From Ocean to Table: Microplastic contamination in Nordic salts

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From Ocean to Table: Microplastic contamination in Nordic salts

Quantifying micropollutants from Icelandic and Danish salts

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Abstract

Large amounts of plastic in the oceans originate from mismanaged plastic waste, and microplastics (MPs) are the most common type of waste. They can be found in household products, such as sea salts. Therefore, monitoring pollution levels is essential to improve marine health and food safety.

This study examined the MP levels in salts produced from the North Atlantic and North Seas and analyzed the concentration of particles and their color, shape, and size distribution. The concentrations of microplastics were quantified by dissolving the salts in water and then filtered, followed by particle counting under a light microscope. Two sea salts from Iceland and one rock salt from Denmark were analyzed. Three blank samples were also examined during the laboratory work to determine the background contamination of microplastics. The most important result shows that all three salts and blank samples contained microplastics. The sea salts had higher amounts of MP and micropollutants than rock salt, but with the limited number of samples, it is hard to make general conclusions about the difference in pollution levels between sea salt and rock salt.

These results from the North Atlantic and the North Sea only emphasize the necessity of further research to investigate how widespread microplastic pollutions are and the need to develop effective strategies to improve plastic waste management practices.

Keywords: Microplastic (MP), MP pollution, plastic pollution, sea salt, rock salt, Nordics, Iceland, Denmark, plastic waste management, human health, marine environment.

Populärvetenskaplig sammanfattning

Mellan 4.80 och 12.7 miljoner ton plastavfall hamnade i haven runt om i världen år 2010. Stora delar av den plast som hamnar i haven kommer från dålig hantering av plastavfall och den vanligaste typen av avfall i haven är mikroplaster. Mikroplaster kan därför finnas i livsmedel som exempelvis salt. Mikroplaster förekommer inte bara i plast, de är överallt, i luften, i marken och även i vårt blod. Snart kommer det finnas fler plast partiklar i haven är fisk, om vi fortsätter släppa ut plast i haven som vi gör nu. Hur kan man undersöka mängden plast i våra hav, vad kan vi göra? Hur ser vår framtid ut? De frågorna är viktiga att ställa, för vem vill äta, andas in, och bestå av plast? Ingen.

I studien undersöktes två havssalt från Island och ett bergsalt från Danmark. Resultaten visar att alla tre plaster som undersöktes innehöll mikroplaster. Majoriteten av mikroplaster som analyserades var röda och blå, till mesta dels i form av fragment och fibrer. De allra minsta mikroplasterna var ungefär 5 mikrometer (μm) och de största var runt 2000 μm.

Kunskapen kring vad våra livsmedel innehåller är mycket viktig, men även att ha möjlighet att övervaka ökningen av plastföroreningarna i haven. Att salt innehåller mikroplaster är en indikation på hur stora mängder plast det finns i haven vilka konstant bryts ner till mindre och mindre partiklar och förstör dyrbara marina ekosystem. Det finns ett stort behov av vidare studier och ytterligare forskning om föroreningsnivåerna av mikroplaster i haven. Specifika analyser som spektroskopi behövs, det används för att avgöra vilka typer av plast mikropartiklar är. Det kan användas för att utveckla vidare arbetet med de analyserade salterna. Detta är viktigt för att i framtiden ha möjlighet att införa begränsningsstrategier och förbättringar i avfallshanteringen av olika typer av plast. Det är viktigt att arbeta med frågan om mikroplastföroreningar genom kollektiva ansträngningar för att minska plastavfall, främja hållbara metoder och utveckla innovativa lösningar för plastavfallshantering.

Studien bidrar med väsentlig kunskap till företag som producerar salt, de som använder det och för Livsmedelsverket. Kunskapen är viktig för att konsumenterna ska veta hur de får i sig mikroplaster som i framtiden kan komma att riskklassas. Lärdomarna som erhålls kan då omsättas för en minskad saltkonsumtion men främst minskad plastkonsumtion i samhället.

Konsekvenserna av dålig information och kunskap kan leda till att plast i exempelvis mat, luft och vatten ökar. Följderna är fortfarande inte helt klara men för att vara på den säkra sidan för både de marina miljöerna och för framtida generationer bör förändring ske nu.

