Analysis of Plastic Pellet Distribution Using Citizen Science Nurdle Patrol Data and Batch Identification to Differentiate Spills Within Samples

Melanie Quan

Under the direction of

Colleen Johnson, Project Scientist, EarthCon Consultants, Inc.
Jace Tunnell, Reserve Director, University of Texas Marine Science Institute

Research Science Institute
July 27, 2020

Abstract

Microplastics in the environment are a source of emerging pollution with proposed negative impacts across all ecosystems. Plastic preproduction pellets called nurdles are a form of microplastics that are becoming increasingly present in beaches and waterways across the globe. In this study, citizen science data from the organization Nurdle Patrol was analyzed in relation to plastic manufacturers and railroad crossings in three, 50 square-mile regions along the Texas Gulf Coast. Results of this analysis indicate that the proximity of plastic manufacturers and railroad crossings to nurdle collection sites are important factors to be considered in predicting plastic pellet concentrations, yet must also be observed in conjunction with other environmental variables. Batch identification of polymer types with Fourier-transform infrared spectroscopy (FTIR) showed an abundance of polymers and polymer additives in the spectra of samples of nurdles that were analyzed. In all, 89 different production batches were identified across the 355 plastic pellets analyzed, indicating significant release of nurdles into the environment after production from a variety of sources. By identifying nurdle distributions and production batches in this study, the research highlights the need for establishing guidelines to classify nurdles as an environmental pollutant. In addition, state and federal regulations need to be established to prevent accidental spills of nurdles during all stages of production, handling and transport.

Summary

Small, plastic preproduction pellets called nurdles are being found in beaches and waterways all over the world, with a global estimate of 230,000 tons polluting the environment every year. In order to gain a better understanding of the relationship of nurdle manufacturing sites to nurdle distribution, manufacturing locations and railroad crossings were analyzed in conjunction with citizen science data from the organization Nurdle Patrol. In addition, analysis of the chemical and physical composition among the nurdles in samples helped identify a variety of different batches of nurdles that were produced and accidentally released into the environment. Findings showed a variety of nurdle batches, indicating many spills of nurdles into the environment. This study highlights the urgent need for legislation and policy to address the production, handling and transport of nurdles and better managing and classification of nurdles as an environmental pollutant.

1 Introduction

Plastic pollution in the marine environment has become a global crisis, with nearly 8 million tons of plastic waste discarded into waterways annually [1]. While large, macro-plastic articles pose a threat to environmental and human health through entanglement, ingestion, and interactions with light and dissolved oxygen content [2], smaller microplastics (<5mm) pose a significant health risk due to their ability to sorb toxins and be easily ingested by wildlife [3]. One form of primary microplastics found in the environment are nurdles. Nurdles are virgin plastic resin in pellet form that are used to create almost all plastic products. In order to aid the transportation and manufacturing processes, nurdles are created to be lightweight and small in size. Typically, nurdles are about 2-5mm in diameter and weigh approximately 20mg. The produced pellets are transported from the production site (via train, ship, or truck) to a facility where the final product is molded and extruded from the virgin pellets. Due to their small size, buoyancy, and light weight, nurdles are difficult to contain and can be lost in all steps of the production chain [4]. Current global estimates for nurdle pellet loss is 230,000 tons per year [5].

Nurdles have been used as a basic plastic resin since plastic production greatly increased in the 1950s. Studies have reported nurdle presence in the waterways since the 1970s [6]. Later reports in the 1990s indicate knowledge of nurdle spills and transportation loss, yet because of the nontoxicity of the pellets, there was no significant policy reform [7]. At this time, California is the only state that classifies nurdles as a pollutant, which can lead to irresponsibility among manufacturers in safely transporting and handling nurdles to prevent release in the environment. Further information regarding legislation and court cases on nurdle release into the environment can be found in Appendix A.

Despite virgin plastic pellets not being toxic upon ingestion, nurdles have a significant health risk once they enter the environment. Microplastics like nurdles are associated with co-contaminants such as heavy metals, persistent organic pollutants (POPs), and pathogens that have been known to attach to the plastic's surface [8] [3] [9] [10] [11]. Additionally, the shape and color of many nurdle pellets appear to resemble fish eggs in nature. This similarity can cause confusion among animals and lead to ingestion of the pellets, which offer no nutritional value, thus leading to organ entanglement, intestinal blockage, starvation, or death. They can also transport the toxins the plastics absorbed up trophic levels where they can bioaccumulate [12]. While many studies have observed the physiological and behavioral effects of microplastics such as nurdles on marine life [13] [14], as of this time, the full extent of the impact of nurdles on human, ecosystem, and animal health are not completely known.

While the exact amount of nurdles lost in handling and spills is unknown, a global estimate is 230,000 tons per year [5]. Events such as nurdle spills are typically labelled as being responsible for large inputs of nurdles into the environment, such as the 2018 Durban Harbour spill, where forty-nine million tons of nurdles spilled into the Harbour in South Africa. Since that spill, only 23 percent of the nurdles have been recovered [15]. Similar spills of nurdles have occurred along the coasts of California, in the Gulf of Mexico, and in Hong Kong. Because of their buoyancy and small size, nurdles are easily circulated, so unless immediate action is taken after a spill, nurdles rapidly disperse in the environment [15].

In order to monitor nurdle dispersal in the environment, the Mission-Aransas National Estuarine Research Reserve at the University of Texas Marine Science Institute established a citizen science project Nurdle Patrol to sample and map nurdle abundance along waterbodies. Nurdle Patrol's active use of citizen science to collect nurdle concentrations along the coasts is one way the public can assist in identifying the spread of nurdles in the waterways after spills. The use of citizen science allows for a large collection of data from a variety of locations at a minimal cost. In addition, the act of encouraging the public to participate in Nurdle Patrol also promotes finding resolutions to the problems surrounding nurdle handling and pollution [16]. While the individual reports of nurdles may have inaccuracies, compiling the reports into a larger database to map nurdle distribution can reveal the trends in nurdle abundance in waterbodies.

In order to gain a better understanding on the relationship of nurdle manufacturing sites to nurdle distribution, manufacturing locations provided by the United States Environmental Protection Agency's Toxics Release Inventory and railroad crossings provided by the United States Department of Transportation were analyzed in conjunction with Nurdle Patrol Data from November 2018-June 2020. This study is a first analysis of Nurdle Patrol data in relation to potential sources of nurdles along the Texas Gulf Coast. Additionally, this study identifies the number of spills found in nurdle samples collected with Nurdle Patrol methodology, providing an understanding of the frequency of spills in handling and transportation. Analysis of the chemical composition among the nurdles in a sample will help identify how many batches and spills are in a certain area and highlight the need for policy in nurdle handling techniques. This serves as a policy-relevant study for other states and countries for creating legislation and requiring infrastructure (i.e. storm water drainage separation systems) for managing nurdle and microplastic pollution.

