Quantification of Organic Pollutants and Detection of Microplastic within Soil from Varying Landscapes in Antarctica

by

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ABSTRACT

Advanced technology has increased access to Antarctica; consequently, there has been an increase in research and tourism. The production of the new technology and the increased number of individuals visiting can increase the presence of persistent organic pollutants and microplastic within Antarctic soil. Studies have focused primarily on identifying these pollutants in high human impact areas with perhaps an assumption that low human impact areas would have lower concentrations of pollutants. The object of this paper, therefore, was to test the hypothesis that higher concentrations of persistent organic pollutants and microplastic are found in soils collected near research stations and tourist areas, as opposed to sites that are further from stations and have less direct human impact.

Soil samples were collected along a 1,500 km transect of the Scotia Arch and Antarctic Peninsula from three high human impact sites and three low human impact sites to compare the concentration of contaminates identified within the soil. The presence and quantities of microplastic were identified using Nile Red and fluorescence microscopy, while gas chromatography-mass spectrometry was used to detect polychlorinated biphenyls, pesticides, polycyclic aromatic hydrocarbons, n-alkane, and phthalates. Although varying contaminate concentration levels were found at all six sights, counter to the hypothesis, there were no clear patterns of increasing pollutants with increasing human activities. These findings could imply that global sources of pollutants can increase local pollutants indicating the best way to solve any pollution problem is through a global lens.

DEDICATION

For all those who dare to be different and chase their dreams.

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CHAPTER 1

PERSISTENT ORGANIC POLLUTANTS

Persistent organic pollutants (POPs) are organic chemicals that are synthetically produced or emitted by humans' use of fossil fuels. The chemical properties of POPs enable them to remain and accumulate in varying environmental matrices. Once in these environments, POPs can cause toxicological damage to the ecosystems that they contaminate. The detrimental effects of these pollutants raised global concerns, and in 2001 the United Nations Stockholm Convention placed bans and restrictions on several of these compounds. Despite the restrictions, POPs remain in the atmosphere, making them legacy pollutants. These chemicals are grouped by chemical structure and consist of polychlorinated biphenyls, pesticides, polycyclic aromatic hydrocarbons, phthalates, and microplastic.

Polychlorinated Biphenyl

Two hundred and nine contaminants, called congeners, form the group of persistent organic pollutants known as polychlorinated biphenyls (PCBs). Each of the 209 congeners consists of a biphenyl base where chlorines replace hydrogens. The PCB congener is determined by the number and location of chlorine substitutions (Stackelberg 2011). PCBs are heat resistant, chemically stable, and have excellent insulation. From about 1929-1979, roughly 1.5 million metric tons of PCBs were used as an ingredient for producing electrical and construction materials including plastic, paints, and insulators (Thomas 2008). Production, mismanaged disposal, and burning of materials containing PCBs released them into the atmosphere and began to accumulate. PCBs' ubiquitous

nature, environmental hazards, and health concerns eventually led to a ban in the United States and Europe. Although these two countries banned PCBs, it was not until 2001, under the United Nations Stockholm Convention, that the use of PCBs began to be eliminated worldwide (Boer 2005). Although PCBs were banned, they continually persist in the atmosphere in the 21st century, making them legacy pollutants.

Pesticide

Pesticides are synthesized organic compounds that control unwanted pests such as weeds, fungus, ants, and mosquitoes. There are different types of pesticides; however, priority has been placed on banning and phasing out a group of highly toxic chlorinated pesticides known as organochlorine pesticides, from this point on, referred to as 'pesticides.' DDT is the most notorious pesticide that inspired Rachel Carson to write her book, "Silent Spring," which informed the public of the dangers of pesticides. Two banned pesticides usually detected in persistent organic pollutant studies are hexachlorobenzene (HCB) and mirex. From 1978-1981, at its peak use, per year, one thousand metric tons of HCB were produced globally (Barber et al. 2005). Countries began placing restrictions and bans on the production of HCB, and since then, there has been a seventy to ninety-five percent reduction in emissions (Barber et al. 2005). Mirex was produced from 1957 to 1976 in the United States to combat fire ants and act as a flame retardant; however, the global use of mirex continued until the Stockholm Convention in 2001 (United Nations 2002). Mirex has twelve chlorines and adsorbs strongly to soil particles; therefore, it is less likely to be distributed by long-range

atmospheric transport. Mirex is most likely distributed long distances because it bioaccumulates in migratory species (Agency for Toxic Substances 2020).

Polycyclic Aromatic Hydrocarbon

Polycyclic aromatic hydrocarbons (PAHs) are persistent organic pollutants that can be emitted naturally or anthropogenically. Volcanoes and burning forests are the primary sources of naturally emitted PAHs. Incomplete combustion of fuels from motorized transportation, oil spills, and industrial emissions are sources of anthropogenic PAH pollution (Stogiannidis and Laane, 2015). In 2007, humans emitted an estimated 504 Gg of PAHs into the atmosphere (Shen et al. 2013). PAHs are biphenyl rings fused together and, depending on the number of fused biphenyls, are grouped as high and low-weight PAHs. Low-weight PAHS contain up to three benzene rings, and high-weight PAHs have more than three benzene rings. Low-weight PAHs are typically used in fuel production and are more toxic to the environment than heavy-weight PAHS (Net et al. 2015). PAHs are semi-volatile and lipophilic and will remain in the soil longer than in the atmosphere (Meador 2010).

Phthalate

Plastics for consumer and commercial goods and materials are cheap, durable, and flexible. To make plastic strong and flexible, chemicals called plasticizers are added during production. The final plastic product can contain ten to sixty percent of plasticizer by weight (Giuliani et al. 2020). Of the one-hundred different types of plasticizers, phthalates are used the most globally, and six to eight million metric tons are produced

annually (Baloyi et al. 2021). A phthalate contains a phthalic anhydride esterified by an alcohol ranging from C3 to C6. Phthalates are not chemically bonded to plastic, allowing them to break away from their parent material and enter the environment. The ubiquitous and potentially toxic nature of several phthalates in the environment has caused concern in several countries. The United States and the European Union have officially listed several phthalates, including diethylhexyl phthalate and dibutyl phthalate, as chemicals of concern and are working towards phasing them out of production (Wang et al. 2018).

Microplastic

In 2015, an estimated 322 million metric tons of plastic were produced worldwide (Plastics Europe 2017; Borelle et al. 2020), with a calculated plastic waste of 66-99 million metric tons (Lebreton and Andrady 2019). The amount of plastic production and pollution can potentially become a geographical marker for the Age of the Anthropocene (Zalasiewic et al. 2016). Plastic and its derivatives can therefore be included as a persistent organic pollutant that has become ubiquitous in the environment. Microplastic, a type and derivative of plastic has been a hot topic issue with copious amounts of research published since 2006. For an in-depth, comprehensive review of the most current research, refer to the work published by Rozman and Kalčíková (2022). In brief, microplastic is a piece of plastic measuring 1000µm-1µm in size and categorized as either primary or secondary microplastic (Hartmann et al. 2019). Primary microplastic is produced at the defined size, while secondary microplastic derives from a larger degraded piece of plastic (Huang et al. 2021). Mismanaged recycling and waste management practices can lead to the dispersal of microplastic within the environment causing

toxicological effects on soil communities (Borelle et al. 2020; Guo et al. 2020). Only four percent of all microplastic research focuses on soil (Weber et al. 2021).

Transport of Persistent Organic Pollutants

Persistent organic pollutants (POPs) can travel miles from the source of contamination via the atmosphere, known as long-range atmospheric transport. If the POP is chlorinated, the number of chlorine substitutions can determine the distance traveled in the atmosphere. POPs with higher chlorine substitutions tend to remain in a particulate phase and travel a short distance. Lower chlorine substituted POPs tend to stay in a gas phase and travel great distances (Shields et al. 2014). Lower temperatures can cause all gas-phase POPs in the atmosphere to condense and collect in soil. Scavenging is another mechanism in which POPs partition from the atmosphere and enter the soil matrix. Once in the soil POPs degrade slowly because microbes, the main degrader of POPs in soil, are less efficient than the hydroxyl radicals in the atmosphere (Shields 2014). As temperatures rise, POPs can re-volatilize, be transported through the atmosphere, and be deposited in soil at a different location. This is known as the grasshopper effect (Bhardwaj et al. 2018). The grasshopper effect, combined with meteorologic patterns and the persistence of POPs in the atmosphere, enables POPs to be transported from Chile, China, Indonesian Islands, and West Australia all the way to Antarctica (Szumińska et al. 2018; Choi et al. 2008; Möller et al. 2012).

Persistent Organic Pollutants in Antarctica

The occurrence and resulting environmental consequences of persistent organic pollutants is an understudied topic within Antarctic soil research. An intensive literature review on POPs in Antarctica by Wang X. et al. (2019) suggests that only twelve percent of the studies focus on Antarctic soil. A majority of these studies focus on the occurrence and source of POPs and typically are conducted in single local areas within the South Shetland Islands (Szumińska et al. 2018; Carrizo et al. 2019; Na et al. 2020; Deelaman et al. 2021; Duarte et al. 2021; Perfetti-Bolaño et al. 2022).

Microplastic presence in Antarctica is a new area of research, and literature is scarce. Interest in microplastic-focused research began in 2017 with only four articles published. Literature on microplastic slowly gained traction until it peaked in 2020 with twelve published papers, and as of June 3, 2022, nine papers have been published. Microplastic research within the first two years focused on determining if Antarctica even contained microplastic, and indeed it was detected in the South Ocean (Absher et al. 2019; Isobe et al. 2017; Cincinelli et al. 2017), sediments (Munari et al. 2017; Reed et al. 2018), and even penguin scat (Bessa et al. 2019). Since the 2020 research peak, microplastics have been discovered in numerous abiotic and biotic matrices including the atmosphere (Marina-Montes et al. 2022), freshwater (González-Pleiter et al. 2020), benthic invertebrates (Sfriso et al. 2020), and soil (Perfetti-Bolaño et al. 2022).

CHAPTER 2

PERSISTENT ORGANIC POLLUTANTS IN ANTARCTIC SOIL

When people think of Antarctica, they often imagine a beautiful ice-covered continent that rests at the bottom of the world. In the earliest days of Antarctic exploration, only a handful of captains sailed into the unknown, fighting harsh seas seeking out the uncharted continent of Antarctica. Once discovered, these captains were followed by profit-seeking whalers and sealers or thrill-chasing explorers whose contributions helped chart the Antarctica of today. Advancements in transportation and technology have granted countries around the globe access to Antarctica, where scientists seek knowledge, tourists discover exotic lands, and fishermen provide resources for their respective countries. (Day 2013).

Twelve countries came together in Washington D.C. on December 1, 1959, to draft and sign the Antarctic Treaty (AT) allowing open access to all nations wanting to peacefully pursue science on the continent:

> *"[I]t is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord."*
> *(Antarctic Treaty Preamble, 1959)*

Countries with sovereign claims on areas prior to the AT were not required to relinquish these claims (Article IV, AT); however, they made the land open to all treaty nations, allowing for ungoverned access to science (Article II, AT). The USSR and the United States were able to set aside their Cold War differences and agreed to no military operations or maneuvers (Article V, AT) and no nuclear weapons or waste (Article V,

AT), allowing for peaceful scientific opportunities even between nations with low diplomatic relations (Secretariat of the Antarctic Treaty).

When the Antarctic Treaty went into effect in 1961, there were only 12 nations with a political interest in Antarctic exploration. Since the AT's signing, the original countries have grown to a total of 29, which are called the Antarctic Treaty Consultative Members (ATCM). The ATCM convenes to discuss and vote on policies and the future of Antarctica. Antarctica is utilized by these countries for three purposes: science, tourism, and commercial fishing. As technology advances, Antarctica has become more accessible, creating an ever-growing human presence.

The increase from twenty-six research stations in 1961 to seventy-six research in 2022 shows that scientific research has grown since the signing of the AT (Secretariat of the Antarctic Treaty; Council of Managers of National Antarctic Programs; Wratt 2013). Some would argue that this increase resulted from politicians rushing to increase presence in Antarctica by taking a build first research later approach (Jabour 2009). Regardless of the cause, an increase in the stations built on scarce ice-free land can put pressure on terrestrial biota and occupy areas utilized for breeding (Brooks et al. 2019). The disposal of waste and wastewater generated by the stations is required for sanitation. Prior to Madrid Protocol in 1991, there was no clear guidance on waste disposal practices, leading to pollutants being introduced to the environment (Brooks et al. 2019; Gröndahl et al. 2009). Lastly, ships and planes carrying personnel and resupply equipment to bases burn fuel and can create a pollutant known as black carbon (Cordero et al. 2022; Khan et al. 2019).

The Commission for the Conservation of Marine Living Resources (CCAMLR) manages year-round commercial fishing operations for krill, toothfish, and ice fish in Antarctica (Constable 2011). Each species has specific fishable sectors; for example, krill trawling contains sectors around the Shetland Islands that overlap environmentally sensitive areas, specifically penguin and seal feeding grounds (Watters et al. 2020; Lowther et al. 2020). When combined, all the sectors for each species circumnavigate the entire continent, exposing Antarctica's oceans and coasts to fishing pollutants. The number of vessels for each species varies from year to year. In the case of krill trawling, an average of 10 ships were used in the past decade; however, the fishing vessel count may be higher or lower because it is unclear if vessels fish for multiple species. Fishing in the South Ocean may be on the decline because, in 2021, fifteen ships requested fishing permits for krill, and no permits were requested for toothfish or icefish (CCAMLR Secretariat 2020). Although regulated, fishing waste includes unintentional fishing gear pollution and partially burnt fossil fuel (Puasa et al. 2021).

The International Association of Antarctica Tour Operators (IAATO) has reported Antarctic Tourism has increased yearly from 2015 to 2020. Modern tourism in Antarctica includes cruise-only voyages, flight tours, and terrestrial landings to view penguins and participate in other tourism activities (IAATO, 2021). The increase in human activities has raised concerns about how the increased anthropogenic fingerprint will affect Antarctica's environment (Caruso et al. 2022; Cajiao et al. 2020; Puasa et al. 2021).

Sustaining transportation for increased tourism to and within Antarctica has required an increase in burning fossil fuels, which in turn can contribute to a rise in pollutants (Wong et al. 2021). Other sources of pollutants from increased cruise ship traffic include liquid fuel leaks from the vessels and the possibility of illegal dumping by tourists or staff. (Kariminia et al. 2013).