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Introduction

The total input of plastic pollution to the oceans 2010 was between 4.80 and 12.7 million tonnes globally (Jambeck et al., 2015). Most of these plastics originate from mismanaged plastic waste that has increased with the rising use and production of plastic products (Geyer et al., 2017; Zhang et al., 2023). Nevertheless, how long these plastics remain in the environment is still unknown, it can be due to their durability and slow degradation (Wayman & Niemann, 2021). Wayman and Niemann (2021) also explain that microplastics, abbreviated MPs, are one of the most common types of litter found in the ocean. Microplastics are therefore found in household items like salt and tap water (Kosuth et al., 2018).

MPs are not visible to the naked eye, but there is no standard size range of what makes it a microplastic. A microplastic and nanoplastic pollution study defines MPs as particles ranging between 0,1 μm – 5000 μm (Ng et al., 2018). This study proceeds to use this as a measure as well. Microplastics can be divided into two categories based on their origin. Primary MPs are manufactured to appear in various products, such as facial cleansers and scrubs (Praveena et al., 2018). Secondary microplastics are broken down from larger plastics, macroplastics, through UV light that breaks the chemical bonds in the plastic's polymer chains (Singh & Sharma, 2008). MPs enter the ocean by wind and runoff in the forms of produced MPs or as weathering macroplastics. MPs can be further categorized as fibers, fragments, and sheets based on their physical form. Fibers originate from synthetic materials like nylon or polyester, while sheets and fragments are smaller pieces of plastic that have broken off from larger pieces and continue to break down (Kapukotuwa et al., 2022).

Microplastic is a persistent pollutant in the marine environment due to slow plastic disintegration, meaning it has a high environmental impact. Therefore, it is not easy to reduce directly from the ocean, and it takes a very long time to degrade. According to Kim et al. (2018), the concentration of microplastics in sea salt can be related to plastic entering the oceans in coastal regions, meaning it could be a method for monitoring marine plastic pollution.

Today, a great deal of research has been done on MP content in different types of salts (Kim et al., 2018; Lee et al., 2019). To the greatest extent, research is found in different parts of Asia. In a study done on salts from Sri Lanka, microplastics were found in all types, table salt, sea salt, rock salt, raw sea salt that had not been packaged or purified, and also in NaCl classified for use in laboratories (Kapukotuwa et al., 2022). Studies have also been carried out in, for example, Bangladesh and Indonesia

(Dwiyitno et al., 2021; Siddique et al., 2023). A global review of previous research was conducted while they also conducted a study on the MP contamination of table salts from Taiwan (Lee et al., 2019).

Similar studies have yet to be done for sea salt produced in the Nordic region, specifically from the North Atlantic and North Seas. It is essential to conduct work regarding MP pollution in the Nordic regions and the knowledge about exposure through consumables such as salt.

Aim

This study can contribute essential knowledge to the companies that produce salt, those who use it, and the Swedish Food Agency. Research gaps occur as it is not known precisely what amounts of microplastics one inhales or ingests during one's lifetime and how they can accumulate (Blackburn & Green, 2022). Further research into the pollution levels of MPs in the oceans and specific spectroscopy analyses are needed to develop mitigation strategies and improvements in the waste management of plastics. Here I present the first look at the findings from three Nordic salts and their MP concentrations.

This study aims to measure the concentration of microplastics in salts from Denmark and Iceland. The work also aims to add knowledge about microplastic pollution in the North Atlantic and the North Sea and to highlight the significance of microplastic exposure for humans from consumables like salt.

Research questions

I. *Are there microplastics in sea salt and rock salt?*

II. *How high is the concentration of microplastics in the salt samples?*

III. *What is the distribution of microplastics according to color, shape and size?*

Hypotheses

The hypotheses of the study were that all analyzed salts contain microplastics/microparticles.

Ethical reflection

During this thesis, no personal information was handled, no names of products were used, and no survey or interview was conducted. The choice of method posed an ethical issue since it was taken from a published article. It was, therefore, necessary to correctly refer to the literature where the same method has been used and developed.

Other ethical dilemmas appeared when analyzing the results that affect society. Results showing high amounts of impurities in the salt samples can affect food safety. This issue can be sensitive but manageable through clear information, comparisons, and communication. Based on other similar studies of MPs in salt, it is inevitable that the salt samples will contain microplastics, but they may not be of concern because of low concentrations. Therefore, this study only aims to show that even salts produced in Nordic countries like Iceland and Denmark also contain microplastics, to track marine plastic pollution further. The companies making the salts were not named to limit ethical dilemmas. Still, the results from this study are not alarming, meaning they would not cause any concern for the company's products.