2 Methods

In order to determine the effect of location on nurdle distribution, regression tests comparing distance from manufacturing or transportation sites to Nurdle Patrol reports were conducted. In addition, in order to determine sample variety, individual Nurdle Patrol sample composition analysis was conducted on selected samples.

2.1 Data Formatting and Statistics for Nurdle Patrol Data

Data were obtained from Nurdle Patrol, led by the Mission-Aransas National Estuarine Research Reserve at the University of Texas Marine Science Institute in Port Aransas, Texas.

Locations of plastic manufacturing sites were gathered from the Toxic Release Inventory, with NAICS Code 3261. Data of railroad crossings was obtained from the United States Department of Transportation for the state of Texas.

Standard Nurdle Patrol reports are of the submission of the number of nurdles found in a 10 minute time period along the high tide line. If nurdles are not found along the high tide line, then the previous high tide line is used and reported into the database. Since Nurdle Patrol allows for submissions that are greater than 10 minutes and have more than one participant, the data was standardized to the number of nurdles collected by one individual in 10 minutes. Abundance of nurdles from the reports were calculated and mapped with geographic information systems (GIS) software (Caliper's Maptitude and Esri's ArcGIS). Statistical tests were conducted with Graphpad Prism [17] and Python.

Three, fifty square mile regions along the coast of Texas were defined near the cities of Corpus Christi, Galveston, and Bay City due to high numbers of nurdle reports in these areas. These regions were analyzed for nurdle concentrations in relation to plastic manufacturers and nurdle concentrations in relation to railroad crossings.

The distance between the closest plastic manufacturers and each nurdle report was calculated and then graphed. Regression analysis was performed on locations with high numbers of nurdle reports to determine the relation between distance and concentration. To calculate distances from longitudes and latitudes, the Haversine formula was used. This formula takes into account the spherical shape of the earth. Assumptions in distance calculation are that the earth is a perfect sphere, without topographical features such as mountains or valleys.

2.2 Nurdle Sample Collection

Using the described Nurdle Patrol collection method, samples were gathered for Fourier-transform infrared spectroscopy (FTIR) analysis. Nine locations in Texas were chosen to determine the number of chemically different plastics in each collection. Since each production batch of nurdles is made to order, chemically different plastics belong to different batches. Figure 1 shows the locations of the nine sites in relation to where the majority of Nurdle Patrol sampling has been conducted.

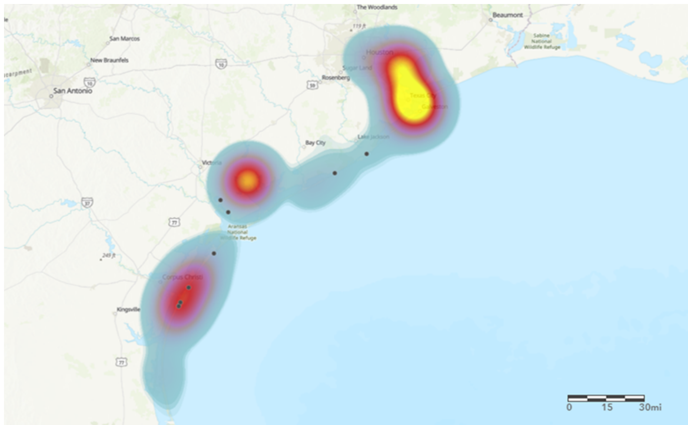

Figure 1: The map of the Texas Gulf Coast shows the locations of the nine different sampling sites. The overlay indicates areas of high numbers of citizen science reports on nurdle abundance, with yellow areas indicating regions of highest sampling and blue areas indicating minimal sampling. Uncolored regions have zero reports on nurdle concentrations.

2.3 Categorizing nurdles based on physical differences

Each nurdle sample was sorted by visual differences such as shape, size, and color. This data was used to support the findings of the FTIR analyses. Within each sample, up to 50 nurdles were randomly selected to be analyzed by FTIR. In total, out of the 709 nurdles, 355 were tested. The following Figure 2 shows the samples used for the study, containing nurdles from the same sample regions as the data analysis.

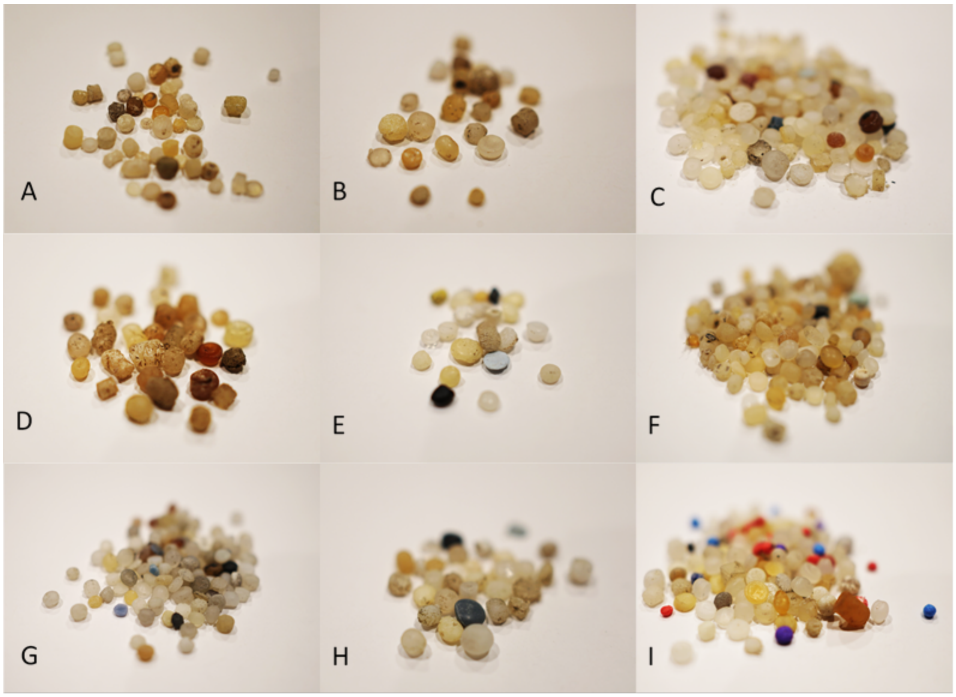

Figure 2: Images of nurdle samples from the nine regions taken before cleaning. Pellet sizes range from 2mm to 5mm in diameter. A: 44 nurdles (-96.8045, 28.5191), B: 22 nurdles (-96.7232, 28.4090), C: 188 nurdles (-97.1186, 27.7492), D: 31 nurdles (-95.3424, 28.9216), E: 22 nurdles (-97.2006, 27.6174), F: 142 nurdles (-95.6579, 28.7548), G: 111 nurdles (-97.2200, 27.5815), H: 36 nurdles (-96.8689, 28.0471), I: 113 nurdles (-97.2172, 27.5875)

2.4 FTIR analysis

Nurdle samples from the various locations were collected for the determination of chemical composition using Fourier-transform infrared spectroscopy with a single beam Thermo Scientific Nicolet iS 50. Within the same plastic types, samples from different batches can have spectral differences depending on the presence of various plastic additives.