The influx of anthropogenic activity can bring pollutants of particular concern classified as persistent organic pollutants (POPs), which can persist for decades in the environment and cause long-term environmental damage (Isla et al. 2018). Several POPs have been identified in different Antarctic environments, including polychlorinated biphenyls, pesticides, and polycyclic aromatic hydrocarbons (Nash 2011; Fuoco et al. 2012; Wang et al. 2022; Kim et al. 2021; Lodygin et al. 2021; Na et al. 2020). There seems to have been a focus on these legacy POPs without considering new emerging POPs such as phthalates and microplastic (Fu et al. 2020; Duarte et al. 2021).

Plastics can cause physical harm to animals by causing airway obstructions, starvation through food replacement, or acting as a vehicle to introduce varying chemicals to organisms' internal organ systems; furthermore, varying forms of degradation reduce plastics to microplastics (Huang et al. 2021). A microplastic is a piece of plastic either reduced or produced at a size ranging from 1000µm-1µm (Hartmann et al. 2019). Fewer studies focus on chemical plasticizers, such as phthalates, associated with microplastic production (Rozman and Kalčíková, 2022). Plasticizers are not chemically bonded to the microplastic and can be transported to and throughout different environments. In soil, these phthalates can disassociate from on and within the microplastic and migrate through the soil column, causing adverse effects on the soil

community (Net et al. 2015; Rozman and Kalčíková, 2022). There are significant knowledge gaps on POP's occurrence and effects in Antarctic soil; only 12% of Antarctic POP research is dedicated to the soil matrix (Wang et al. 2019), while 4% of all MP research accounts for soil (Weber et al. 2021).

Most people have focused on identifying persistent organic pollutants and microplastic within soil at various locations within the South Shetland Islands (Szumińska et al. 2018; Carrizo et al. 2019; Na et al. 2020; Deelaman et al. 2021; Duarte et al. 2021; Perfetti-Bolaño et al. 2022), with perhaps the assumption that high human impact areas contain higher amounts of pollutants than low human impact areas. The object of this paper, therefore, was to test the hypothesis that there are higher concentrations of persistent organic pollutants and microplastic found in soils collected near research stations and tourist areas, as opposed to sites that are further from stations and have less direct human impact. As persistent organic pollutants and microplastic can be transported long distances through the atmosphere (Petersen and Hubbart 2021; Evangeliou et al. 2020; Zhang et al. 2019; Szumińska et al. 2018; Möller et al. 2012; Barbra et al. 2005), it is not possible for this study to identify the source of contaminants. However, if there are increased concentrations of pollutants at sites with increased human activities, this may indicate that human presence is an important contributor to the type and concentration of persistent organic pollutants and microplastic in Antarctica.

Methods

Study Site Description

From November 2015 to January 2016, six soil samples were collected from each of the six sites (36 total soil samples) along a 1500 km transect of the Scotia Arch and Antarctic Peninsula: Signy Island, Anchorage Island, Biscoe Point, Berthelot Island, Jenny Island, and Ares Oasis (Figure 1) (Ball et al. 2022). For the rest of this study, sites will be referred to by the first word of the location, i.e., Signy Island will be referred to as Signy. Using anthropogenic data from Pertierra et al. (2017) and site location factors, we assumed that three sites had a higher human impact (Signy, Anchorage, and Biscoe, hereafter referred to as "high impact" sites) and three sites had a lower human impact (Berthelot, Jenny, and Ares, hereafter referred to as "low impact sites) (Figure 1). Researchers frequently use high-impact sites and are closer to larger stations that regularly receive air and marine traffic for scientists and tourists. At the smaller, harder to access low impact sites, there are fewer studies conducted. Ares was assumed to be the lowest impact site because it is isolated and situated amid glaciers and sea ice. Furthermore, Ares can only be accessed by air coupled with a long trek across a glacier, making it the least accessible of all six sites.

Each of the six soil samples was collected from each site using random sampling intervals from bare soil, or soils free of vegetation and snow cover (Ball et al. 2022). A 10 cm diameter metal core was used to contain the sample area and depths of 1-10 cm were homogenized in-situ using a metal spatula. Young soils and shallow depths limited samples to be taken at depths of 1-10 cm. High organic content prevented successful separation from soil using a sieve. At least six 25g samples of soil were collected from

each contained sample area, placed into a plastic whirl-pak bag, and stored at -20 degrees Celsius. Extensive physicochemical measurements were made on each of the soil samples (Ball et all, 2022). However, the high organic content of the soils prevented measurements of soil texture and bulk density. Analysis results showed that soils had varying, but generally low, levels of organic material, measured as percent lost on ignition or LOI (Table 1).

Persistent Organic Pollutant Quantification

Sample preparation. Soil samples were thawed and homogenized using a porcelain mortar and pestle. A 5g subsample was obtained and placed into a borosilicate glass jar with polytetrafluoroethylene (PTFE) lined lids and mixed with 30 mL of Hexane and 30 mL of acetone to extract semi-polar and nonpolar compounds. Additionally, 1mL of 39 µg/mL p-terphenyl was added as a method recovery surrogate (Polidoro et al. 2022).

To achieve equilibrium, sample jars were placed on a rotator with the hexane: acetone solution for at least 48 hours. The hexane: acetone solution was then filtered using a glass fiber filter (Whatman, 7-micron pore size) and a vacuum flask. Sample extracts were then passed through a large glass filter column containing sodium sulfate and silica gel to remove excess water and polar compounds. Several extracts were still rich in naturally occurring organic material; therefore, they required a second round of filtration. For this round, a small column containing Florisil, or magnesium silicate, filtered out the remaining organic acids and similar soil compounds. Samples were then condensed to 0.5 mL using Nitrogen gas and placed into a gas-chromatography mass

spectroscopy (GC-MS) glass vial. 0.2 mL of each extract was sub-sampled and analyzed for organic pollutants using gas chromatography in tandem with mass spectroscopy (GC-MS).

Gas chromatography-mass spectroscopy. A Varian 3800 gas chromatographer was used for the analysis of compounds. An auto-injector collected and dispensed 0.1 mL of sample into the gas chromatograph. The samples were gradually heated in a column and separated based on molecular weight and volatilization temperature. Compounds with lower volatilization temperatures were separated from the sample first and then pushed through the column with helium gas. If two molecules had the same volatilization temperature, the molecule with less mass would move faster, reaching the column's end before the slower molecule with a greater mass. A detector generated a peak based on the amount of time it took the compound to reach the end of the column (retention time) by a function of the compound's molecular weight, volatilization temperature, and concentration amount (M-count). The peak was compared to combinations in the NIST library to identify a possible match. Gas chromatography was coupled with mass spectroscopy to verify the compound's identity and quantify its concentration.

A Saturn 2200 electron ionization mass spectrometer was used to analyze compounds. The compound dropped from the column of the GC-MS into the mass spectrometer and was bombarded by electrons. Electrons broke the compound into molecular ions; however, the high amount of electrons can also break molecular ions into fragments. The different ions travel through a quadrupole and are sorted into relative amounts of differing molecular ions, or quant ions. In doing so, the compound was given

a chemical ‘fingerprint,’ and when it was compared to the NIST library database, the compound identification was verified. Fingerprint data was collected from varying concentrations of pure known compounds, or standards. This information was used to create calibration curves to quantify the amount of the compounds found in the Antarctic soil samples.

Samples were analyzed for approximately three hundred individual contaminants, with detection limits reported in Polidoro et al. (2017). Minimum detection limits (MDL) were estimated by doubling the lowest standard concentration that showed a peak, with a signal-to-noise ratio greater than three. Extraction method recoveries ranged from 40% to 90% for PCBs, 25%–70% for pesticides, from 30% to 80% for phthalates, and from 20% to 90% for PAHs. All results presented are uncorrected for method recoveries.

Calibration curve and analysis. Compound standards were required to accurately analyze mass spectroscopy data and quantify the unknown concentrations of polychlorinated biphenyls, polycyclic aromatic hydrocarbons, pesticides, phthalates, and n-alkane within Antarctic soil samples. Samples were tested for more than 350 compounds; therefore, the standards were consolidated into pre-determined groups to minimize the required calibration sets. To make the compound standards, pure compounds were measured and dissolved in 10mL of Hexane. At least six serial dilutions were taken from the 10mL standard twice to obtain two sets of decreasing concentrations. One set of dilutions was tested prior to the soil samples to obtain a baseline concentration, and the other set of dilutions was tested after all samples to account for any change in concentration. To create the calibration curve, the known dilution

concentrations of the compound were plotted against the area underneath the peak of the compound's retention time. The resulting linear regression and trend line equation was used to create the calibration curve for the known compound.

Antarctic samples that were tested produced peaks at specific retention times, indicating unknown compounds within the soil. GC-MS data were used to determine and verify the type of compound, and the calibration curve of that specific compound was used to quantify the concentration. The linear trend line equation was y=mx: where y=the area beneath the peak of the unknown; m=the area of the peak beneath the standard; and x= the concentration of compound (µg/mL) in the sample. This is possible because the area beneath the peak calculated by the GC-MS is directly related to the concentration amount of the sample. The concentration value of each detected pollutant was then divided by the sample weight of 5 grams which gave the final concentration in parts per million (ppm) or µg pollutant / g of soil.

Microplastic Quantification

Isolation from soils. The remaining 20g of soil from each sample was placed into a 250 mL borosilicate glass sample jar with PTFE lids and subject to a series of hydrogen peroxide treatments to oxidize organic matter. On day one, 30 mL of 30% hydrogen peroxide (H_2O_2) was added to the soil sample jar. On days two and three 10 mL of H_2O_2 was added to replace H_2O_2 lost as carbon dioxide from the organic material being oxidized (modified from Roblin and Aherne 2020; Herrera et al. 2018). After the three-day, hydrogen-peroxide bath, 100mL of 5 M sodium chloride was added to the sample jar and left for 3 days to let clay particles settle. Although samples still maintained a turbid

appearance, skimming took place after 3 days to prevent extended exposure to hydrogen peroxide causing changes in polymer structure (Pfohl et al. 2021). The samples were skimmed using a glass baster and aliquoted into new 250 mL borosilicate glass sample jars. This process was repeated four times (over 12 days) to extract all pieces of microplastic. This iterative density floatation method has been shown to isolate at least 85% of microplastic from soils and sediment matrices (Polidoro et al. 2022, among others).

Oil extraction treatment. As some lighter minerals and undigested organic matter was noted in the sodium chloride extracts; a second oil extraction treatment was developed (modified from Lechthaler et al. 2020) to separate microplastic from the other low-density minerals or other compounds. The sodium chloride extracts from each soil sample were left for approximately 1 week allowing all clay particles and dense materials to settle at the bottom of the sample jars. The top layer was then skimmed with a glass baster using caution to keep the settled bottom layer undisturbed. The top layer was aliquoted into a borosilicate glass separation funnel, with 5 mL of filtered store-bought canola oil. This mixture was mixed by swirling the separation funnel and creating a vortex. The separation funnel was left for 20 minutes, allowing time for the oil to separate from the sodium chloride and water solution. It was noted that 20 min was not ample enough time for the clay and/or other minerals to settle completely to the bottom of the separation filter; again, due to time constraints, filtration was conducted regardless of the turbidity of the sample. The oil was then filtered through a 1 μm black polycarbonate filter using a vacuum flask. Excess oil was broken-up by using Alco-jet, a

low suds soap. The polycarbonate filter was then transferred to a microscope viewing slide.

To account for any losses of microplastic due to sticking on the sides of the glass separation funnel, the drained sodium chloride sample, including the sediment, was re-introduced into the used separation funnel a second time. The sample jar was rinsed out into the separation funnel using di-ionized (DI) water, and the sides of the separation-funnel were also sprayed down using DI water to collect any plastics that had adhered to the glass. An additional 5mL of canola oil was added to the separation funnel and swirled to create a vortex and let sit for 20 min. The oil was then filtered onto a second 1 µm black polycarbonate filter using a vacuum flask and transferred onto a second microscope viewing slide.

Detection with fluorescent microscopy. A day prior to viewing the sample with an Olympus Bx3 microscope, 4-6 drops of 1mg Nile Red to 1L of methanol were added to each filter sample. Nile red is a dye that adsorbs to plastics, fluorescing under the microscope (Maes et al. 2017; Stanton et al. 2019; Nel et al. 2021). A count of microplastic was obtained by visually scanning the filter paper and taking a count of the fluorescing objects using images taken with the computer program cellSense.

Statistical Analyses

One-way analyses of variance (ANOVAs) were run using Minitab Statistical Software to identify any statistical significances in average persistent organic pollutants (POPs) concentrations detected across the six sampling sites. Given that source, timing

and degradation state of POPs are generally not known in non-target contaminant analyses, resulting in a distribution that tends to be very patchy, pollutant concentration data may not be normally distributed. As a result, many contaminants detected were only detected in one or just a few soil samples, with widely varying concentrations. Additionally, reported contaminant concentrations were not corrected for method recoveries due to the wide range of recoveries including a high number of non-detects or zero values (which does not necessarily mean the contaminant was not present, but that it was not detected in concentrations above method or instrument detection levels.) For these reasons, one-way ANOVAs could only be conducted for selected contaminants that had detections (e.g. non-zero values) in the majority of the 36 soil samples (e.g 2,4,4 Trichlorobiphenyl, Anthracene, Dibutyl Phthalate, the Alkanes, and Microplastics). Where site differences were significant, a post hoc Tukey test was run to determine which sites differentiate.

Results

Counter to the hypothesis, there were no clear patterns of increased pollutants with increased human activities in selected sites.

Polychlorinated Biphenyl (PCB)

Ares, a low impact site, contained the highest concentration of PCBs, with an average summed PCB concentration of 0.40 parts per million (PPM). The remaining sites (including all three high impact sites) contained average summed PCB concentrations below 0.17 PPM (Figure 2). Nine different types of PCBs were found across all six

sample sites, eight of which were at concentrations below 0.018 PPM (Figure 3). PCB 2,4,4'-Trichlorobiphenyl was by far the most abundant PCB contained in each site's soil sample, except for Anchorage, with levels below the detectable limit. The concentration range of 2,4,4'-trichlorobiphenyl was between 0.28 PPM at Biscoe and 5.7 PPM at Ares. (Figure 4).