The results will not cause controversy but may instead be a call to consume less salt. The potential impact of high levels of microplastics in salt requires follow-up work with more advanced analysis and, later on, contacting the production companies and other responsible authorities.

Method

Laboratory work and analysis

Material

This study used three salts: two sea salts and one rock salt. The selection of these salts was based on the limited amount of salts produced in the Nordic regions, therefore only one groundwater salt was chosen and two different sea salts, for better comparison. All three salts were purchased in different stores.

The first sample, Salt A, had a production date of 29-09-2022. According to their official website, seawater from the Arctic Ocean, southwest of Iceland, was pumped to the production site, where it is filtered from dirt and seaweed to maintain its mineral content. The salt was then stored, and the water was evaporated in a stainless-steel tank and then heated with geothermal energy in open pans so the salt crystals could form. The salt is hand harvested and later sold in plastic bags inside metal containers.

The second sample is from Salt B, and the production date is unknown. The salt is produced southwest of Iceland, and the seawater is pumped from the North Artic Ocean. According to their website, they use hot water from geysers and geothermal energy for the heating, boiling, and drying process. After hand harvesting, the salt crystals are stored and sold in glass containers.

The third sample is Salt C, with a production date of 31-01-2022. According to their website, the salt contains "a number of minerals" due to being evaporated from groundwater. The website also states that the seawater around the production site in Denmark, only contains 2% salt, while the groundwater used for the salt extraction contains 14%. In the production, firewood is used as heating fuel. After production, the salt is stored and sold in cardboard containers with a cork lid.

According to their websites, all three salt samples have a similar traditional salt production process. The only difference is that Salt A and Salt B use geothermal energy for the processes, while Salt C uses firewood burning. Another important aspect that sets them apart is that groundwater is used in the production of Salt C and not sea water like for the other two samples.

Laboratory work

The microplastics were extracted according to Kim et al. (2015) with some specific adaptations. Before any laboratory work, the deionized water was tested for background concentrations of MPs. The process for the Procedural blank test was implemented, like the preparation of each sample. In the laboratory, an Air blank test was carried out. Air blank 1 was conducted during laboratory work with Salt A whilst Air blank 2 was conducted during laboratory work with Salt B and C.

A small petri dish, 60 mm in diameter, with a small amount of deionized water, was placed where the laboratory was conducted for approximately one hour. The sample was analyzed and filtered after the laboratory work. This process was conducted to determine if there was airborne contamination from clothes, the ventilation system, or outside air in the laboratory. The process of filtration was the same as with the salt samples.

For all three salt samples, the same laboratory process was used. Into a 1 L pre-cleaned Erlenmeyer flask, 250 g salt was placed along with 1000 ml deionized water and then covered with pre-cleaned aluminum foil. After that, the salt was dissolved on a hot plate at 50-60 °C. The samples were divided, 2x500 ml, and passed through a Whatman glass fiber filter using a water suction device. The filter was a Whatman glass microfiber, grade GF/F with 47 mm diameter and 0.7 μm pore size. The filter was carefully placed in a clean petri dish, approximately 60 mm in diameter, with a pair of tweezers and covered with pre-cleaned aluminum foil.

Quality control

Protocols to minimize the risk of contamination was followed, like wearing cotton clothing and cotton lab coats to avoid fiber particles in the samples. All the instruments were rinsed three times with deionized water before use, and no plastics were used. The filters were used immediately and stored with a cover to minimize contamination. Samples were kept covered at all times, except during analysis with a microscope.

Analysis

Identification and quantification of microplastic particles were made under a microscope, according to Kim et al. (2018). Mineral particles and biological soft tissues were excluded as much as possible. The physical characteristics such as color, size, and shape were visually observed under a microscope (Olympus S2X10) equipped with a Digital camera. Photographs through the microscope made it possible to showcase the plastics and measure size differences and colors. The magnification used on the microscope was 20- and 25-times magnification, and with the camera, the zoom magnification in the computer program was 40. Figure 1 shows all the significant categories with a 10-1000 μm scale.

The particles found in the samples were classified by size, shape, and color. Colors were identified in 11 classes: ivory, yellow, orange, red, pink, green, brown, grey, blue, black, and transparent. Furthermore, shapes were classified into fiber, fragment, and sheet. A fiber has a thin straight, and often cylindrical shape, while fragments are more irregular and have an uneven surface, while a sheet is a thin plane with an even surface. The sizes of the microparticles were categorized approximately as small 5 - >200 μm, medium 200 – 1500 μm, and large 1500 < μm. The data was visualized into diagrams and figures that show quantification and results for further analysis and conclusion.