The nurdles were cleaned and prepared for FTIR analysis by soaking in deionized water for 10 minutes. The nurdles were then soaked in 3% hydrogen peroxide for 20 minutes to remove surface organic pollutants. The nurdles were then air dried for 24 hours and sliced to fit the FTIR instrument.

The FTIR spectra of the samples were collected in attenuated total reflectance (ATR) using a single beam Thermo Scientific Nicolet iS 50 Spectrometer with iD5 ATR Assembly, equipped with a diamond crystal. The spectrum of the diamond crystal was recorded as background and subtracted from the total recorded spectra of the sample.

The spectra were collected in 4000 and 650 cm-1 range with 4.000 resolution after 16 scans using the cosine function as apodization technique. The FTIR spectra were baseline corrected and smoothed. This preprocessing was necessary to enhance the resolution and interpretation by reducing noise and ghost peaks. The spectra were saved as .spa files for use in the Thermo Scientific OMNIC Anywhere software. Using the OMNIC database of plastic polymers and additives, the specific composition of each nurdle was determined, recorded, and compared to the spectra of the other nurdles within the sample. Nurdles with the same chemical composition and physical appearance were considered to be from the same batch.

3 Results

3.1 Determination of Sample Regions With High Numbers of Nurdle Reports

To create a model determining the effect of distance from plastic manufacturers and railroad crossings on nurdle concentrations, three sample regions were chosen from areas of large amounts of nurdle reports. After creating a density map for the areas of high numbers of nurdle reports, the longitudes and latitudes of three, 50 square mile regions (about 130 square kilometers) that maximized nurdle reports were determined and are shown in Figure 3. From this map, it was shown that the majority of nurdle reports have occurred in these three regions.

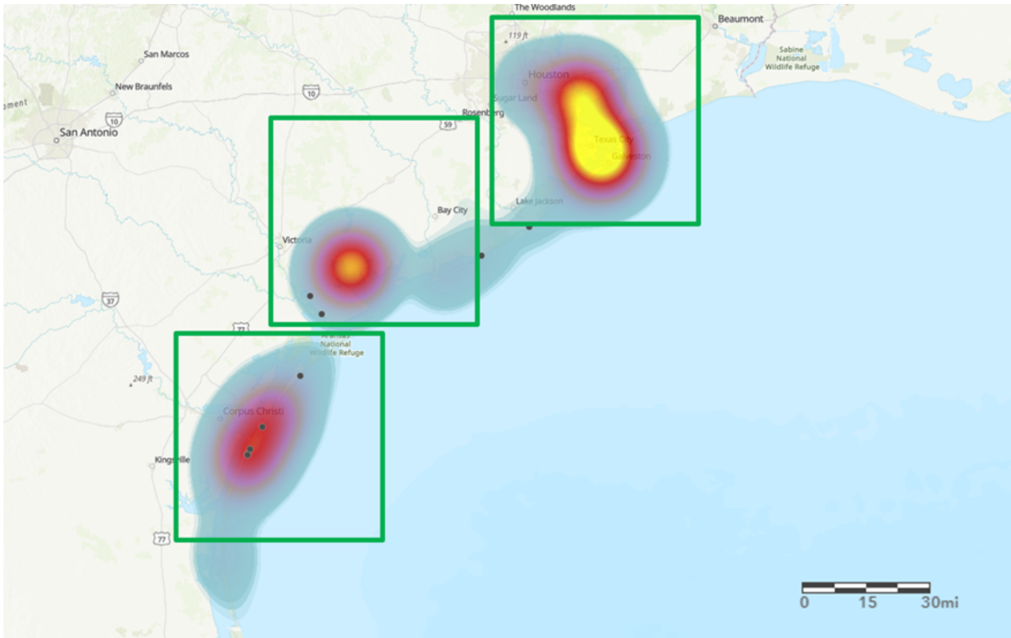

Figure 3: Regions were selected to maximize the number of nurdle reports in a 50 square-mile area. These three highlighted regions along the Gulf of Mexico in Texas indicate the areas where there are the highest number of nurdle reports.

See Appendix B for longitude and latitude coordinates of the sample regions.

3.2 Distance from Plastic Manufacturers is Weakly Correlated with Reported Nurdle Concentrations

After defining the three regions of high nurdle reports, distances from the nearest plastic manufacturer for each report in the region was calculated to determine the effect of distance on the number of nurdles found. Linear regression tests were performed and showed that distance from the closest plastic manufacturer is a significant factor to be considered ($p<0.0001$, $p= 0.0401$, and $p=0.0008$) for the three respective regions. However, the r-squared values were not significant (0.095, 0.6917, and 0.0228 respectively) and therefore indicates that the distance from manufacturers and number of nurdles collected relationship only accounts for a small percentage of the variation. This test shows that distance from plastic manufacturers does have an impact on reported plastic pellet numbers, yet is potentially influenced by other factors that were not included in this study. Distance from railroad crossings was considered as another factor to be evaluated.