Pesticide

Samples from Berthelot and Ares, both low impact sites, had the highest average summed or combined pesticide concentrations of 0.010 PPM and 0.008 PPM, respectively. The third highest concentration was found at Biscoe, a high impact site with a concentration of 0.004 PPM. The remaining three sites had average concentrations that were more than 10 times lower than Biscoe (Figure 6). Only four types of pesticides were found across the six sample sites, hexachlorobenzene, mirex, fenitrothion, and 4H-cyclopenta[def]phenanthrene. The highest concentration pesticide was 4H-cyclopenta[def]phenanthrene in Ares at 0.06 PPM (Figure 7). The other three pesticide maxima ranged from a high of 0.009 PPM to a low of 0.001 PPM across the sample sites (Figure 8).

Polycyclic Aromatic Hydrocarbon (PAH)

Average summed concentrations of PAHs were below 0.001 PPM across five of the sample sites. The sixth sample site, the low impact site Ares, had an average summed PAH concentration of 0.002 PPM (Figure 9). Nine types of PAHs were found across the sample sites; seven of which were below 0.001 PPM and dibenz(a,h)anthracene in

Anchorage had a concentration of 0.002 PPM (Figure 10). Anthracene was the highest PAH contaminant found at all six locations with a concentration of 0.009 PPM. Fluorene was identified as the second highest PAH contaminant in soil samples from Signy, Jenny, and Ares containing 0.003 PPM, 0.002 PPM, and 0.003 PPM respectively (Figure 11).

n-Alkane

Average summed concentrations of n-alkane were highest in the high impact site of Anchorage, reaching concentrations of 2.12 PPM (Figure 13). Four types of n-alkane were detected in large quantities in a majority of soil samples from all site locations. The maximum concentrations of all four n-alkane were detected in Anchorage: 1.52 PPM of C-16, 6.89 PPM of C-18, 5.25 PPM of C-30 and 6.66 PPM of C-36 (Figure 14).

Phthalate

No clear patterns of summed phthalate concentrations were observed across the sample sites (Figure 19). The lowest average summed concentration of 0.0006 PPM was detected in soils from Biscoe and the highest concentration was 0.002 PPM in soils from Anchorage; both sites were assumed to have high impact. Four types of phthalates were detected in total, di-butyl phthalate concentrations were detected in all site samples. Ares was the only sight with undetectable concentrations of butylated hydroxytoluene and Anchorage was the only site with undetectable levels of di-cyclohexyl phthalate (Figure 20).

Microplastic

The estimated, averaged numbers of microplastic varied across sites. In the high impact areas, Signy had an average of 1.3 microplastic per gram of soil (MP/g), Anchorage had an average of 0.53 MP/g, and Biscoe had the highest average of 2.65 MP/g. In low impact areas, Berthelot had an average of 1.21 MP/g, Jenny had an average of 0.65 MP/g, and Ares had an average of 1.4 MP/g (Figure 22).

Pollutant Relationship to Soil Properties

All persistent organic pollutants and microplastic correlation coefficient values fell below 0.70; therefore, there was no discernable relationship between soil properties and detected soil contaminants (Table 2). Four individual POPs and n-alkanes had enough non-zero values to investigate significance across the six sites. The average concentration of PCB 2, 4, 4' -trichlorobiphenyl (Figure 5) was significant across sites ($p < 0.045$) with the difference among sites due to differences between Anchorage (no detects) and Ares (highest concentrations). Average concentrations of Anthracene (Figure 12) were also statistically significant ($p < 0.001$), which was due to Ares concentrations being much higher than the rest of the five sites. Dibutyl phthalate was marginally significant ($p = 0.037$), but the post hoc Tukey test was not able to detect any significant pairwise comparisons (Figure 21). The average microplastic count (Figure 23) was also significant ($p < 0.001$) with Biscoe concentrations being much higher than the other five sites. Lastly, all n-alkanes were statistically significant across sample sites with varying degrees of pairwise significance (Figures 15-18). N-alkanes produced naturally in plants and other degraded organic materials may have caused the variance; however, Anchorage

stood out as being different than the other sites in the majority of n-alkane pairwise comparisons.

Discussion

Overall, there were no detectable patterns of increasing contaminants and microplastic associated with sample sites that were assumed to have higher levels of direct human activity. This indicates that atmospheric deposition and other sources are likely contributors to soil contaminants detected, in addition to human activity. As the source and timing (age) of contaminant deposition are also impossible to estimate, local transport processes (e.g. by wind, erosion, biota, ice melt, etc.), complicated by varying rates of contaminant degradation, are also likely playing a role in the observed contaminant concentrations. Some specific transport mechanisms, environmental behaviors and potential toxicological impacts of detected contaminant groups are discussed here.

Polychlorinated Biphenyl (PCB)

Polychlorinated biphenyl 2,2',3,3',4,5',6,6'-octachlorobiphenyl (PCB 201) was detected in all six locations including max values at the high-impact site Biscoe (0.01 µg/g) and the low-impact site Berthelot (0.003 µg/g). Interestingly, no studies were found on PCB 201's potential toxicological effects on soil communities; therefore, it is unknown if there are negative effects on Antarctica's soil communities. 2,4,4'-trichlorobiphenyl (PCB 28) was detected at all locations, excluding Anchorage. The maximum values of PCB 28 (≥0.277 PPM) at these five locations were significantly

different than the maximum values of the remaining eight PCBs (≤0.017 PPM). Furthermore, the highest maximum concentration of PCB 28 in Ares (5.73 PPM) and Signy (2.32PPM) should prioritize studies at these locations to understand the effects on soil communities.

Soil properties and composition, combined with a PCB's properties and composition, dictate responses within soil. The loss on ignition percent implied that Signy soil had higher levels of organic matter than Ares. PCB 28 has a log K_{ow} value of 5.67 and is comprised of three chlorines attached to a biphenyl. Because of these characteristics, PCB 28 has decreased possibility of dissolution in water and an increased chance of adsorption to the soil colloidal (Henry and Divito 2003). Conversely, the presence of aqueous humic acid can promote the dissolution of PCBs in water, lowering the ability to adsorb to the soil (Adeyinka and Moodley 2019). Although more research is required, this may explain why the maximum concentration of PCB 28 is higher in Ares rather than Signy. Signy's warmer wetter climate during the austral summer enables PCB 28 to dissolve in the soil's water content and evaporate into the atmosphere where a lower half-life will quickly degrade the contaminate (Sinkkonen and Paasivirta 2000).

The high K_{ow} value could also lead to the bioaccumulation of PCB 28 in Antarctica's above-ground vegetation, which is mostly mosses and lichen (Williams et al. 2017). For example, the concentration of PCBs was higher in vegetation with a higher lipid content (Cabrerizo et al. 2012); however, the effects of the PCBs on these above-ground communities in Antarctica need further studying. To highlight the importance of research, non-native Antarctic species can take up and distribute PCB 28 throughout the plant (Teng et al. 2017). Also, PCB 28 is toxic to plants at concentrations as low as 0.2

ppm (200 µg/L) (Wang et al 2021). Considering several samples in this study had max concentrations of PBC 28 greater than 0.2 ppm, it is imperative to study how PCB 28 physiologically affects Antarctic above-ground communities.

Antarctica's variation of extreme conditions can affect the relationships between the below-ground and above-ground soil communities (Ball et al. 2022) which could decrease or exacerbate PCBs presence and effect within soil communities. Below-ground bacterial communities in Antarctica soil have been found to contain Biphenyl dioxygenase genes, BphA, which degrades PCBs (Luz et al, 2004); however, the presence of the gene does not confirm if these communities are still able to degrade PCBs in Antarctica's harsh conditions (with temperatures below 0 °C). Antarctic bacteria found in lakes and sediments containing BphA have been found to degrade PCBs when collected and stored at 4 °C (Papale et al. 2022); therefore, with more studies testing extreme conditions, we may find these soil bacteria could in fact degrade PCBs in the cold climate.

Pesticide

In this study, the average summed concentrations were higher in low impact sites indicating that researchers in Antarctica are not the source of pesticides. Concentration levels of pesticides in the atmosphere of Antarctica have been declining (Pozo et al. 2017) which may explain why there were no detectable limits of DDT and only four types of pesticides were identified in the soil samples. Scarce information on the most abundant pesticide detected, cyclopenta[d, e, f]phenanthrene, prevented the investigation of effects within soil communities; however, hexachlorobenzene (HCB) and mirex were

detected in samples and have been persistently detected within the atmosphere and biology of Antarctica (Krasnobaev et al. 2020; Ko et al. 2018; Wang et al. 2022; Khairy et al. 2016; Pozo et al. 2017).

Hexachlorobenzene (HCB) was found in all low impact sites and the high impact site Anchorage, which contained the maximum concentration. High atmospheric concentrations of HCB suggest long-range transport and atmospheric deposition are the main sources of Antarctic soil pollution (Khairy et al. 2016; Pozo et al. 2017; Wang et al. 2022). Higher concentrations of HCB have been detected in soils collected within stations suggesting there may be a local source as well (Wang et al. 2022). Similarly, Anchorage's maximum concentration may indicate a local source of HCB pollution from around the area. In the case of mirex, it has been suggested different mechanisms, other than long-range atmospheric deposition, are responsible for transporting mirex to Antarctica (Strobel et al. 2018). One possibility is that south polar skuas wintering in Asia can ingest mirex (Midthaug et al. 2022) and deposit it via guano in Antarctic soil.

There is an interesting often-overlooked detail when considering the source and transport of HCB and mirex. Most papers from Antarctica identify HCB and mirex as pesticides (Krasnobaev et al. 2020; Ko et al. 2018; Wang et al. 2022; Khairy et al. 2016; Pozo et al. 2017; Midthaug et al. 2022); however, pesticides may not be the only source of HCB and mirex. Although it was banned in 1978, mirex was also used as a flame retardant for plastics, rubber, paint, and electrical equipment (United Nations 2002). Improper disposal or weathering of these old materials can introduce more mirex into the environment. HCB can also be a byproduct of cement (Mykhailenko and Safranov 2021) and tire (Barber et al. 2005) production, thus, adding new compounds to the legacy

compounds. These two examples indicate significant gaps in knowledge that need to be considered when studying HCB and mirex within soils of Antarctica.

Polycyclic Aromatic Hydrocarbon

Polycyclic aromatic hydrocarbon (PAH) originates from incompletely burnt fuels and geochemical processes; therefore, it is essential to note the possibility of geochemical contamination when studying PAHs (Szopińska 2019). The concentrations of 3-ringed PAHs and the lack of chrysene found in this study could indicate the burning of diesel fuel as a source (Stogiannidis and Laane 2015). The extreme environment of Antarctica requires the use of a particular fuel similar to diesel, An8, to withstand extreme cold, containing trace elements of fluorene (Lister et al. 2015). The 3-ringed PAHs fluorene and anthracene had detectable levels across all six research sites without detection of chrysene; therefore, the source of PAH contamination is most likely An8. Further research on An8 would be beneficial to identify other PAHs to monitor.

Airport proximity may also play a role in the levels of PAHs found in these soils. In other studies, samples collected from two airfields on King George Island contained higher PAH concentration levels when compared to soils collected near research stations (Lodygin et al. 2021; Na et al. 2020). However, the summed PAH average concentrations in Ares (1.65 ng/g) and Anchorage (0.125772 ng/g) were lower than Fildes Peninsula (155 ng/g over several seasons) (Na et al. 2020), indicating more anthropogenic activities on the Shetland Islands.

Results from this study could imply that Ares can be considered a high impact sight for PAHs. Ares is a site that is located roughly 58 km from Fossil Bluff. Fossil

Bluff is a summer season refueling point for expeditions within Antarctica. Anchorage is much closer, about 5 km, to a Rothera Station containing an airport; therefore, the samples in Anchorage should have higher concentrations than Ares. However, the average sum of PAHs was higher at Ares than at Anchorage. Differences between the airports may play a role in the unpredictable levels. Rothera Station, maintained by the United Kingdom, is operated year-round, and personnel are flown into Antarctica from the Falkland Islands or Punta Arenas, Chile. Flight distances to Rothera may make refueling and fuel storage unnecessary and fewer flights to the airfield may lower the amount of PAHs released into the environment. Refueling trends, varying types of aircraft, and duration of stay at Fossil Bluff may play a role in increased concentrations of PAHs at Ares. Fossil Bluff may have smaller craft refueling for multiple expeditions within Antarctica during the season; furthermore, as a refueling station, fuels are stored on-site possibly increasing PAHs at Ares. A toxicological risk assessment conducted by Deelaman et al. (2021) on King George found PAHs to be a low risk to soil biota; however, continued monitoring of PAHs is needed as well as identifying the risk to soil communities.

n-Alkane

In this study, detection of n-alkane was omitted initially; however, after several mass spectral analyses, n-alkane was ubiquitous in samples from all sites, especially samples from Anchorage. It is important to consider both the biological and anthropogenic production of n-alkane when calculating and analyzing samples. Although the samples were taken from bare soils, recent studies indicate that both microbial

processes and plant material can produce n-alkane (Chen et al. 2019), thus, acting as a natural source for n-alkane. Anthropogenic sources contributing to contamination levels of n-alkane include accidental spills of liquid fuel, partially burnt diesel fuels, and misguided dumping practices prior to the Madrid Protocol (Green and Nichols 1995; Goldsworthy et al. 2003; Bargagli 2008). It is suggested that cold climates can trap n-alkane (Carrizo et al. 2019); however, glacial retreats caused by the warming climate could lead to Antarctica becoming a future source of n-alkane (Horrocks et al. 2020; Vega-García et al. 2021). Further studies are still imperative to fill in the knowledge gaps of n-alkane in soil.

Phthalate

This study found several phthalates in soils, with little concentration differences among sampled sites. However, it is essential to note that samples were stored in plastic zip-lock bags which could slightly increase phthalate concentrations within the samples due to leaching. Regardless, samples contained concentrations of dibutyl phthalate and di-n-octyl phthalate, both classified as priority pollutants by the U.S. Environmental Protection Agency (EPA) in 2014 (EPA, 2017). Collection and storage methods, coupled with random phthalate concentration trends across sites, prevent this study from using phthalates as a secondary indicator of physical plastic pollution in these sites. The phthalate source location may become even more challenging to identify because research has found that several Antarctic algal species can naturally produce dibutyl phthalate (Namikoshi et al. 2006).