The blank samples are analyzed for more general knowledge about microplastic pollution from air and water. Since the laboratory work for the Procedural blank was the same as with the salt samples it gives a measure of what can be expected as background contamination later on in the salt samples. While the air blank samples can be analyzed as a potential source of contamination in the lab. Therefore, the analysis of the air blanks can show that the potential for contamination exists even though quality controls were implemented. The Procedural blanks showed an actual contamination while Air blank 1 and Air blank 2 showed the potential contamination levels. Meaning the analysis of these samples can also show a significance in the analysis of the salt samples.

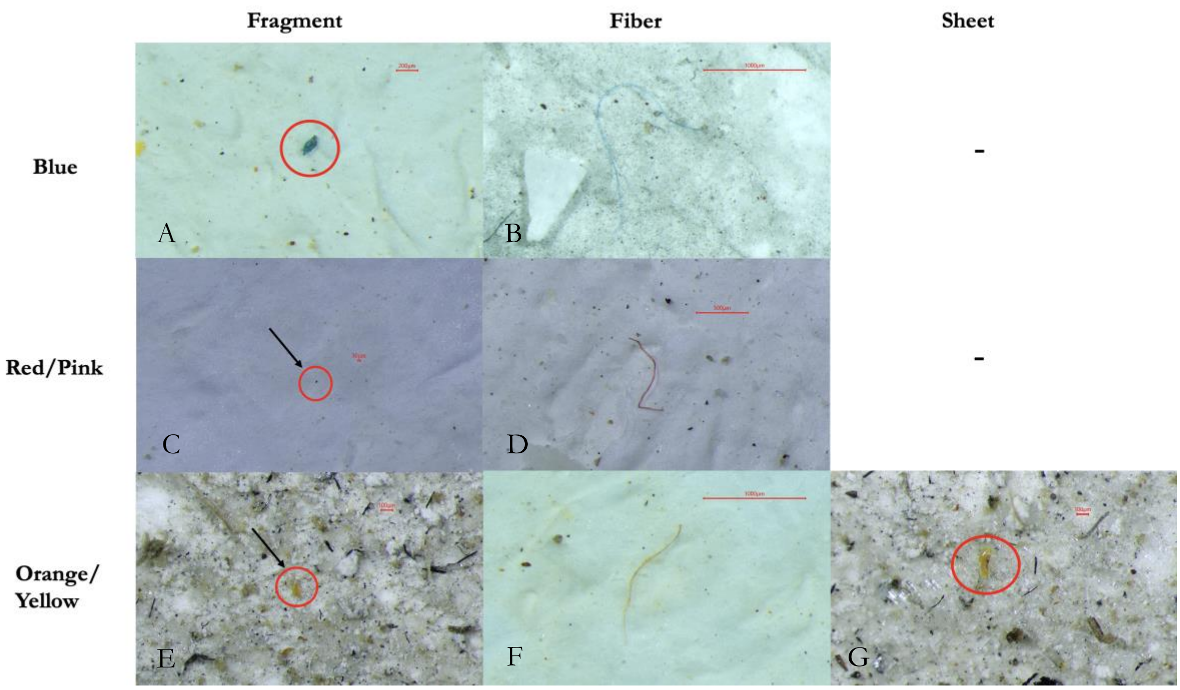

Figure 1. Visual categorization of microplastics
The shape distribution is categorized as fragmnet, fiber and sheet. The most prominent colors were choosen as examples to showcase the differences between colors and shapes. As seen under fragments they are smaller and have an uneven surface whilest the fibers are medium and large. The fibers are straight and cylinder shaped, the sheets are more flat with an even surface. No blue and red sheet were found, only orange/yellow. Picture A, C, D and F are from Salt A, B is from Salt B and E and G are from Salt C.

Delimitation

The limitation of this study is that only three salt samples were analyzed in the laboratory work, where two are sea salts, and one is a rock salt. Due to time limitations only the three salts were analyzed. Sea salt and rock salt are only produced by a limited number of producers in the Nordic countries, and the salts used here were salts that could be sourced from local supermarkets. Furthermore, the method was limited to analyzing one sample from each type of salt instead of analyzing multiple replicates from each salt, this is also due to time constraints.