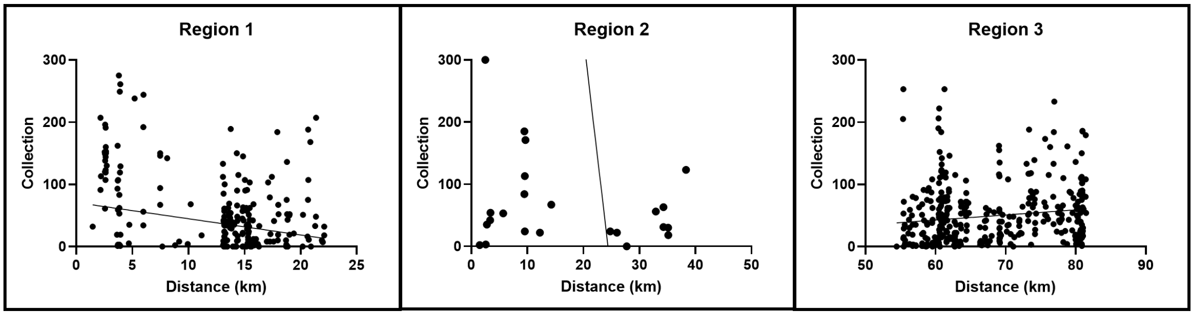

Figure 4: Linear regression tests were conducted on the relationship between the distance from each nurdle report to the closest plastic manufacturer and the number of nurdles reported. A: Region one ($p<0.0001$, r-squared=0.095), B: Region two ($p=0.0401$, r-squared=0.6917), C: Region three ($p=0.0008$, r-squared=0.0228)

3.3 Distance from Railroad Crossings is Weakly Correlated with Reported Nurdle Concentrations

Having observed that distance from plastic manufacturers is a significant factor in determining nurdle distribution but weakly related to the variation in relationship, the next test determined the correlation between the distance to the closest railroad crossing and the number of nurdles reported. Across the three study regions, linear regression tests indicated that distance to railroads is a significant facter in predicting the number of nurdles found ($p<0.001$, $p=0.102$, and $p=0.0008$). The r-squared values are not significant (0.095, 0.058, and 0.023). This suggests that other models or factors must be considered to better understand and predict the distribution of nurdles in the environment.

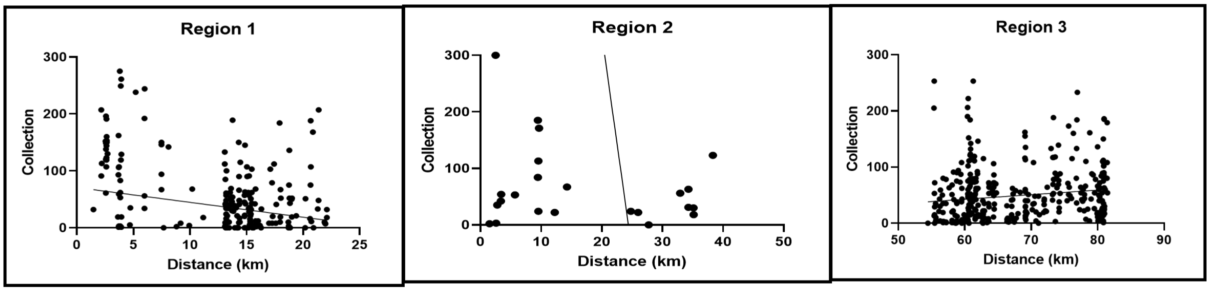

Figure 5: Linear regression tests were conducted on the relationship between the distance from each nurdle report to the closest railroad crossing and the number of nurdles reported. A: Region one ($p<0.0001$, r-squared=0.095), B: Region two ($p=0.102$, r-squared=0.058), C: Region three ($p=0.0008$, r-squared=0.023)

3.4 Batch Identification with FTIR Shows Abundance of Plastic Types in Samples

FTIR analysis was used to determine the polymer type and additives in each nurdle. Nurdles exhibiting the same spectral data were considered to be of the same batch. Overall, 89 different batches were identified across all the nurdles tested in the nine samples. A variety of batches were found in multiple samples across the different regions. The following Figure 6 shows the number of batches identified in each sample. Figure 1 can be referenced for the location of each sample along the Gulf Coast of Texas.

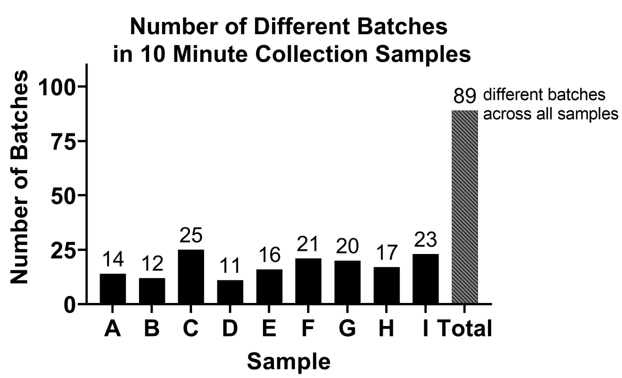

Figure 6: The number of different batches identified by FTIR in each sample are compared.

In order to determine batches, plastic type was identified using the functional group side of the infrared (IR) spectra. Overall, Low Density Polyethylene (LDPE) was the most common plastic identified among all of the samples. Other common plastic types found among the samples included Polypropylene (PP), Ethylene Propylene Diene Monomer (EPDM), and Medium Density Polyethylene (MDPE). Figure 7 shows the percentages of various plastic types within each sample.

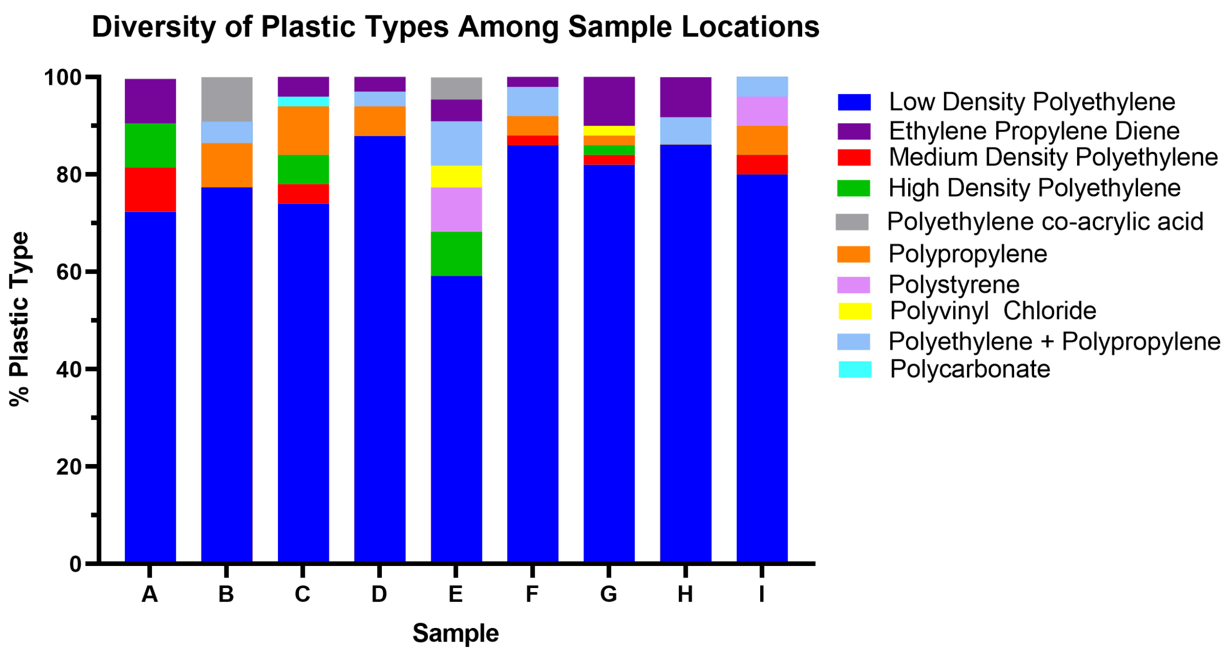

Figure 7: The functional group region of the FTIR spectra was used to determine polymer type. Each plastic type is represented by a different color. Most common plastic was Low Density Polyethylene.