More research must be done to fill significant knowledge gaps on phthalate's source and effect on Antarctic soil communities. The first phthalates in Antarctica were detected in snow at varying altitudes and in seawater (Desideri et al. 1994, 1995, 1988). More recently, phthalates have been found in phytoplankton (Duarte et al. 2021) and krill (Zhang et al. 2018); however, studies are needed to determine if trophic transfer to local bird species can lead to soil contamination. Within non-Antarctic soil communities, phthalate type determines the effect on soil structure and species. Studies on non-Antarctic soil communities suggest that dibutyl phthalate decreased nitrogen, phosphorus, and carbon levels, which stunted plant growth (Kong et al. 2018). Dibutyl phthalate changed microbial diversity and affected the fecundity and survivability of earthworms, collembolas, and nematodes (Kong et al. 2018; Jensen et al. 2001). To better understand the effects or non-effects of phthalates in Antarctica, local species should be the focus of the research. Although some phthalates can be naturally produced (Namikoshi et al. 2006), it is better to apply the precautionary principle and keep phthalates a contaminant of concern until the effects of natural and synthetic phthalates are understood.

Microplastic

Preliminary results suggest little differences among microplastic detected across the six sites, however, these results need to be interpreted with caution and require validation. The lipophilic nature of microplastic readily adsorbs Nile Red and when viewed under a fluorescent microscope, allows for the visual identification of possible microplastic. However, it appeared that there may have been other unknown material stained by the Nile Red, which would create false positives in several samples (Figure

22). These false positives, and for the reasons discussed in the phthalate section, dictate that the presence of phthalates alone cannot act as a marker for unseen or missed microplastic. Therefore, it is imperative to use secondary methods, such as Ramen spectroscopy and Fourier transform infrared spectroscopy, to verify the microplastic visually identified in this study.

The soil from Antarctica brought to light issues that can be encountered during microplastic extraction. The addition of the oil method helped to remove some of the persistence of organic matter after the hydrogen peroxide bath; however, pieces could still be seen with the naked eye. Although the filters were cleaned with Alco-jet to eliminate excess oil, there is still a possibility that the oil was stained with Nile Red as well. Finally, an unknown mineral and clay material could also possibly affect the microplastic count. These issues need to be addressed in order to perfect microplastic extraction from Antarctic soils. Furthermore, this can demonstrate methods may change depending on the physical properties of soil and the call for a standard method for microplastic extraction from soil needs to be rethought. Despite not being able to verify if the microplastic count was accurate, it is important to check for microplastic when considering persistent organic pollutants in Antarctica.

Plastics have been found in specially protected areas where bird species use them as nesting material (Finger et al, 2021). These plastics can degrade to microplastic and present choking hazards, nutrient deficiency caused by false food fullness, and leaching of sorbed contaminants to the nesting birds who may mistake it as food (Puasa et al. 2021). Scat samples of several species of adult penguins contained microplastic, suggesting that there is a trophic transfer between species (Fragão et al. 2021). Trophic

transfer to bird species can provide a means for the microplastic to be distributed to in-land soils. Once the microplastic makes landfall, soil species could ingest the plastic. For example, collembolans collected from polystyrene shore debris ingested the material (Bergami et al. 2020). Although collected from the shore, this could imply that other species of collembola located further inland can ingest microplastic.

Biofilms located on plastic debris need to be investigated as well. Although found on oceanic pieces of plastic, different prokaryotic and fungal communities (Cappello 2021, Lacerda 2020) were found on varying plastics, which could provide the means of transport through Antarctica, causing shifts in soil communities by introducing invasive or novel species. Bacterial colonies with antibiotic resistance have been found on plastic from King George Island which may or may not be a concern (Laganà 2019). There is evidence of the presence of microplastic in Antarctica now studies need to fill the gap on how the physical presence of microplastic can affect soil communities.

Conclusion

In conclusion, this study showed that regardless of a site being influenced by an assumed high or low human impact, there are no clear patterns dictating the concentration of persistent organic pollutants. For instance, in assumed high impact sites, Anchorage had the highest concentration of n-alkanes; however, Bisoce had the lowest concentration of phthalates and the highest microplastic count. Comparatively across all six sites, the assumed lowest human impact area, Ares, contained the highest concentrations of polychlorinated biphenyls (PCBs), pesticides, and polycyclic aromatic hydrocarbons (PAH).

Specific concentrations of persistent organic pollutants were inconsistent with other studies. The concentrations of PCBs and phthalates in soil samples were higher in this study than in others (Klánová et al. 2008; Wang P. et al. 2012; Corsolini et al. 2019; Desideri et al. 1994, 1995, 1988). PAHs and n-alkanes were detected in lower concentrations than in other Antarctic soil studies (Rodríguezn et al. 2018). It is difficult to compare the microplastic count of this study with the one other study (Perfetti-Bolaño et al. 2022) for several reasons. The main reason was that in this study the hypothesis that phthalate could act as a secondary indicator of microplastic had to be rejected, and there was no secondary confirmation with Raman or Fourier-transform infrared spectroscopy. Perfetti-Bolaño et al. (2022) used a different definition for microplastic, used other extraction techniques, and did a visual count without using Nile red. Finally, the measurement used by Perfetti-Bolaño et al. (2022) was recorded as "particles/ 50ml," which makes comparison with the current study of "particles/ gram soil" difficult.

Determining a contaminants source, transport mechanism, and time within the soil presents its own challenges. Contaminations are not equally distributed across any given area; therefore, a sample with no pollutants could have been collected feet away from a highly contaminated soil patch. Variance in the time a contaminant enters the atmosphere, how long it has been exposed to degradation factors, and the potential to accumulate makes it challenging to distinguish when the contaminant first arrived in the soil. In this study, these conditions make it impossible to determine the sources of the pollutant; however, long-range atmospheric transport, local point sources, or biological transport cannot be ruled out. Regardless of a contaminant's source and deposition time, the toxicological effects on Antarctic soil ecology are still unknown and must be studied for a better understanding of persistent organic pollutants within the Antarctic environment.

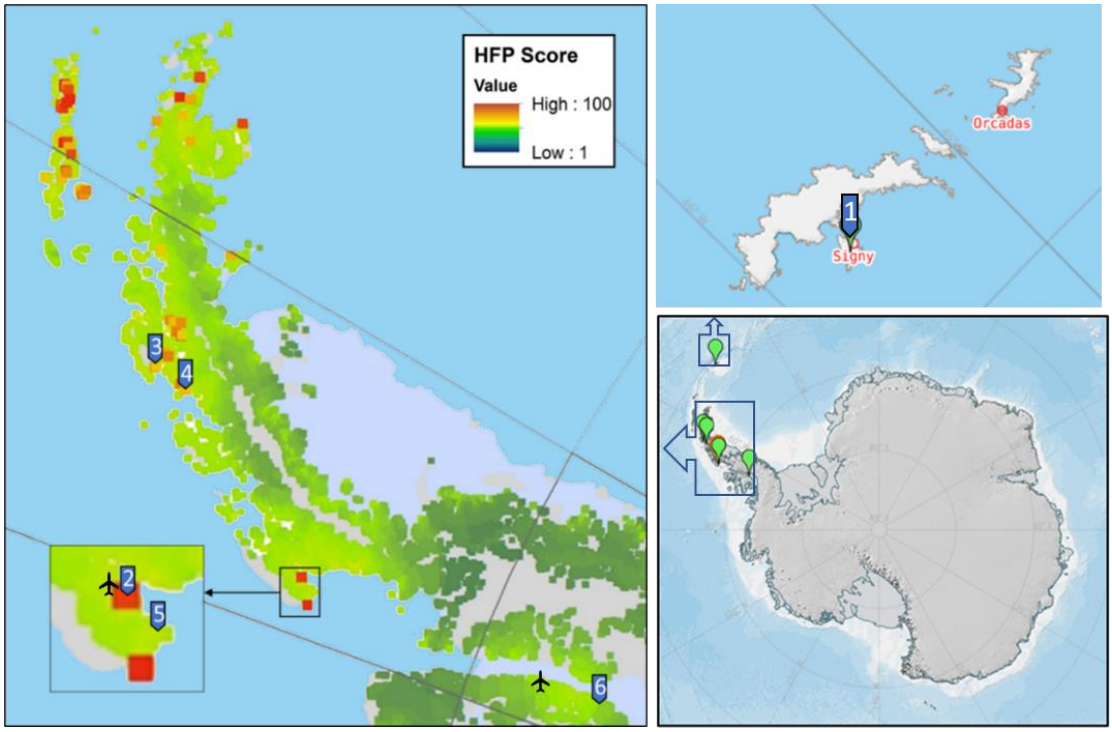
CHAPTER 3

NEXT STEPS

The realization that persistent organic pollutants are understudied within soil research is a consistent theme throughout the literature. Standardizations would be key for collecting comprehensive data suitable to obtain an understanding of how these pollutants influence Earth's soil in the past, present, and future. First, there is a need for a clear definition of microplastic, many papers tend to mention the problem without many solutions. Hartmann et al. (2019) addressed the issue and presented their solutions for a clear definition of microplastic. Currently, eight hundred and sixty-one have referenced this work (Hartmann et al. 2019); however, studies still use varying definitions with a call for a standardized definition of microplastic. I purpose that we use the microplastic definition of Hartmann et al. (2019) to resolve the issue instead of continually stating an issue.

Microplastic separation from soil is a difficult task, and there have been calls for standardization of extraction methods. These calls may seem warranted and ideal to achieve similar and repeatable results; however, in practice, standardization can be impractical. Soil's heterogeneous nature may make one extraction method great for one soil, yet, be inefficient with another. For example, this study used a combination of two extraction methods because the first failed to fully separate the microplastic from the sample. Microplastic separation is time-consuming, frustrating, and should be improved. Instead of standardizing lab methods, emphasis should be placed on finding cheaper, quicker, and more efficient extraction methods.

Most persistent organic pollutants (POPs) within Antarctic soil identify the occurrence and transport of pollutants. While identifying the source and amount of pollutants is important, little is known about the resulting effects imposed on soil communities. Degradation rates vary between all POPs and the extreme environmental conditions of Antarctica could increase the amount of time that they remain in the soil. It is important to address how these pollutants degrade in extreme temperatures to better understand the amount of time that they pose a risk to the soil community. Understanding the soil-pollutant relationship would aid in creating ideal dosing experiments to explore the effects of the pollutant on the surrounding soil biota. Antarctica's simplistic environment may be able to shed light on how pollutants affect the whole soil system and not just one piece. In turn, this information can be used as baseline data when studying other ecosystems helping us to identify issues caused by global pollution.



Numeral Designator	Location Name	Latitude	Human Impact
1	Signy Island	60.7	High
2	Anchorage Island	67.6	High
3	Biscoe Point	64.8	High
4	Berthelot Island	65.3	Low
5	Jenny Island	67.7	Low
6	Ares Oasis	71.8	Low

Figure 1: Site locations adapted from Perteirra et al. (2017) and the British Antarctic Survey.

Table 1

Site Soil Properties

	Soil Properties			
Site	LOI	pH	EC	SWC
Signy	9.40 ± 4.2	4.87 ± 0.38	28.67 ± 11	21.92 ± 2.7
Anchorage	14.10 ± 7.5	4.00 ± 0.74	34.80 ± 21	56.17 ± 34
Biscoe	2.92 ± 1.9	6.29 ± 0.99	23.07 ± 11	7.67 ± 4.6
Berthelot	8.87 ± 1.5	5.37 ± 0.38	50.70 ± 20	54.22 ± 12
Jenny	9.07 ± 4.1	4.27 ± 0.72	33.19 ± 18	30.11 ± 12
Ares	1.98 ± 0.53	7.71 ± 0.56	45.68 ± 11	13.61 ± 3.9

Table 1: Average soil properties of sample sights with standard deviation in parenthesis. LOI is the percent of organic material lost on ignition. EC is electric conductivity and measured in siemens, and SWC is soil water content calculated in (Θ).

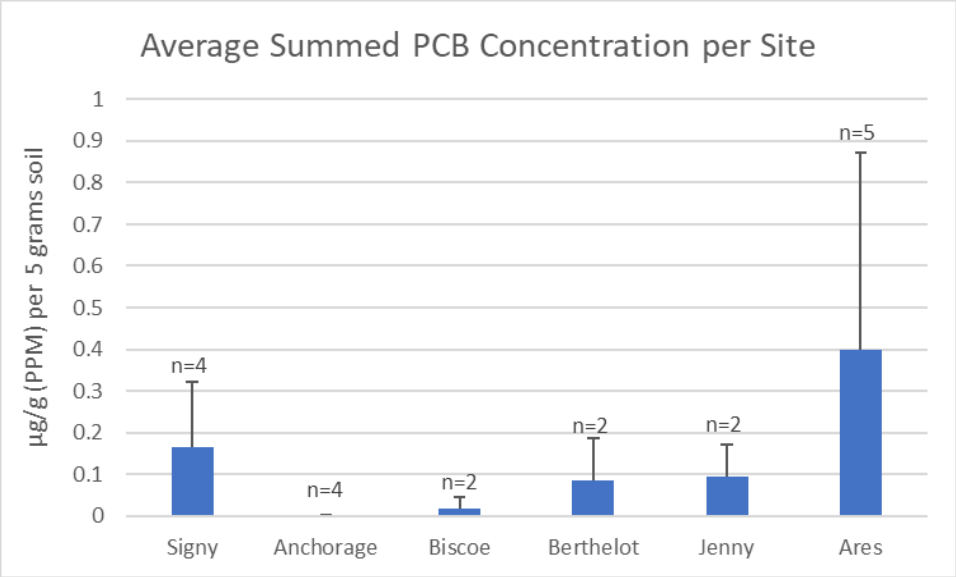


Figure 2: The average summed concentrations and standard deviations of polychlorinated biphenyls (PCBs) within each sample site. Sites are listed in order of decreasing human impact. The number PCBs detected is represented by (n).

