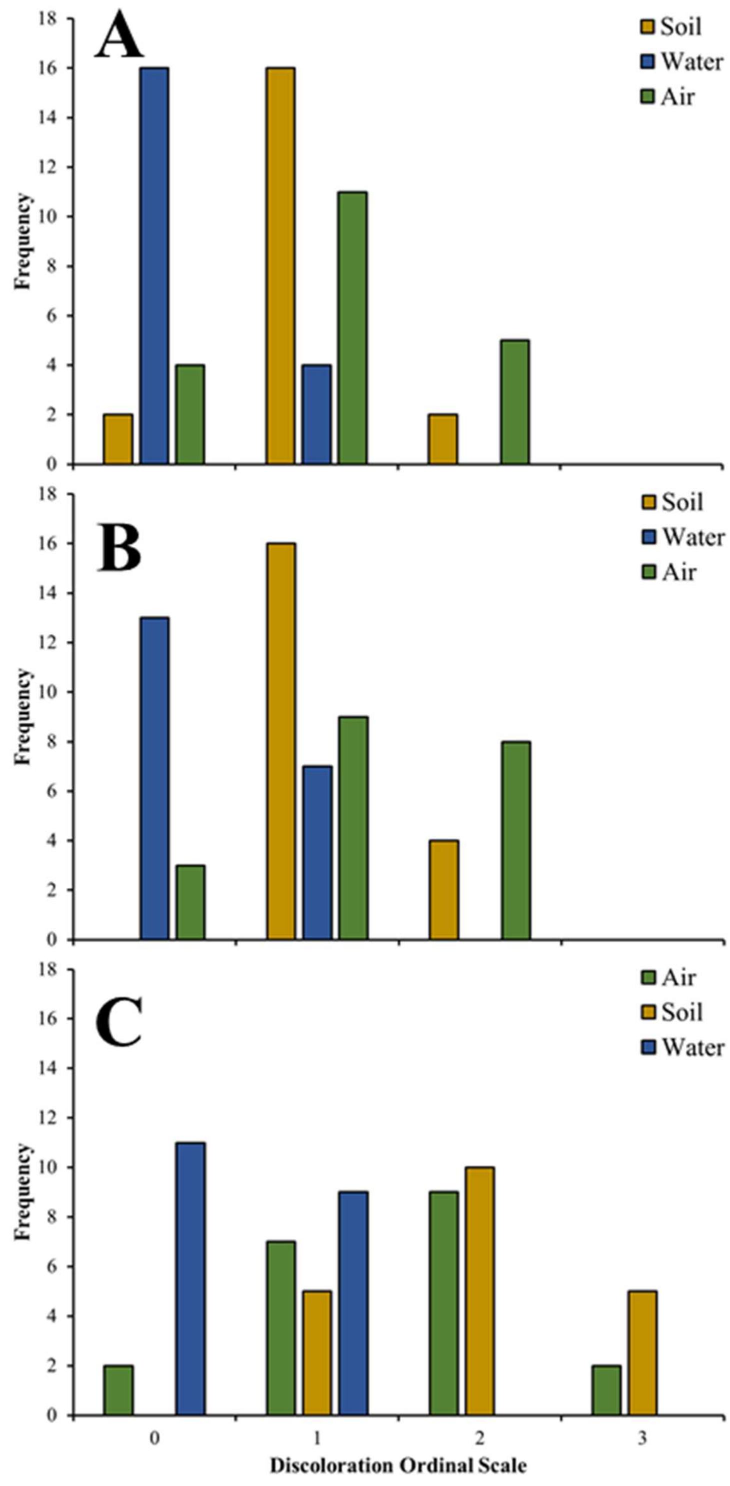

Figure 3: Balloons in the Water Treatment did not become as discolored as balloons in Air and Soil Treatments. (A) Day 6 (B) Day 13 (C) Day 20.