Using the fingerprint region of the IR spectra and other identifying functional group peaks, various combinations of additives were identified within each plastic type to further sort the nurdles and identify the number of batches present in each sample. Each group of nurdles with a different IR spectra graph as well as physical appearance (shape, color, size) was determined to be of a specific batch.

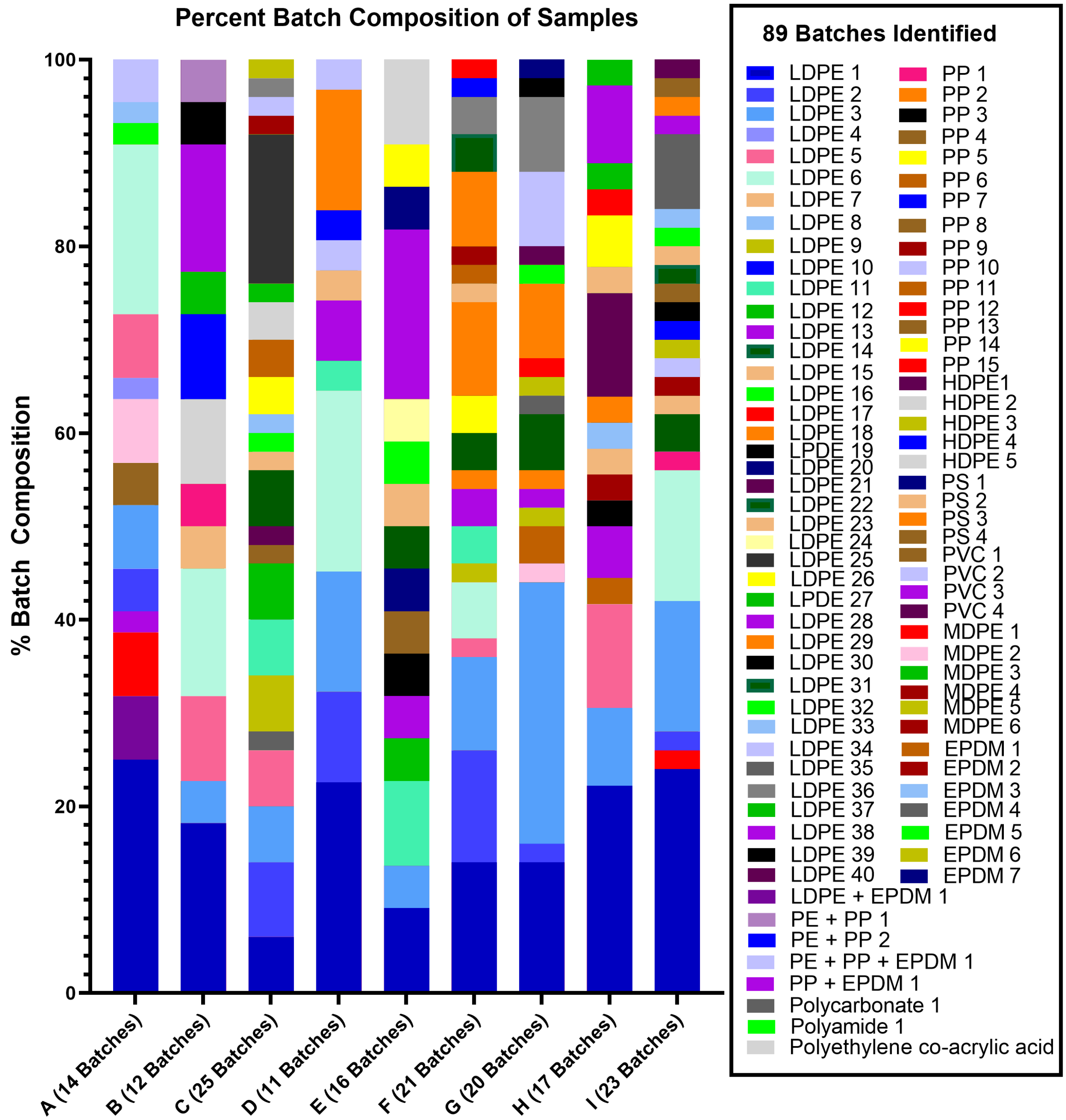

Figure 8: The nurdles were sorted according to color, shape, polymer type, and additives to determine the unique batches of nurdles in each sample. The batch percent composition of each sample of nurdles is represented in the figure.

Reference Appendix C and D respectively for a list of additives and properties tested among the nurdles and the IR spectra of 8 common plastic batches found.

3.5 Samples Near Plastic Manufacturers Exhibit Lower Batch Variety

To determine basic geographic effect on the variety of batches, the samples were divided into the northern and southern samples along the 28-degree latitude. It was found that the Northern samples had less batch variety than the Southern samples, which were mostly concentrated in the Corpus Christi area (Figure 9). The four batches farthest north have an average number of 14.5 batches per sample ($\sigma = 3.25$) and the four batches farthest south have an average number of 21 batches per sample ($\sigma = 3$).