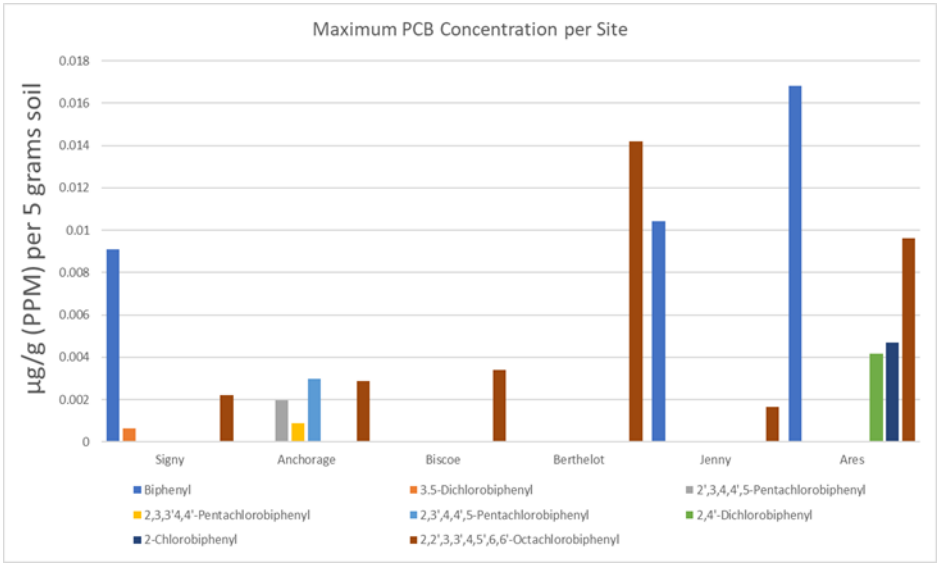


Figure 3: Maximum concentrations for 8 of 9 polychlorinated biphenyls found in each site

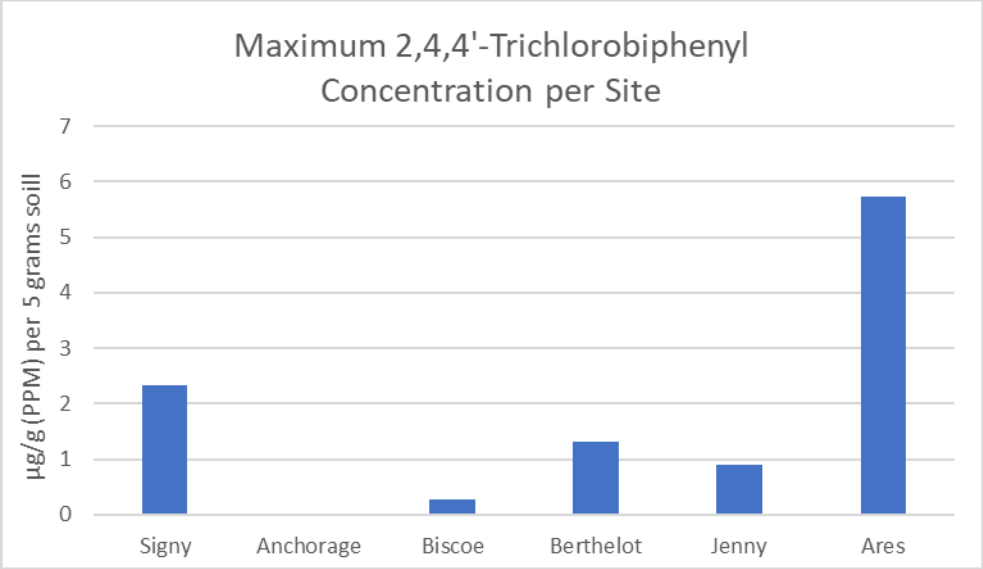


Figure 4: Maximum value for 2, 4, 4'-Trichlorobiphenoy (1 of 9 PCBs). Figure 4 is separate from Figure 3 because of the magnitude difference in maximum values. The greatest maximum value is at site Ares (5.73 PPM).

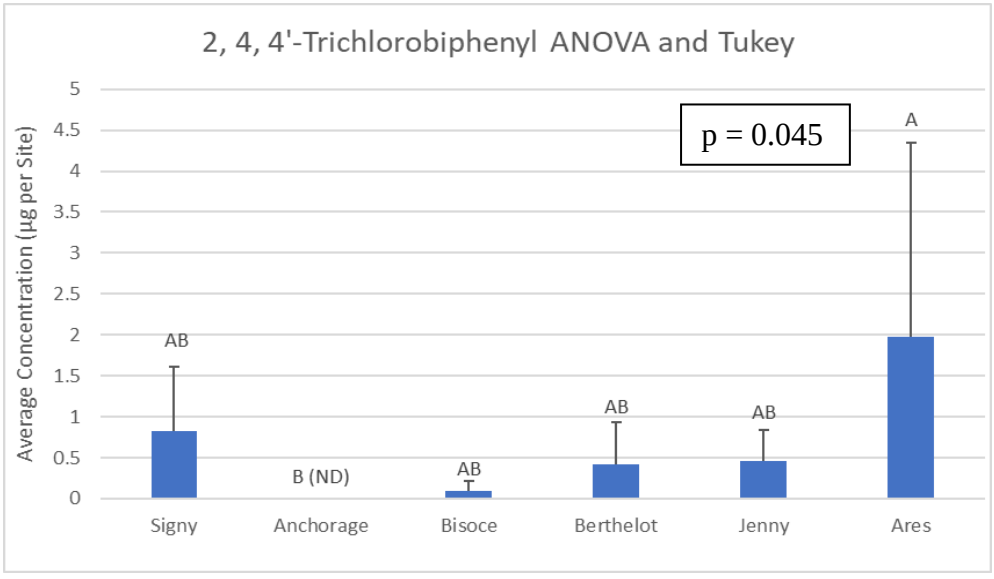


Figure 5: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in 2, 4, 4'-trichlorobiphenyl concentrations between Ares and Anchorage. ND=no detectable value.

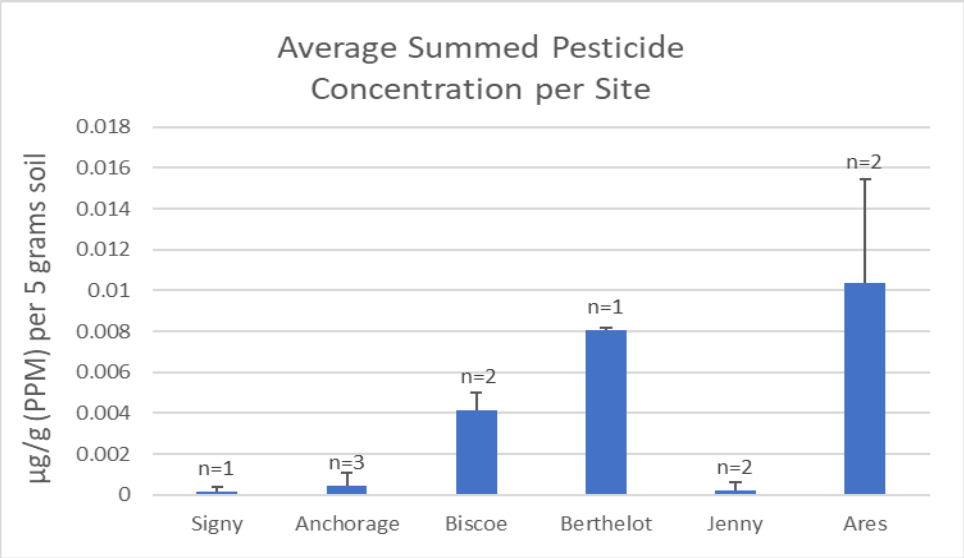


Figure 6: The average summed concentrations and standard deviations of pesticides within each sample site. Sites are listed in order of decreasing human impact. The number of the four pesticides detected is represented by (n).

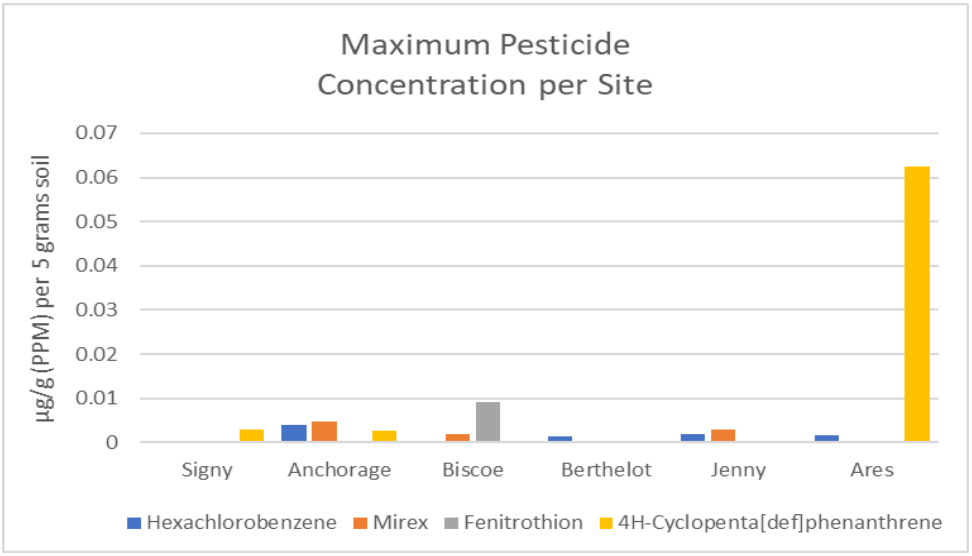


Figure 7: Maximum concentrations for 4 of 4 pesticides found in samples from each soil site.

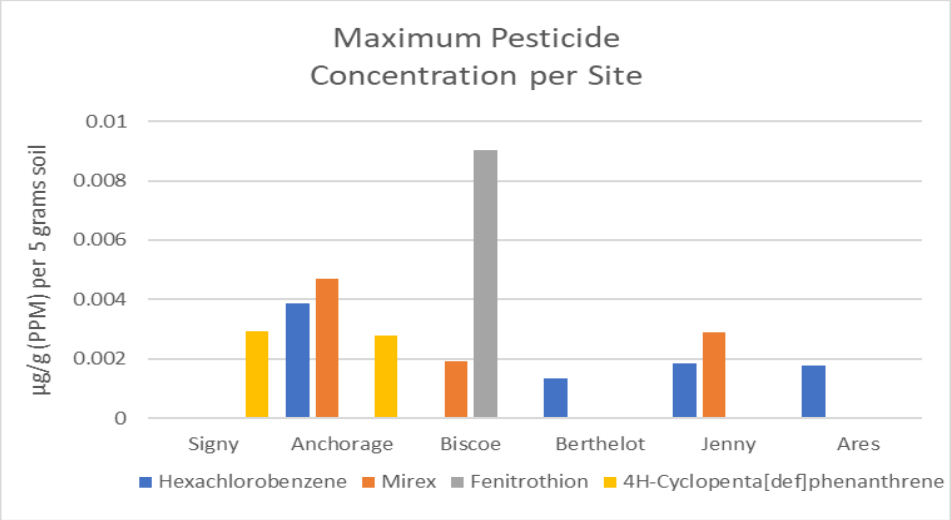


Figure 8: Maximum concentrations for 4 of 4 pesticides found in each soil site with Ares concentration of 4H-Cyclopenta[def]phenanthrene (0.063 PPM) excluded as an outlier.

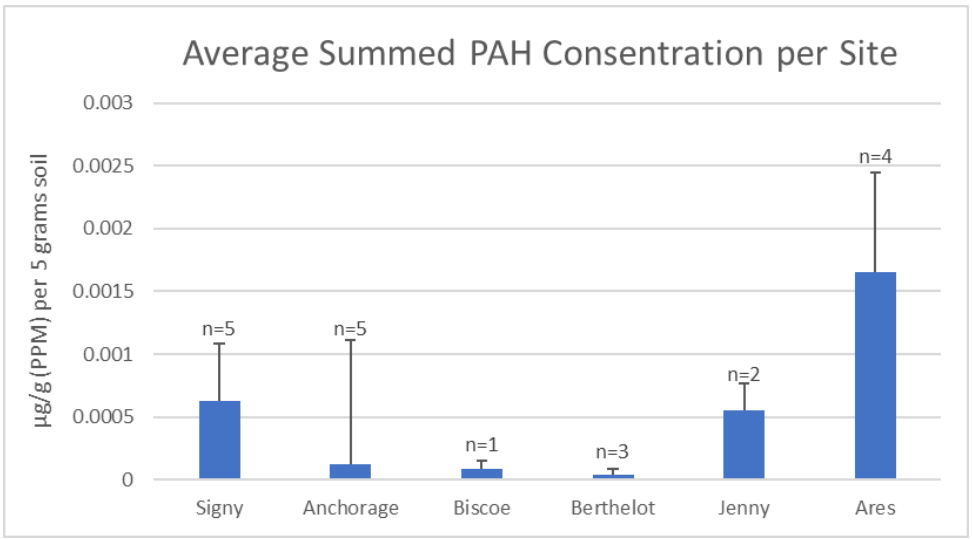


Figure 9: The average summed concentrations and standard deviations of polycyclic aromatic hydrocarbons (PAH) within each sample site. Sites are listed in order of decreasing human impact. The number PAHs detected is represented by (n).

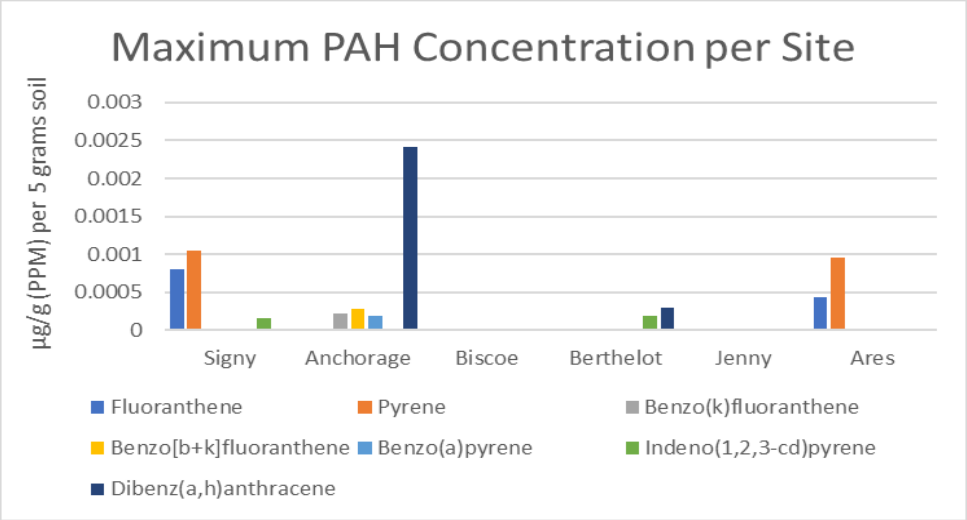


Figure 10: Maximum concentrations for 7 of 9 polycyclic aromatic hydrocarbons (PAHs) found in samples from each soil site.