Further delimitations of this study were that only light microscope analysis was used, and no further analysis with spectroscopy was conducted. Fourier transform infrared (FTRI) spectroscopy is the most common way of identifying microplastics. This study's time limitation and extent limited the use of FTRI to analyze the micropollutants further. According to Kim et al. (2015), hydrogen peroxide (H2O2) was used to dissolve any organic matter and biological soft tissue, but after further consideration and discussions with different scientists, it was excluded from this method. The reasoning for this was that it would be too time-consuming to carry out the method entirely, according to Kim et al. (2015). Also, even if H2O2 were used, it would not eliminate all the organic matter, for example, cellulose fibers. Without the use of FTRI and hydrogen peroxide, the risks of this study were that by mistake, analyzing and identified organic material as plastic.

Results

Concentration of microplastics

Figure 2 illustrates the number of particles found in each salt sample and in the blanks. Salt A contains the most microparticles where out of the 432 particles the majority were small particles with a size range between 5 – 200 μm (small). Salt B contains 387 particles with far more large particles, around 120. Salt C contained the least number of particles out of the tree salt samples, the distribution between sizes was similar to Salt A.

The blank samples also contained microparticles (Figure 2). Even in the Procedural blank 10 particles were found, most of which were in the large size range. In Air blank 1 with 48 particles, almost all are in the bigger size range, 1500< μm, while Air blank 2 had a higher concentration of small particles, 5 - >200 μm.

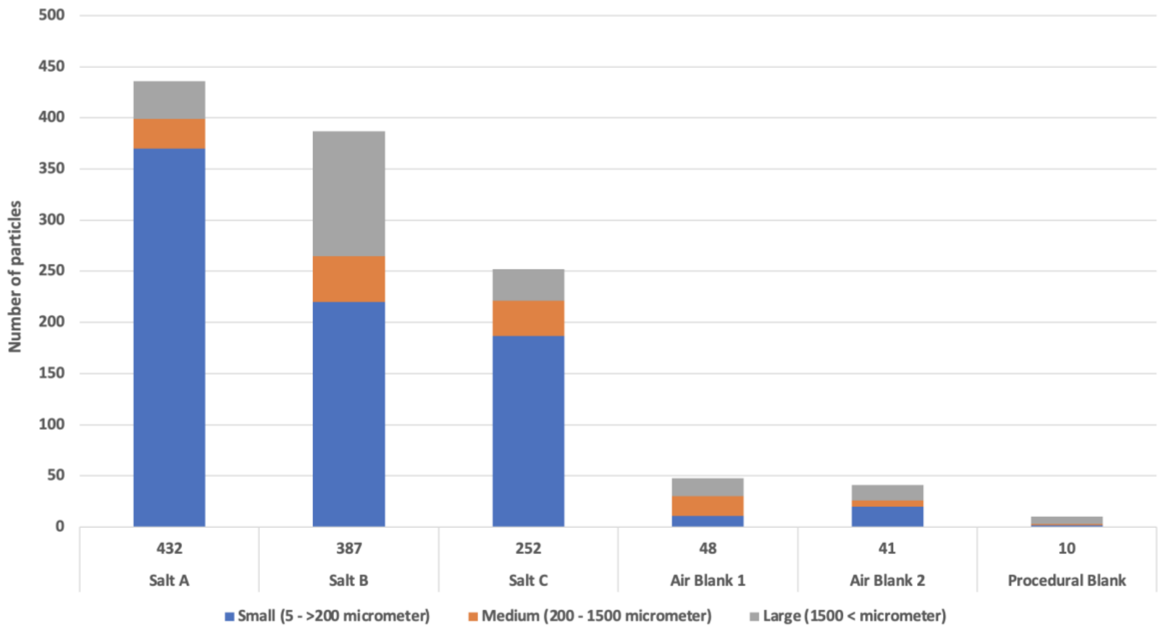

Figure 2. Number of particles in the salt samples and the blanks. Categorized in small with the size range 5 – 200 µm, medium with 200-1500 µm and large with 1500< µm.
Salt A contains the most particles, followed by Salt B and the least amount of particles were found in Salt C. Most of these particles were small in size. In the blanks, particles could be found randing from 48 in Air blank 1, approximately 41 in airblank 2 and in the Procedural blank only 10 particles. They were mostly in a larger size that the other blanks.