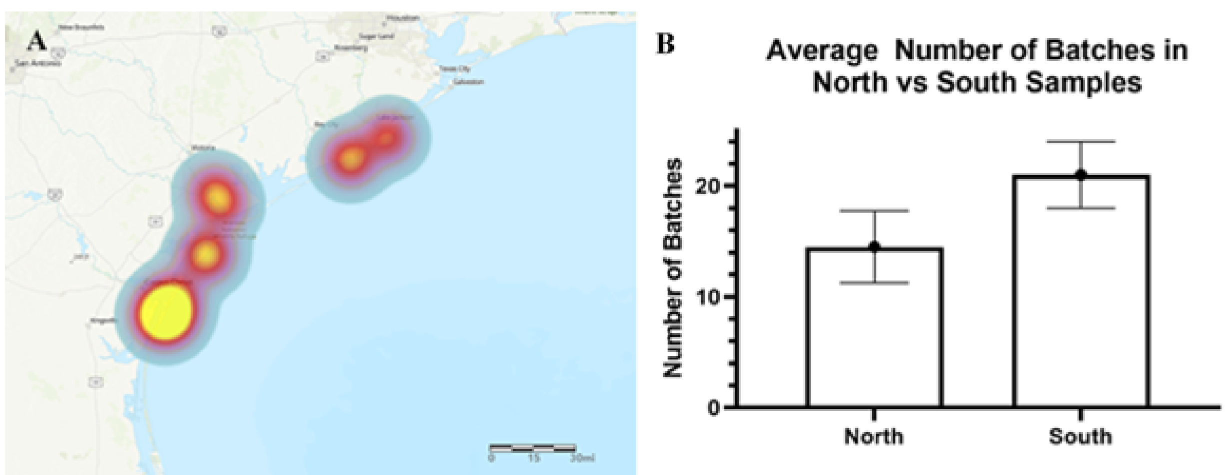

Figure 9: When organized by location, samples South of 28 degrees latitude exhibited greater numbers of production batches than samples in North of 28 degrees latitude. A: The map of the Texas Gulf Coast shows the locations of greater diversity in production batches identified with FTIR. The overlay indicates areas of high batch diversity, with number of batches identified proportional to the size of the yellow regions. B: Average numbers of batches for samples in northern and southern regions.

4 Discussion

While the release of nurdles into the environment is often attributed to large spills (such as the 2018 Durban Harbour Spill), this study identifies a large variety of plastic types within samples in a region, indicating the potential for many sources of nurdle input into the environment, rather than single events.

4.1 Identification of Study Regions

The study regions identified to have the most nurdle reports were all along the Gulf of Mexico in Texas (Figure 3). Given that Nurdle Patrol is run by the University of Texas Marine Science Institute and the Mission-Aransas National Estuarine Reserve, it is understandable that the program has expanded the most in this area. These regions help identify the scope of the program, where the majority of samples have been collected. As the program expands and more data is collected by citizen scientists, other areas can be evaluated to create maps and models of nurdle distribution in the area that can help target cleanup.

Previous analysis of nurdle patrol data supports the current data indicating regions 1 and 3 (Figure 3) to have the highest numbers of nurdles reported in the area [18]. These locations coincide with the plastic manufacturing regions in the US, but are also influenced by currents such as the Loop Current and Yucatan Current that meet near Padre Island close to Corpus Christi in region 3 [19]. This might be a contributing factor to the high numbers of nurdles reported in region 3 despite having fewer plastic manufacturers than regions 1 and 2.

4.2 Plastic Manufacturers and Railroad Crossings Effect on Nurdle Concentrations

Non-significant r-squared values fail to show manufacturers and railroad crossings as being the sole factors in determining nurdle distribution (Figures 4 and 5). Failure of plastic manufacturer and railroad crossing proximity to sample sites in explaining variation in the data could be attributed to the limited sample size that is mostly concentrated along the coasts. Expansion of Nurdle Patrol collections to include more data, such as inland areas, could help fill these voids in the future. While there was no significant correlation between distance from manufacturers/railroads and nurdle concentrations, the p-values suggest that these are factors to consider in a larger, multi-variable model. Other factors such as currents, wind, geography, and extreme weather events should be considered to understand and predict nurdle distribution in the environment.

4.3 Plastic Batch Analysis

Large batch varieties among nurdle samples indicate that large nurdle spills (which would be of the same batch and composition) are not the sole source of nurdle input into the environment. This is supported by previous case studies in Sweden that note the accidental release of plastic pellets in transportation and handling [4]. The high number of plastic pellets lost from multiple releases from different batches indicate a broader issue regarding the handling of nurdles and accidental release into the environment beyond one-time spills. Thus, this has implications in legislation and industry in trying to prevent pellet loss into the environment.

Of the samples tested, it was found that LDPE was the most common plastic type (Figure 7). While this could indicate LDPE is most commonly spilled and released into the environment, LDPE's popularity in samples could be also due to its more buoyant nature, which allows waves to carry it to shore, where most of the nurdle sample collection occurs. Nonetheless, categorizing plastic type and additives (which determine buoyancy) could be helpful in identifying regions to collect nurdles and implement filtering techniques.

Of the nine samples tested, sample C had the most nurdles found in 10 minutes (188) and had the highest number of batches present (25). This sample falls within region 3, which was identified to have many currents convene near Padre Island, Corpus Christi, and Mustang Island where the sample was collected. Further research on the effect of currents and tides could help predictions of plastic pellet movement in waterbodies.

4.4 Limitations of Citizen Science

Although citizen science allows for low-cost, widespread data collection while increasing awareness of an issue, data gathered from citizen science has potential for inaccuracies. Recruiting volunteers who fail to follow Nurdle Patrol methodology can lead to mislabeling of data (i.e. whether the collection was at the new tide line) or misidentification of nurdles (i.e. confusion for airsoft pellets or beads). Citizen scientists can also miss nurdles in an area, therefore leading to underreported nurdle concentrations [20]. One way that Nurdle Patrol combats the false reports is by requiring the submission of a photo revealing the nurdles collected and the waterbody that the nurdles were collected from.

4.5 Future Work

This study reveals the complicated nature, yet necessary task, of tracking nurdles in the environment after their release. Due to many environmental factors, locations of production and transportation are not the only factors needed when creating a model of nurdle distribution. In addition, the large variety of plastic types found indicate that various physical properties such as buoyancy or coalescence may differ among individual nurdles, which further complicates models of nurdle spills. Further understanding of these properties is necessary to be able to develop a model of nurdles in the environment in the future.

In addition, this study raises fundamental questions of the toxicity of nurdles and other microplastics in the environment. Understanding how nurdles interact with animals and transport toxins is necessary for the protection of environmental and human health.

Finally, further expanding the Nurdle Patrol organization can lead to the collection of such data while increasing awareness of the significance of plastic pellet pollution.

5 Conclusion

This study was the first analysis of the Nurdle Patrol data in relation to plastic manufacturers and railroad crossings. Findings show that distances from plastic manufacturers and distances from railroad crossings do not significantly affect nurdle concentrations. Instead, a variety of factors is necessary to be evaluated to better understand the distribution of nurdles in the environment. Additionally, through the use of FTIR spectroscopy and IR spectra analysis, this study helped identify the number of batches and potential spills found in the nurdle samples collected. Overall, 89 different batches were identified across the 355 nurdles tested in the nine samples.