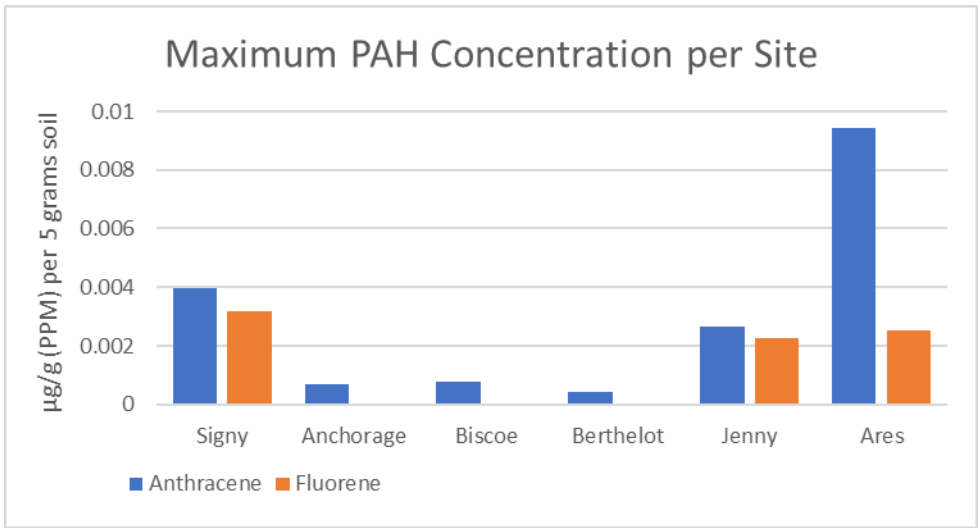


Figure 11: Maximum value of anthracene and fluorene (2 of 9 PAHs) These 3-ringed polycyclic aromatic hydrocarbons can be ideal markers for the detection of PAHs coming from anthropogenic sources i.e. burning of fossil fuels.

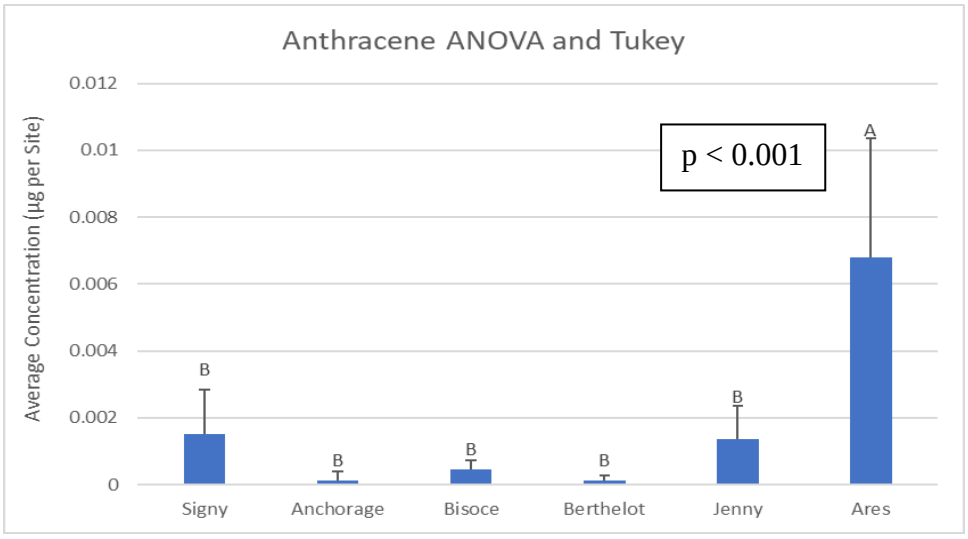


Figure 12: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in anthracene contamination between Ares and all the other sites.

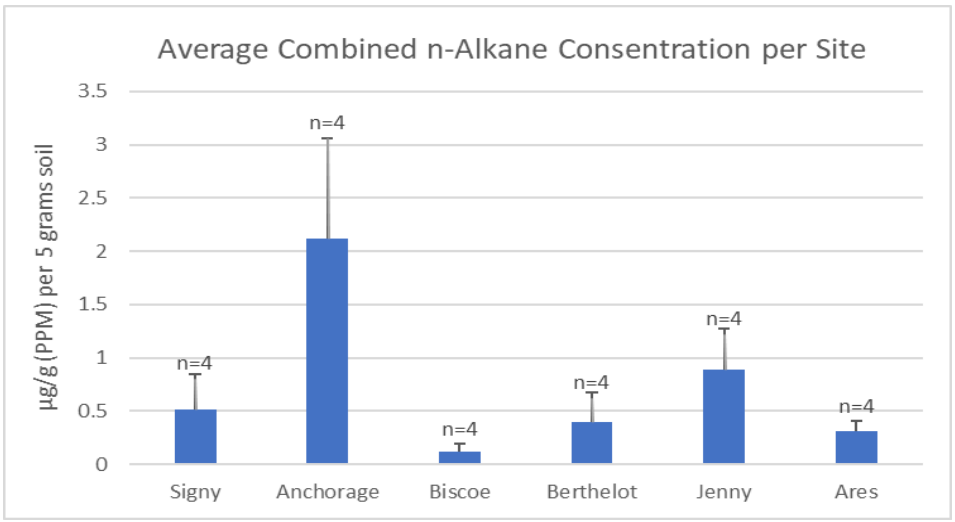


Figure 13: The average summed concentrations and standard deviations of n-alkane within each sample site. Sites are listed in order of decreasing human impact. The number of n-alkane detected is represented by (n).

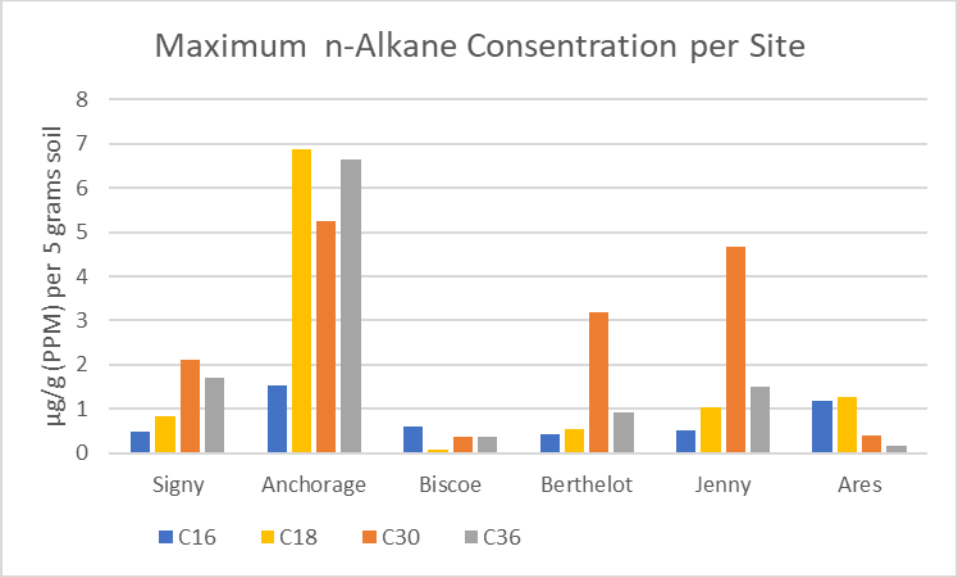


Figure 14: Maximum concentrations for 4 of 4 n-alkane found in samples from each soil site.

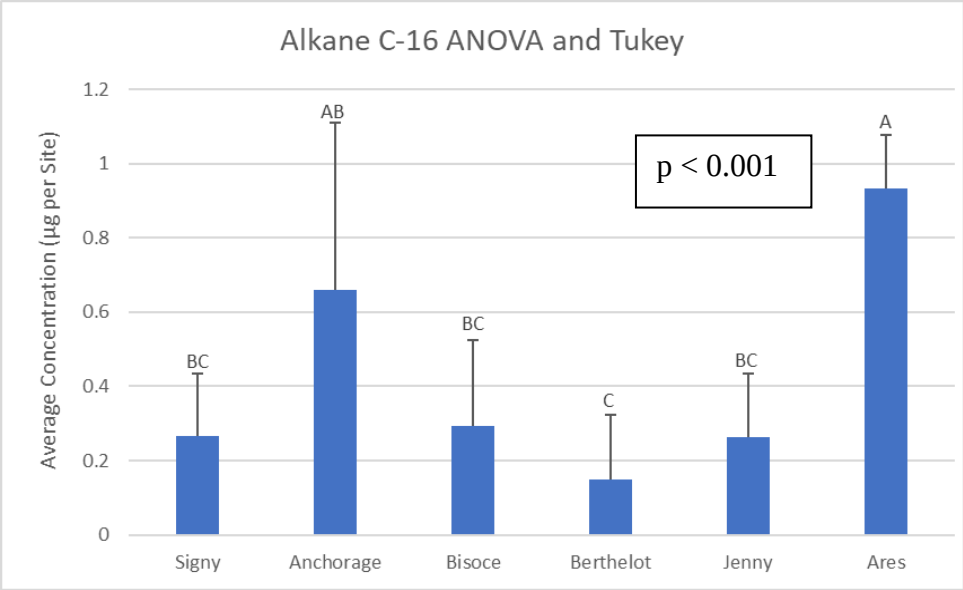


Figure 15: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in C-16 contamination between sites (Signy -Ares), (Anchorage- Berthelot), (Biscoe-Ares), (Berthelot-Ares), and (Jenny-Ares).

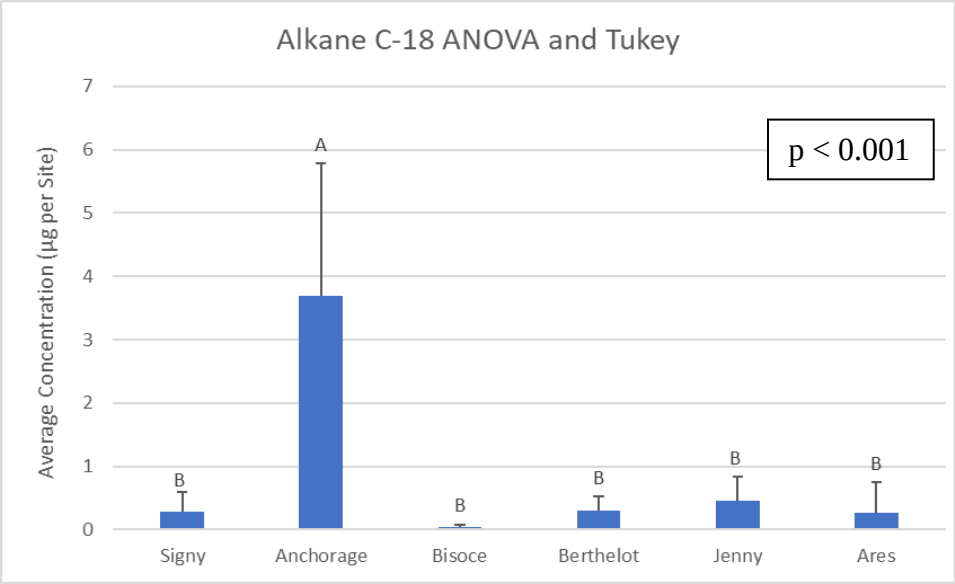


Figure 16: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in C-18 contamination between Anchorage and all the other sites.

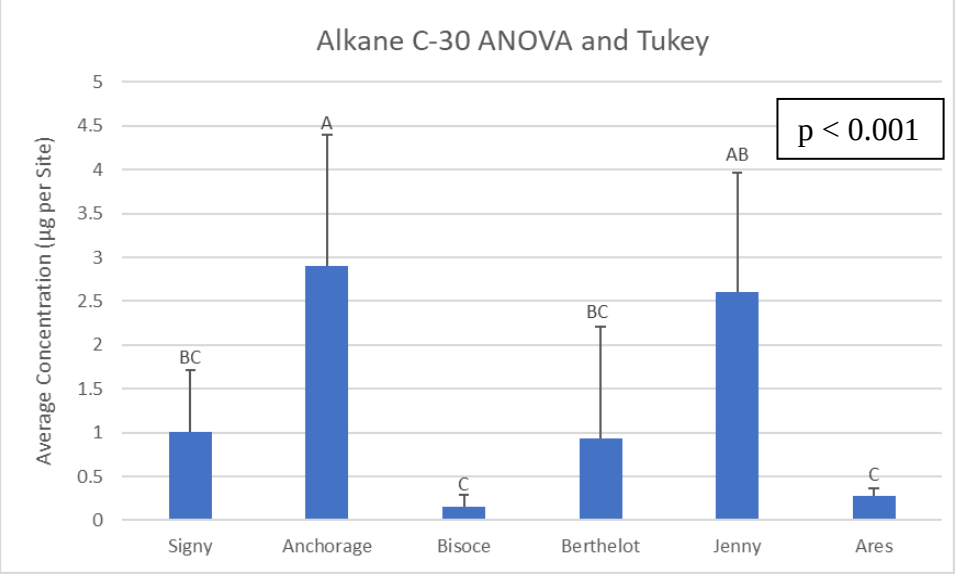


Figure 17: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in C-30 contamination between sites (Signy-Anchorage), (Anchorage-Biscoe), (Anchorage-Berthelot), (Anchorage-Ares), (Biscoe-Jenny) and (Jenny-Ares).

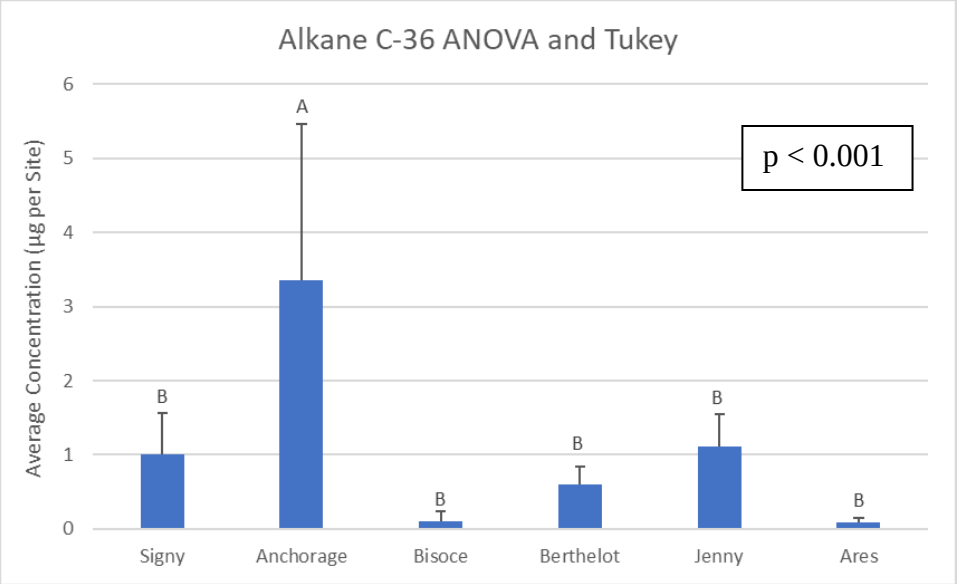


Figure 18: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified p pairwise differences in C-36 contamination between sites Anchorage and all the other sites.