Distribution of microplastics

Blank samples

The results in Figure 3 show the distribution in percentage by the three categories, color, shape, and size. In Air Blank 1, most of the microparticles found were black at 73% (N=48), whereas in Air Blank 2, blue was the most common color with 61% (N=41). The Procedural Blank had less of a color variation. However, transparent and brown particles were the most common. Shape distributions were also very different for the three blanks. In Air Blank 1, most of the particles were fibers, in blank 2 the majority were fragments and in the Procedural blank, 50% (N=10) of the particles were fibers. The Procedural blank also had the highest percentage out of its particles in the larger fraction, 70% out of N=10, meaning seven particles were large. In the Air blanks, the size varied between a majority of medium and small.

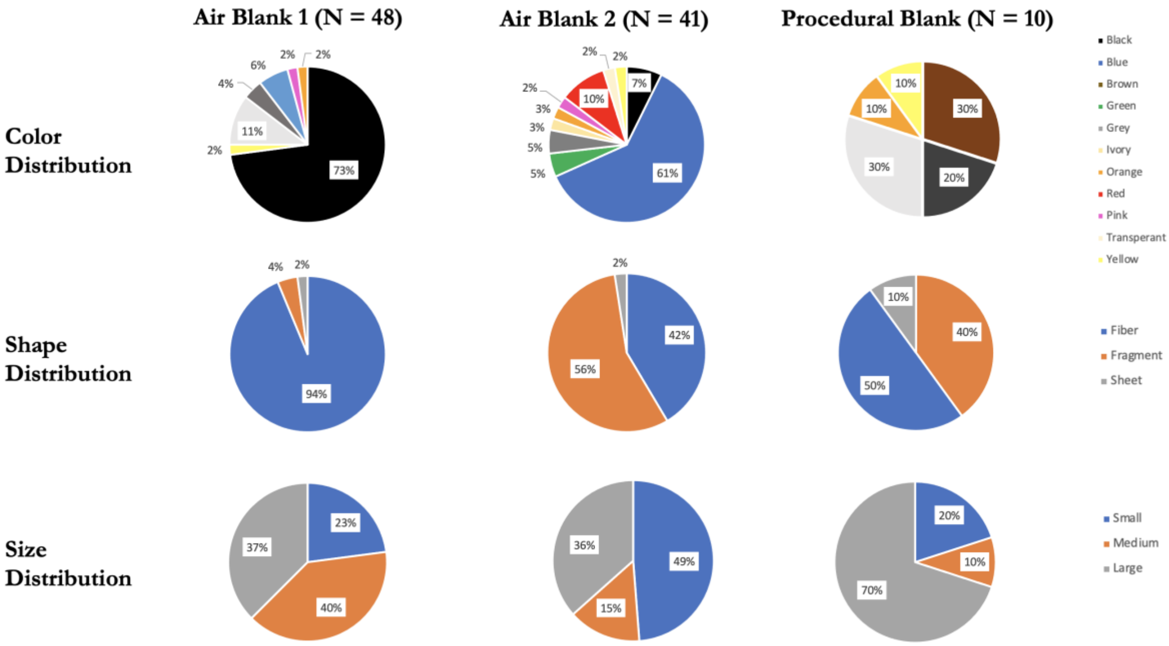

Figure 3. Color, shape, and size distribution of Air blank 1, Air blank 2 and Procedural blank. The major colors in the blanks were black, blue, brown and transperant. The shape varied between fiber and fragment, while size was different from each sample.

Salt samples

Figure 4 indicates that the most common colors in the three salt samples were red, blue, orange and yellow. In Salt A 46% (N=432) of the particles were red, whilst in Salt C it was 29% (N=252) and in Salt B, 17% (N=387). The highest number of blue particles were found in Salt C with 33% (N=252) and the most orange particles were found in the Salt B sample with 28% (N=387). Fragments were the most common shape in all samples, with 81% (N=432) in Salt A, 73% (N=252) in Salt C and 60% (N=387) in Salt B. The rest were mostly fibers. Furthermore, the size of the particles was dominantly small in all three of the salt samples. In the Salt B sample 31% (N=387) of the particles were large whereas in Salt A only 8% (N=432).