This study provides insight on the frequency and widespread nature of spills that lead to many batches of nurdles present in the samples across different regions. By identifying a large number of batches within the samples, this serves as a policy-relevant study to promote more careful handling, storage, and transportation of nurdles to reduce accidental spills.

6 Acknowledgments

I would like to express my sincere gratitude to Colleen Johnson and Jace Tunnell for mentoring me in this research. I would also like to thank my tutor, Ph.D candidate Ana Lyons, for her advice and encouragement throughout this process. Thank you also to Jessie Oehrlein, Aayan Patel, Khushi Kohli, and RSI teaching assistants and staff for providing helpful suggestions and edits to my paper. Additionally, thank you to Ph.D candidate Edward Njoo of Fremont STEM Labs for training me on the FTIR instrument and providing lab access. I would also like to extend my appreciation to the Research Science Institute, the Center for Excellence in Education, the Massachusetts Institute of Technology, and the US Department of Defense and other CEE sponsors for assisting and sponsoring me this summer. Finally, thank you to all of the citizen scientists who have contributed to the Nurdle Patrol database.

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A Current Legislation

At this time, California is the only state with a law that identifies nurdles as a pollutant, which allows the state to penalize nurdle producers under the Clean Water Act if nurdles are discharged into the waterways [21]. In other states, nurdles are not named as pollutants because the virgin plastic pellets are nontoxic when initially produced. Despite evidence indicating the sorption of other pollutants in the waterways, accidental ingestion, and habitat disruption, there are no federal handling guidelines to prevent accidental spills during transport.

During the creation of Nurdle Patrol, millions of nurdles were found along the Mustang and North Padre Islands near Corpus Christi, Texas. Since state agencies attributed this to a single offshore nurdle spill, there were no cleanup measures [18]. Analysis of Nurdle Patrol samples will help indicate how many spills are involved in such events and can potentially reveal multiple sources of nurdle pollution in the environment.

One potential solution to preventing nurdle pellet loss in the environment is Operation Clean Sweep (OCS). OCS is a voluntary campaign dedicated to helping plastic resin handling companies achieve “zero pellet, flake, and powder loss” by the Plastics Industry Association (PLASTICS) and the American Chemistry Council (ACC). Member organizations agree to inspection and employee training to ensure accountability and increase company awareness of the dangers of pellet loss. While there remains flaws in the design that allow for some nurdle loss, implementing Operation Clean Sweep practices can significantly prevent pellet loss into the environment [22]. By identifying nurdle distributions and spills in this study, the research could help influence nurdle manufacturers to adopt similar policies or practices to prevent nurdle loss.

Precedent for adopting strategies to prevent pellet loss are already present in California’s legislation. Additionally, the recent case of San Antonio Bay Estuarine Waterkeeper and S.

Diane Wilson, Plaintiffs vs. Formosa Plastics Corporation resulted in a $50 million settlement and compliance with "zero pellet discharge" for Formosa Plastics' illegal dumping of billions of nurdles and other pollutants into Lavaca Bay, Texas [23]. These examples, as well as the OCS practices, indicate the possibility of moving towards minimizing pellet loss through more careful handling and effective legislation.

B Coordinates of Sample Regions

Region 1:

`(29.818107, -95.559079); (29.818107, -94.696652); (28.955643, -94.696652); (28.955643, -95.559079)`

Region 2:

`(29.091077, -96.965329); (29.091077, -96.102902); (28.28865, -96.102902); (28.22865, -96.965329)`

Region 3:

`(28.087832, -97.781064); (28.087832, -96.918637); (27.225405, -96.918637); (27.225405, -97.781064)`

C List of Properties and Additives Tested on Nurdles

Polymer	Additive	Physical Property
Low Density Polyethylene (LDPE)	Zinc Oxide	Hollow Center
Medium Density Polyethylene (MDPE)	Alumna Silicate	Cylindrical
High Density Polyethylene (HDPE)	Quaternary Ammonium Compound	Flat Disk
Polypropylene (PP)	Paraffin Wax	Sphere
Ethylene Propylene Diene Monomer (DPEM)	Stearmide	Cube
Polystyrene (PS)	Irganox 1093	White
Polyvinyl Chloride (PVC)	Talcum	Clear
Polyethylene + Polypropylene (PE + PP)	Calcium Stearate	Black
Polycarbonate	Octadecanoic Acid	Brown
Poly (ethylene co-acrylic acid)	Polyolefin	Yellow
Polyamide (Nylon)	Methyl Tin Mercaptide	Green
	Dioctadecyl 3,3-thiodipropionate	Red
	Dibasic Lead Stearate	Blue
	Pentaerythritol	

Table 1: Various polymer types, additives, and physical properties each nurdle was analyzed for.

D IR Spectra of Common Plastic Batches

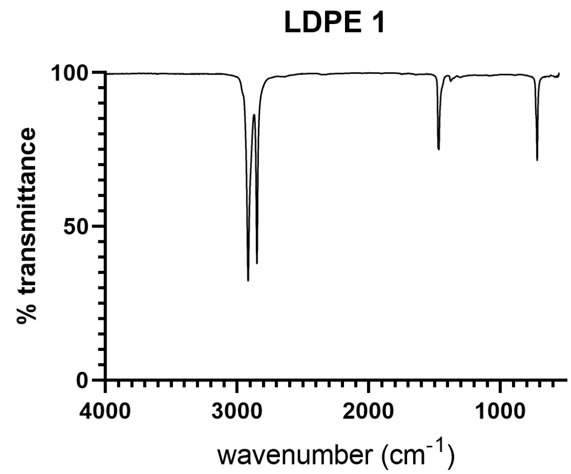

Figure 10: cylindrical, clear, LDPE, Paraffin Wax, Calcium Stearate, Octadecanoic Acid, Oxidized Polyethylene

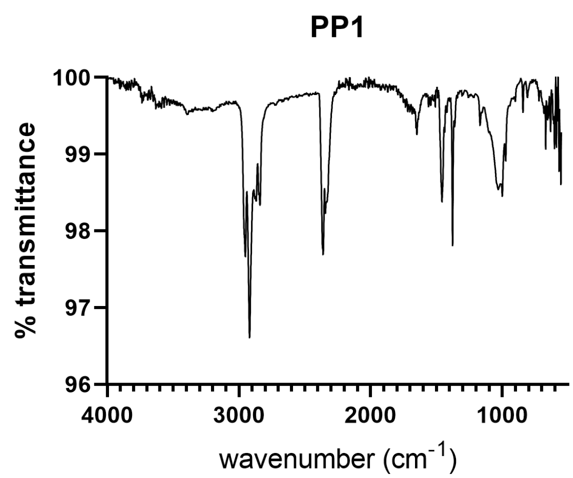

Figure 11: hollow center, cylindrical, clear, PP, zinc oxide, Irganox 1093, Polyolefin, Methyl Tin Mercaptide