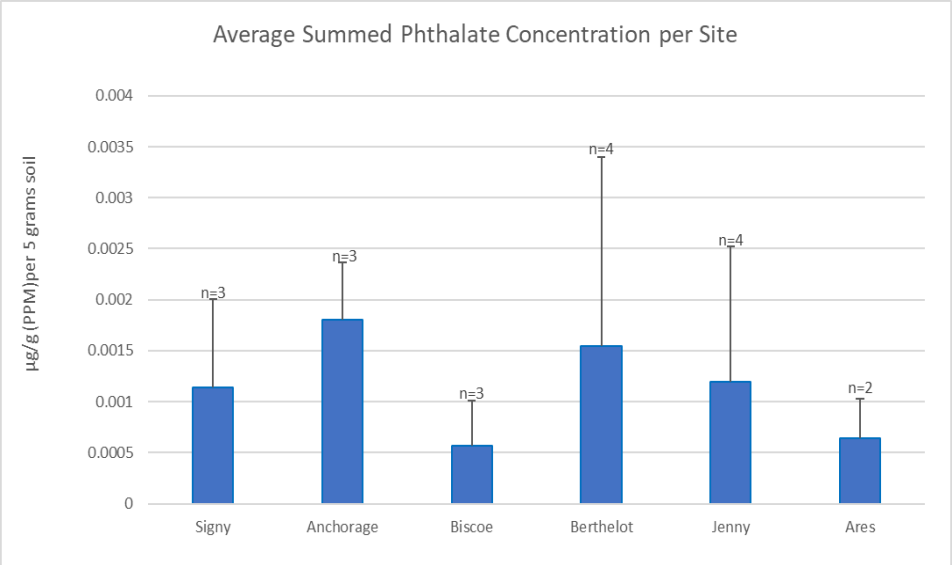


Figure 19: The average summed concentrations and standard deviations of phthalates within each sample site. Sites are listed in order of decreasing human impact. The number of the four phthalates detected is represented by (n).

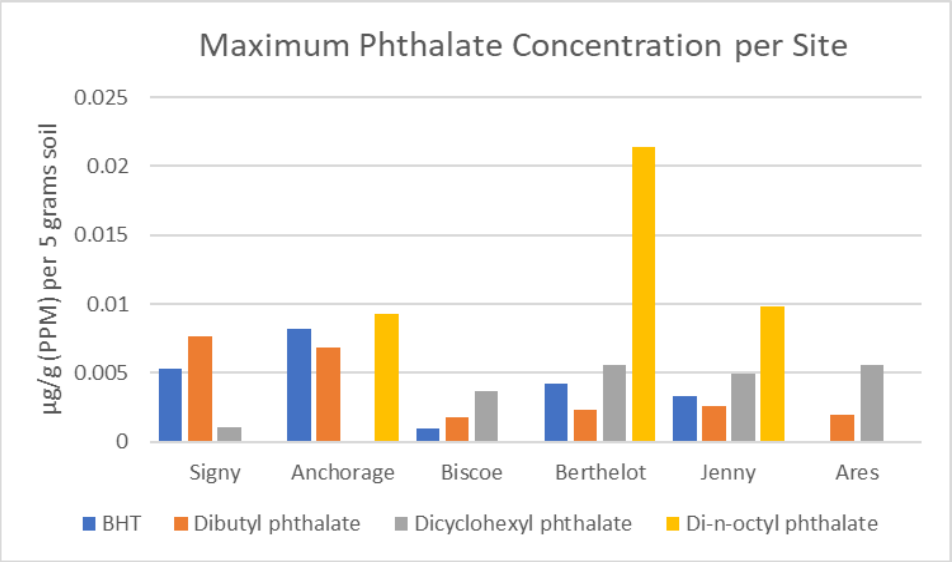


Figure 20: Maximum concentrations for 4 of 4 phthalates found in samples from each soil site. BHT is butylated hydroxytoluene.

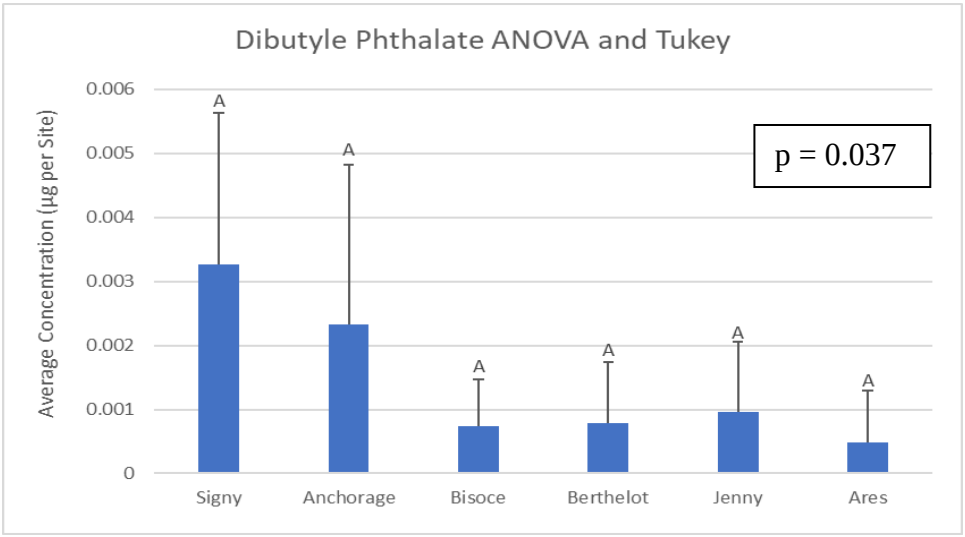


Figure 21: The ANOVA one-way test was marginally significant, but the post hoc Tukey test was not able to detect any significant pairwise comparisons.

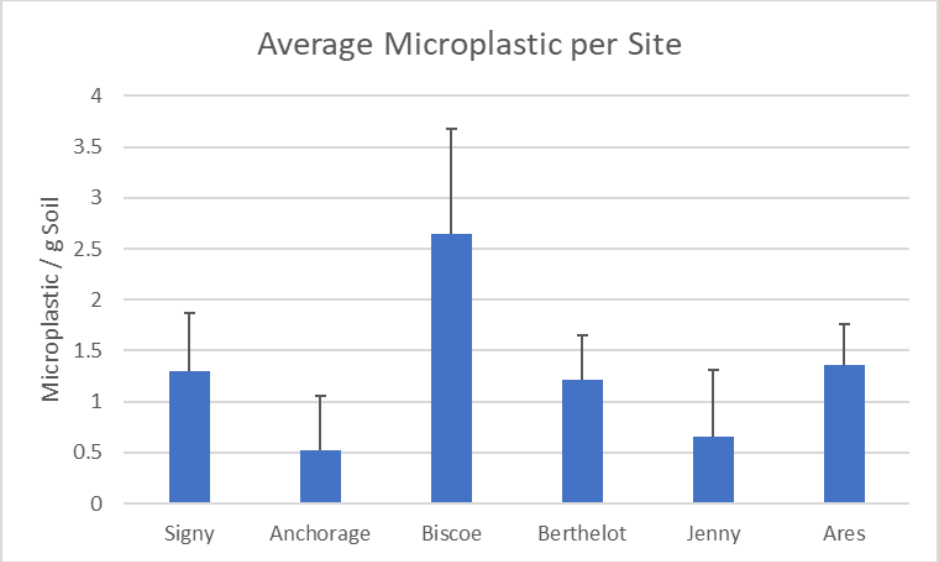


Figure 22: A sites average microplastic per gram of soil and standard deviations. Sites are listed in decreasing human impact.

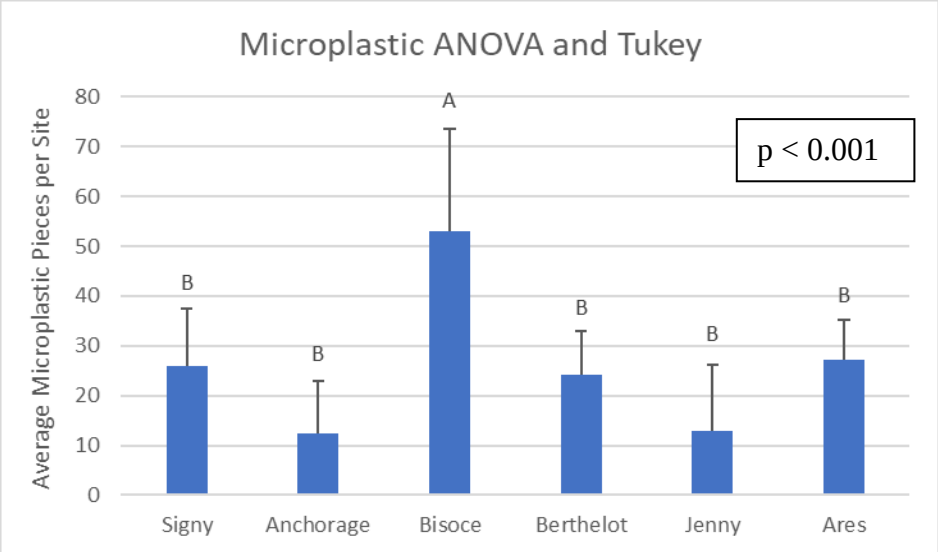


Figure 23: The ANOVA one-way test value is represented by (p). The post hoc Tukey test identified pairwise differences in microplastic count between sites Biscoe and all the other sites.

Table 2

Correlation Coefficient Values

	Soil Properties			
Contaminant	LOI	pH	EC	SWC
PCB	0.05	0.15	0.05	0.05
Pesticide	0.04	0.15	0.03	0.01
PAH	0.1	0.25	0.2	0.09
n-Alkane	0.51	0.32	0.03	0.36
PHTH	0.12	0.13	0.04	0.2
MP	0.21	0.15	0.02	0.16

Table 2: Correlation Coefficient values (R^2) of soil contamination and properties. LOI is the percent of organic material lost on ignition. EC is electric conductivity and measured in siemens and SWC is soil water content measured in (Θ).

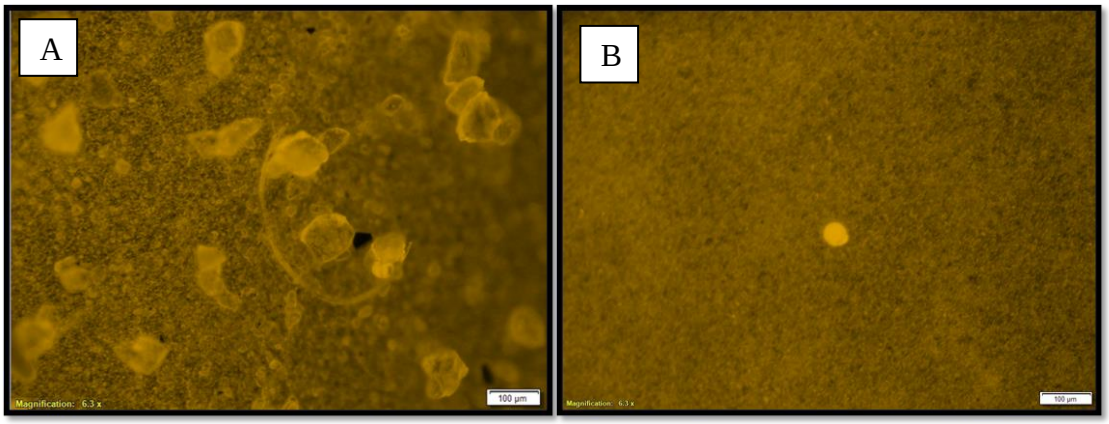


Figure 24: Comparison of possible pieces of microplastic with (A) and without (B) background noise, justifying the need for Raman or Fourier-transform infrared spectroscopy.

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APPENDIX A

DATA TABLES OF CONTMAINATION CONCENTRATIONS

IN INDVIDUAL SOIL SAMPLES AT EACH SITE

Samples were analyzed for approximately three hundred individual contaminants, with detection limits reported in Polidoro et al. (2017). Minimum detection limits (MDL) were estimated by doubling the lowest standard concentration that showed a peak, with a signal-to-noise ratio greater than three. Extraction method recoveries ranged from 40% to 90% for PCBs, 25% to 70% for pesticides, from 30% to 80% for phthalates, and from 20% to 90% for PAHs. All results presented are uncorrected for method recoveries.