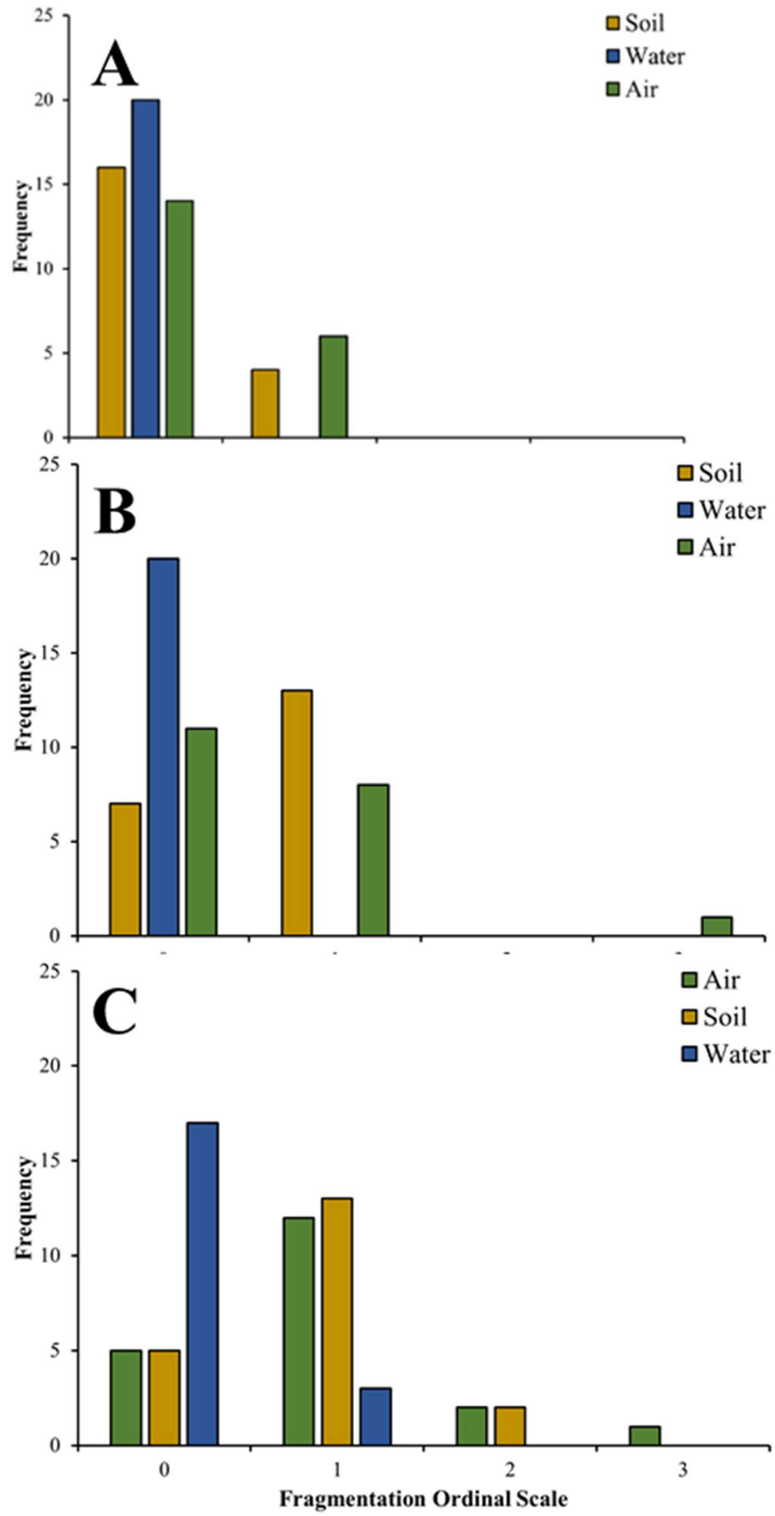

Figure 4: Balloons in the Water Treatment did not fragment as frequently as balloons in Air and Soil Treatments. (A) Day 6 (B) Day 13 (C) Day 20.