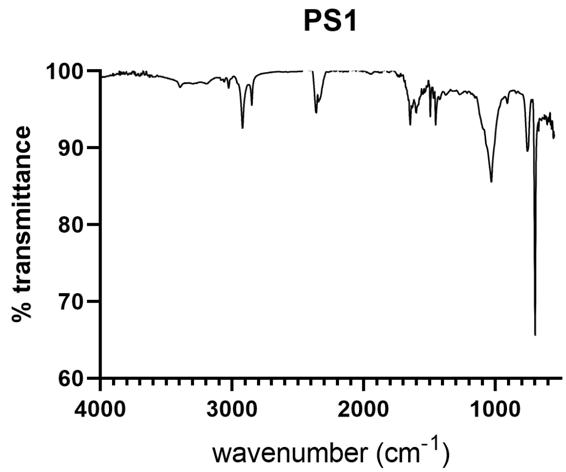

Figure 12: sphere, white, PS

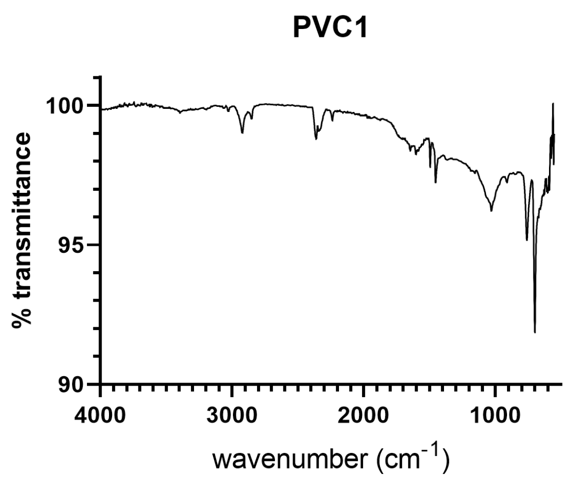

Figure 13: cylindrical, clear, PVC, Zinc Oxide, Alumna Silicate

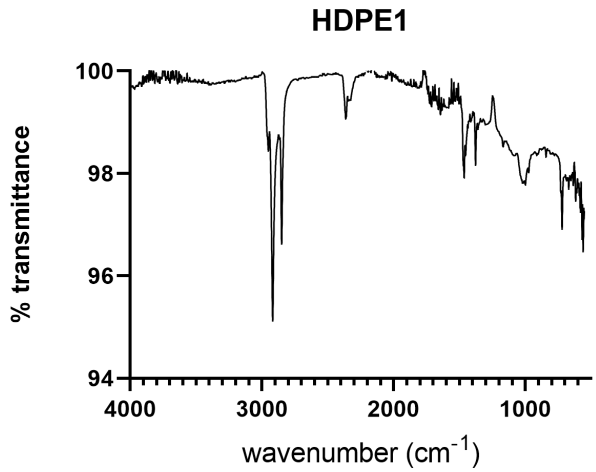

Figure 14: hollow center, cylindrical, clear, HDPE, Paraffin Wax, Calcium Stearate

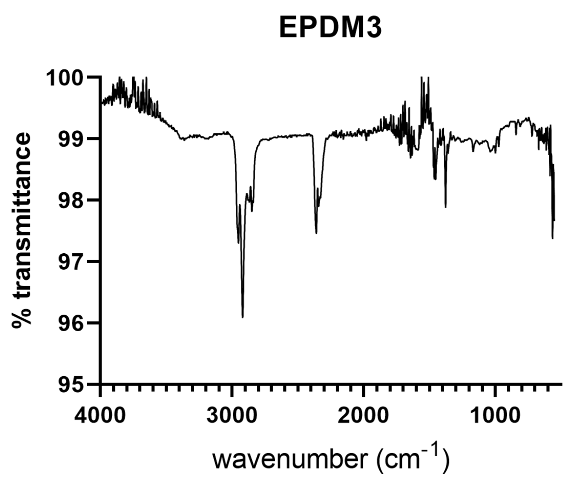

Figure 15: cylindrical, clear, EPDM, Quaternary Ammonium Compound, Paraffin Wax, Stearmide, Irganox 1093

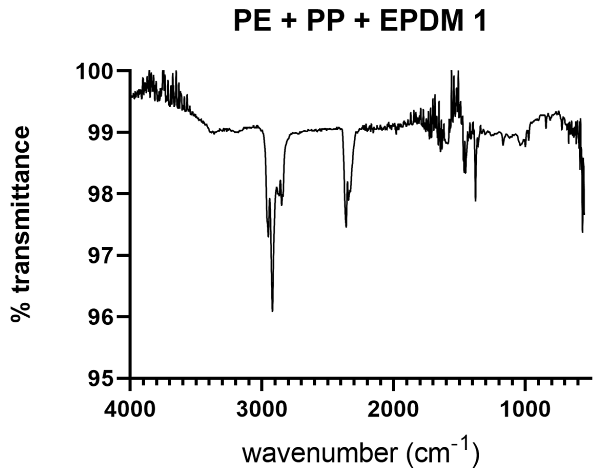

Figure 16: cylindrical, clear, PE, PP, EPDM, Zinc Oxide, Alumna Silicate, Paraffin Wax, Stearmide, Irganox 1093

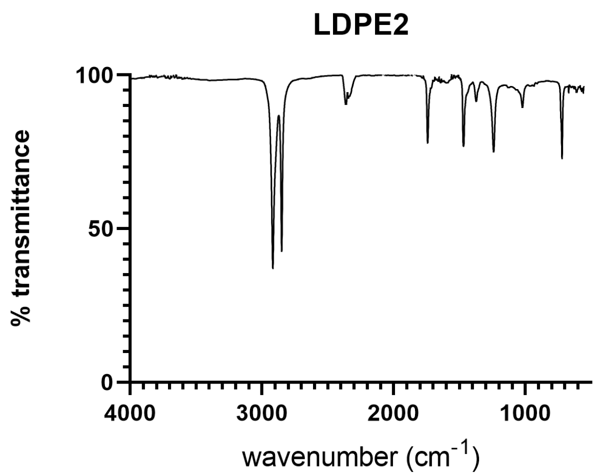

Figure 17: flat disk, clear, LDPE, Paraffin Wax, Talcum, Calcium Stearate, Octadecanoic Acid, Oxidized Polyethylene