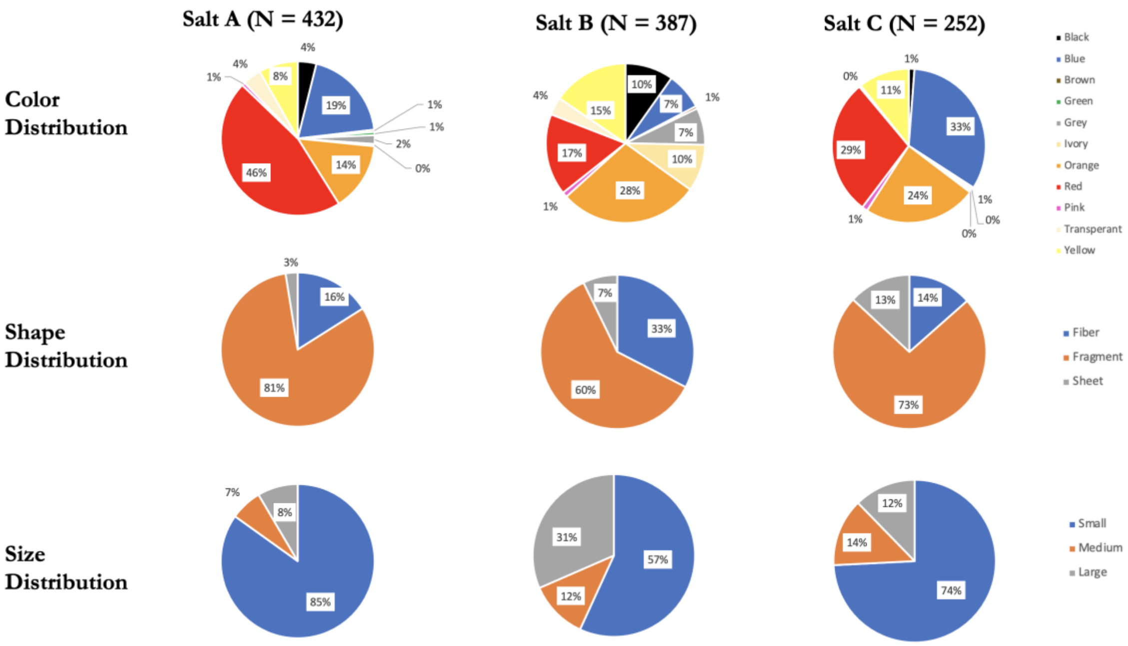

Figure 4. Color, shape, and size distribution of Salt A, B and C.
The colors that occurred most among the particles where red, blue orange and yellow. Shape distribution was predominantly fragments and in size distribution small particles occurred the most.

Visual analysis

The visual analysis is used to further differentiate the salt samples, to further analyze and discuss the obtained concentrations and, distributions in the salt samples. Figure 5 shows the difference between the salt samples. In Salt A it is visible that small fragments are easily detectable. On the other hand, Salt C contained a lot of organic material that made it hard to visually see the microplastics and particles. Similar to Salt C, Salt B had some black organic material or minerals that makes the identification of particles harder. Also, the colors are different between the three samples.

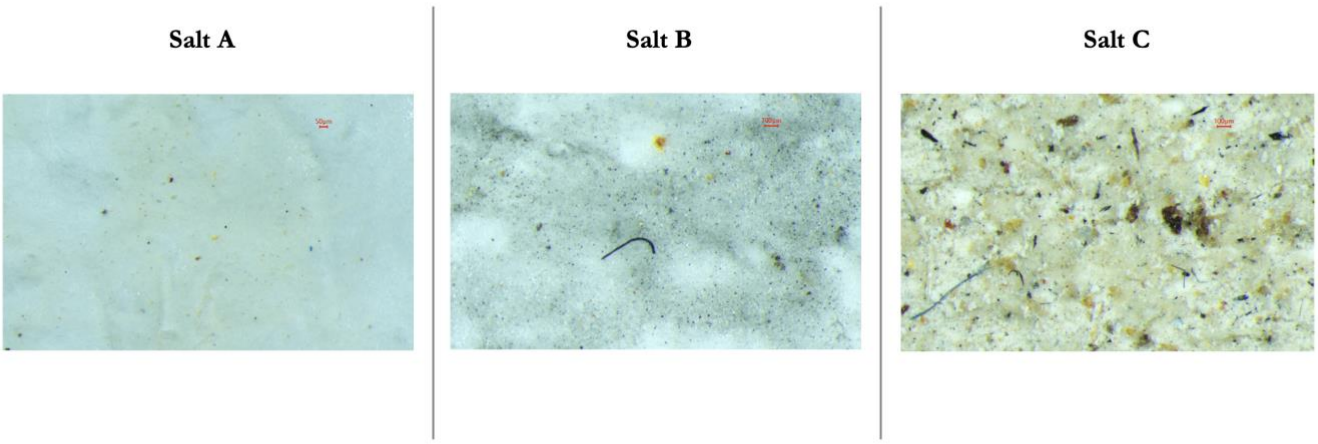

Figure 5. Example picture of the salt samples.
Visual representation of microplastics in the three different samples. The background and particles are different in every sample and the micropollutants that are presumed to be microplastics are viewed differently in each sample.