Table A1

Detected Concentration of PCBs (µg)

	Polychlorinated Biphenyl (PCB)								
Sample	Biphenyl	3,5-Dichloro biphenyl	2,3,4,4,5-Pentachloro biphenyl	2,3,3,4,4-Pentachloro biphenyl	2,3,4,4,5-Pentachloro biphenyl	2,4-Dichloro biphenyl	2,4,4-Trichloro biphenyl	2-Chloro biphenyl	2,2,3,3,4,5,6,6-Octachloro biphenyl
ANT_SIG_44	0	0	0	0	0	0	0.17505	0	0.00222
ANT_SIG_48	0.00652	0.00064	0	0	0	0	0.96656	0	0.00135
ANT_SIG_49	0.00342	0	0	0	0	0	0.35454	0	0.00209
ANT_SIG_50	0	0	0	0	0	0	0.41455	0	0
ANT_SIG_52	0.00910	0	0	0	0	0	2.32162	0	0.00127
ANT_SIG_53	0	0	0	0	0	0	0.68963	0	0.00174
ANT_ANC_11	0	0	0.00195	0	0	0	0	0	0
ANT_ANC_14	0	0	0	0	0.00121	0	0	0	0.00287
ANT_ANC_26	0	0	0	0	0	0	0	0	0
ANT_ANC_30	0	0	0.00078	0	0	0	0	0	0
ANT_ANC_61	0	0	0	0	0	0	0	0	0
ANT_ANC_62	0	0	0.00142	0.00090	0.00298	0	0	0	0
ANT_BISC_43	0	0	0	0	0	0	0.03432	0	0.00149
ANT_BISC_51	0	0	0	0	0	0	0.27739	0	0.00339
ANT_BISC_52	0	0	0	0	0	0	0	0	0.00270
ANT_BISC_54	0	0	0	0	0	0	0.23616	0	0.00110
ANT_BISC_55	0	0	0	0	0	0	0.00415	0	0.00162
ANT_BISC_56	0	0	0	0	0	0	0	0	0
ANT_BERTH_11	0	0	0	0	0	0	0.11061	0	0.00158
ANT_BERTH_12	0	0	0	0	0	0	1.31957	0	0.00184
ANT_BERTH_13	0	0	0	0	0	0	0.17683	0	0.01420
ANT_BERTH_14	0	0	0	0	0	0	0.37448	0	0.00148
ANT_BERTH_15	0	0	0	0	0	0	0.08501	0	0.00146
ANT_JENNY_16	0.00772	0	0	0	0	0	0.89199	0	0.00153
ANT_JENNY_17	0.01042	0	0	0	0	0	0.47068	0	0.00164
ANT_JENNY_18	0	0	0	0	0	0	0.02777	0	0
ANT_JENNY_19	0	0	0	0	0	0	0.15296	0	0.00129
ANT_JENNY_20	0.00864	0	0	0	0	0	0.78504	0	0.00117
ANT_ARES_02	0.01467	0	0	0	0	0.00417	0	0.00471	0.00862
ANT_ARES_04	0.01215	0	0	0	0	0.00241	0	0	0.00963
ANT_ARES_06	0.01286	0	0	0	0	0	2.89192	0	0
ANT_ARES_08	0.01420	0	0	0	0	0	5.73222	0	0.00294
ANT_ARES_10	0.01682	0	0	0	0	0	3.20549	0	0.00136
ANT_ARES_12	0.00821	0	0	0	0	0	0	0.00327	0

Note. Concentrations were detected in micrograms (µg). A zero (0) value indicates a value below the minimum detection limit. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).

Table A2

Detected Concentration of Pesticide (μg)

	Pesticide			
Sample	Hexachlorobenzene	Mirex	4H-Cyclopenta [def] phenanthrene	Fenitrothion
ANT_SIG_44	0	0	0.00292	0
ANT_SIG_48	0	0	0.00170	0
ANT_SIG_49	0	0	0	0
ANT_SIG_50	0	0	0	0
ANT_SIG_52	0	0	0	0
ANT_SIG_53	0	0	0	0
ANT_ANC_11	0	0	0	0
ANT_ANC_14	0	0	0	0
ANT_ANC_26	0.00387	0	0.00277	0
ANT_ANC_30	0	0	0	0
ANT_ANC_61	0.00123	0.00470	0	0
ANT_ANC_62	0.00148	0	0	0
ANT_BISC_43	0	0.00192	0	0
ANT_BISC_51	0	0.00138	0	0.00905
ANT_BISC_52	0	0	0	0
ANT_BISC_54	0	0	0	0
ANT_BISC_55	0	0	0	0
ANT_BISC_56	0	0	0	0
ANT_BERTH_11	0	0	0	0
ANT_BERTH_12	0	0	0	0
ANT_BERTH_13	0	0	0	0
ANT_BERTH_14	0	0	0	0
ANT_BERTH_15	0.00133	0	0	0
ANT_JENNY_16	0	0	0	0
ANT_JENNY_17	0.00092	0	0	0
ANT_JENNY_18	0	0	0	0
ANT_JENNY_19	0	0	0	0
ANT_JENNY_20	0.00183	0.00287	0	0
ANT_ARES_02	0	0	0	0
ANT_ARES_04	0	0	0	0
ANT_ARES_06	0	0	0.06256	0
ANT_ARES_08	0	0	0	0
ANT_ARES_10	0	0	0	0
ANT_ARES_12	0.00178	0	0	0

Note. Concentrations were detected in micrograms (μg). A zero (0) value indicates a value below the minimum detection limit. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).

Table A3

Detected Concentration of PAHs (µg)

	Polycyclic Aromatic Hydrocarbon (PAH)								
Sample	Fluorene	Anthracene	Fluoranthene	Pyrene	Benzo (k) fluoranthene	Benzo [b+k] fluoranthene	Benzo (a) pyrene	Indeno (1,2,3-cd) pyrene	Dibenz (a,h) anthracene
ANT_SIG_44	0	0.00160	0	0	0	0	0	0	0
ANT_SIG_48	0.00239	0	0.00080	0.00104	0	0	0	0	0
ANT_SIG_49	0.00088	0.00123	0	0	0	0	0	0.00016	0
ANT_SIG_50	0.00107	0.00108	0	0	0	0	0	0	0
ANT_SIG_52	0.00318	0.00397	0	0	0	0	0	0.00016	0
ANT_SIG_53	0	0.00125	0	0	0	0	0	0	0
ANT_ANC_11	0	0	0	0	0	0	0	0	0
ANT_ANC_14	0	0	0	0	0	0	0	0	0
ANT_ANC_26	0	0	0	0	0.00022	0.00028	0.00019	0	0.00241
ANT_ANC_30	0	0	0	0	0	0	0	0	0
ANT_ANC_61	0	0	0	0	0	0	0	0	0
ANT_ANC_62	0	0.00067	0	0	0	0	0	0	0
ANT_BISC_43	0	0.00076	0	0	0	0	0	0	0
ANT_BISC_51	0	0.00072	0	0	0	0	0	0	0
ANT_BISC_52	0	0.00045	0	0	0	0	0	0	0
ANT_BISC_54	0	0.00025	0	0	0	0	0	0	0
ANT_BISC_55	0	0.00051	0	0	0	0	0	0	0
ANT_BISC_56	0	0	0	0	0	0	0	0	0
ANT_BERTH_11	0	0	0	0	0	0	0	0	0
ANT_BERTH_12	0	0.00012	0	0	0	0	0	0	0
ANT_BERTH_13	0	0	0	0	0	0	0	0	0
ANT_BERTH_14	0	0.00041	0	0	0	0	0	0	0
ANT_BERTH_15	0	0	0	0	0	0	0	0.00020	0.00031
ANT_JENNY_16	0.00123	0.00175	0	0	0	0	0	0	0
ANT_JENNY_17	0.00183	0.00268	0	0	0	0	0	0	0
ANT_JENNY_18	0.00090	0.00142	0	0	0	0	0	0	0
ANT_JENNY_19	0.00090	0.00093	0	0	0	0	0	0	0
ANT_JENNY_20	0.00227	0	0	0	0	0	0	0	0
ANT_ARES_02	0.00110	0.00942	0	0.00057	0	0	0	0	0
ANT_ARES_04	0.00029	0.00853	0	0.00082	0	0	0	0	0
ANT_ARES_06	0	0.00772	0	0.00096	0	0	0	0	0
ANT_ARES_08	0	0	0	0.00095	0	0	0	0	0
ANT_ARES_10	0.00254	0.00915	0.00043	0	0	0	0	0	0
ANT_ARES_12	0.00101	0.00594	0	0	0	0	0	0	0

Note. Concentrations were detected in micrograms (µg). A zero (0) value indicates a value below the minimum detection limit. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).

Table A4

Detected Concentration of n-Alkanes (μg)

	n-Alkane			
Sample	C-16	C-18	C-30	C-36
ANT_SIG_44	0.10927	0.23310	0.46589	0.51787
ANT_SIG_48	0.32584	0.34630	1.65599	1.66658
ANT_SIG_49	0.37428	0	0.62669	0.90353
ANT_SIG_50	0.23652	0.27198	0.64965	0.76864
ANT_SIG_52	0.49817	0.84346	2.11810	1.71137
ANT_SIG_53	0.05919	0	0.48849	0.47520
ANT_ANC_11	0.74316	5.08922	3.01096	3.89011
ANT_ANC_14	0.31759	3.93285	2.33664	2.42288
ANT_ANC_26	0.47300	2.75163	5.25318	6.65634
ANT_ANC_30	0.57799	2.50696	3.11915	4.13756
ANT_ANC_61	0.32538	0.93955	0.60449	0.34883
ANT_ANC_62	1.51964	6.88774	3.06609	2.70745
ANT_BISC_43	0.29658	0.08012	0.36125	0.37822
ANT_BISC_51	0.53784	0.08094	0.12069	0.07026
ANT_BISC_52	0.58905	0.04329	0.06241	0.06430
ANT_BISC_54	0.10525	0	0.27094	0.05857
ANT_BISC_55	0.22294	0	0.12887	0.05101
ANT_BISC_56	0	0	0	0
ANT_BERTH_11	0	0.24397	0.22618	0.42154
ANT_BERTH_12	0	0.17207	0.16162	0.31352
ANT_BERTH_13	0.15904	0.50770	0.42008	0.91512
ANT_BERTH_14	0.16093	0.54753	0.68860	0.77460
ANT_BERTH_15	0.42377	0	3.17231	0.57615
ANT_JENNY_16	0.17310	0	1.07893	0.39346
ANT_JENNY_17	0.50072	0.39635	4.68298	1.50476
ANT_JENNY_18	0.06444	0.27899	3.07668	1.07296
ANT_JENNY_19	0.22377	1.04572	1.90076	1.42090
ANT_JENNY_20	0.36038	0.54089	2.25458	1.18450
ANT_ARES_02	0.93454	0.01131	0.21829	0.07567
ANT_ARES_04	0.89915	0.10773	0.27962	0.14452
ANT_ARES_06	1.18938	0.12460	0.39998	0.17521
ANT_ARES_08	0.97737	0	0.23036	0.07114
ANT_ARES_10	0.81332	0.04951	0.20220	0.06513
ANT_ARES_12	0.77925	1.27007	0.34723	0.01530

Note. Concentrations were detected in micrograms (μg). A zero (0) value indicates a value below the minimum detection limit. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).

Table A5

Detected Concentration of Phthalates (µg)

	Phthalate			
Sample	BHT	Dibutyl phthalate	Dicyclohexyl phthalate	Di-n-octyl phthalate
ANT_SIG_44	0.00112	0.00156	0	0
ANT_SIG_48	0.00095	0.00316	0	0
ANT_SIG_49	0.00316	0.00346	0	0
ANT_SIG_50	0.00108	0.00274	0	0
ANT_SIG_52	0.00529	0.00768	0.00109	0
ANT_SIG_53	0.00142	0.00099	0.00055	0
ANT_ANC_11	0.00113	0.00158	0	0.00933
ANT_ANC_14	0	0.00064	0	0.00917
ANT_ANC_26	0.00817	0	0	0
ANT_ANC_30	0.00121	0.00143	0	0.00919
ANT_ANC_61	0.00118	0.00349	0	0
ANT_ANC_62	0.00089	0.00680	0	0
ANT_BISC_43	0.00100	0.00133	0.00371	0
ANT_BISC_51	0	0.00182	0.00292	0
ANT_BISC_52	0	0	0.00251	0
ANT_BISC_54	0	0.00073	0.00047	0
ANT_BISC_55	0	0.00058	0.00186	0
ANT_BISC_56	0	0	0	0
ANT_BERTH_11	0.00040	0.00070	0	0
ANT_BERTH_12	0	0.00096	0.00053	0.02141
ANT_BERTH_13	0.00212	0.00230	0.00559	0
ANT_BERTH_14	0.00054	0	0	0
ANT_BERTH_15	0.00419	0	0	0
ANT_JENNY_16	0.00045	0.00158	0.00222	0
ANT_JENNY_17	0	0	0	0
ANT_JENNY_18	0.00301	0.00065	0.00130	0.00982
ANT_JENNY_19	0.00336	0.00255	0.00493	0
ANT_JENNY_20	0	0	0	0
ANT_ARES_02	0	0	0.00317	0
ANT_ARES_04	0	0	0.00160	0
ANT_ARES_06	0	0	0.00555	0
ANT_ARES_08	0	0	0.00538	0
ANT_ARES_10	0	0.00196	0.00075	0
ANT_ARES_12	0	0.00091	0	0

Note. Concentrations were detected in micrograms (µg). A zero (0) value indicates a value below the minimum detection limit. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).

Table A6

Pieces of Microplastic Counted

	Microplastic						
Site	Pieces A	Fibers A	Total A	Pieces B	Fibers B	Total B	Total A + Total B
ANT_SIG_44	13	1	14	12	8	20	34
ANT_SIG_48	12	4	16	13	2	15	31
ANT_SIG_49	10	5	15	0	7	7	22
ANT_SIG_50	18	2	20	14	4	18	38
ANT_SIG_52	11	3	14	7	4	11	25
ANT_SIG_53	6	0	6	X	X	0	6
ANT_ANC_11	6	2	8	3	1	4	12
ANT_ANC_14	3	2	5	11	2	13	18
ANT_ANC_26	0	0	0	0	0	0	0
ANT_ANC_30	14	4	18	8	0	8	26
ANT_ANC_61	0	0	0	0	0	0	0
ANT_ANC_62	8	4	12	3	3	6	18
ANT_BISC_43	36	22	58	24	8	32	90
ANT_BISC_51	11	11	22	5	4	9	31
ANT_BISC_52	9	7	16	29	2	31	47
ANT_BISC_54	9	9	18	32	3	35	53
ANT_BISC_55	29	11	40	9	9	18	58
ANT_BISC_56	17	6	23	12	4	16	39
ANT_BERTH_11	9	0	9	1	4	5	14
ANT_BERTH_12	16	4	20	8	4	12	32
ANT_BERTH_13	0	0	0	14	2	16	16
ANT_BERTH_14	11	10	21	0	5	5	26
ANT_BERTH_15	4	1	5	21	7	28	33
ANT_JENNY_16	10	5	15	11	4	15	30
ANT_JENNY_17	0	0	0	0	0	0	0
ANT_JENNY_18	7	0	7	12	2	14	21
ANT_JENNY_19	8	1	9	3	2	5	14
ANT_JENNY_20	0	0	0	0	0	0	0
ANT_ARES_02	7	2	9	8	1	9	18
ANT_ARES_04	1	1	2	10	19	29	31
ANT_ARES_06	4	6	10	5	10	15	25
ANT_ARES_08	0	0	0	26	13	39	39
ANT_ARES_10	15	7	22	8	1	9	31
ANT_ARES_12	13	6	19	0	0	0	19

Note. Samples were filtered twice. The first filtration is represented by (A), while (B) represents the second. Zero values denote no fluorescent microplastic seen and the (X) represents a dropped sample. Abbreviations are as follows: ANT (Antarctica), SIG (Signy Island), ANC (Anchorage Island), BISC (Biscoe Island), BERTH (Berthelot Island), JENNY (Jenny Island), ARES (Ares Oasis).