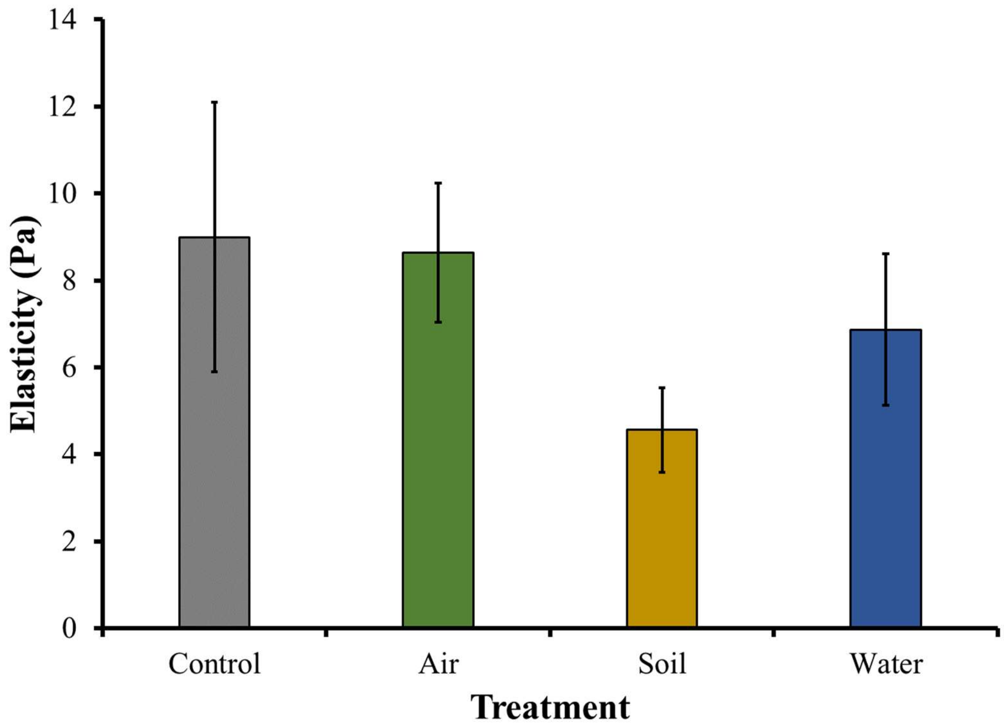

Figure 5: There was no difference between treatments. There is a strong trend of lower elasticity for the Soil Treatment. Height of bars represent means and error bars represent 1SE.

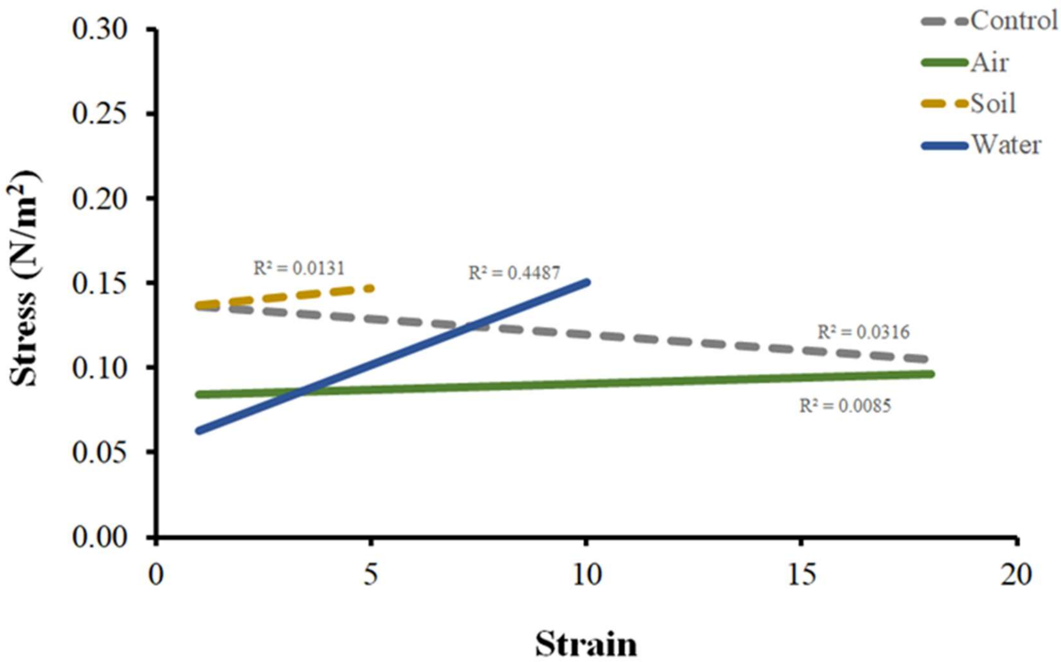

Figure 6: Soil and Water Treatments responded to strain differently than Control and Air Treatments.