Research questions compilation

All the samples contained microplastics/microparticles. The concentration of the salt samples varied between 432 particles in Salt A, to 387 particles in Salt B, to lastly 252 particles in Salt C. Furthermore, the distribution of the salt samples with red, blue, orange and yellow being the most common colors. Their shape distribution was mainly fragment followed by fiber. Lastly their size distribution was small, meaning between 5-200 µm. Both the concentration and the distribution indicate that all three salts produced in the Nordics contained microparticles, specifically microplastics to some extent. The blank samples also contained microparticles. The concentration in the blank samples allows a comparison with the salt samples, they show how many particles the salt samples can come from the background contamination, but the low concentration in the procedural blank indicate that the contamination during the processing of the samples was limited.

Discussion

Result Analysis

Salt samples

The results show that all the salt samples contained microplastics, which confirms the hypothesis of the present study. The concentration of MPs in the samples was high, as seen in Figure 2. Salt from groundwater (Salt C) contained the lowest concentration of microparticles compared to the two sea salt samples. This suggests higher contamination and accumulation of MPs in the ocean than groundwater. However, there needs to be a better comparison with more samples from groundwater to further discuss the differences in pollution levels between oceanwater and groundwater. Different pollution levels in different sources can potentially correlate with particle amounts, as seen in Figure 2. Yang et al. (2015) concluded that sea salt contained more MPs than rock salt. As predicted in the present study's hypothesis, all salts contained microparticles, even the blanks. This is also in accordance with the findings in the study by Kapukotuwa et al. (2022), where all salts contained MPs.

The distribution of color, shape, and size of microplastics/microparticles in the three salt samples was as expected compared to other studies. The samples' most abundant colors, with the highest overall percentage, were red, blue, orange, and yellow (Figure 4). In the studies by Kosuth et al. (2018) and Yang et al. (2015), blue and red/pink were the most abundant colors. Red and blue-colored microplastics were easily observed, and it was clear that they were not organic materials but plastics. However, the study by Yang et al. (2015) also listed black and white as dominant colors, which is in relation to the findings by Kim et al. (2018). Their concentration varied between white, grey, transparent, and blue. In the present study, it is therefore assumed that orange and yellow were likely not microplastics but other microparticles resembling plastics.

The studies mentioned above correlate with the findings in this present study regarding shape distribution. Fragments were the most abundant shape in all three salts, with a maximum value of 81% (N=432) in Salt A and the lowest in Salt B with 60% (N=387). Figure 4 also conveys that along fragments, the salts contained mainly fibers. However, it is worth mentioning that the percentages could be too high since there are uncertainties regarding the analysis and calculation of the particles, where particles that were not microplastics could have been counted.

Blank samples

The results from Figure 2 indicate that MPs were present in all the blank samples. The Air blanks contained a high amount of particles, indicating that the quality control of the laboratory work needed to be improved. In Air blank 1 the concentration of particles was higher than in Air blank 2. Based on these results, the assumption can be that while the first laboratory work was conducted, two people were working in the lab, which means more risk for contamination from clothing and circulation in the air. The same can be assumed about the Procedural blank, since the water used was deionized for laboratory use, it would hypothetically only contain very few particles.

As observed in Figure 2, the size distribution of the blanks, foremost Air blank 1 and the Procedural blank showed that the particles were in the medium to large range, 200-1500< μm. Meaning there was a larger share of this size range in the blank samples compared to the salt samples. The salt samples may have been contaminated throughout the laboratory work, meaning that larger particles in those samples could originate from clothing or air. Although this could explain the larger particles in the salts, the risks are not high due to the handling of the blanks and salt samples. The blanks were open to exposure and contamination from a 60 mm diameter open Petri dish for approximately one hour. The salt samples were always covered except during filtration and the analysis of the filters; therefore, they were not exposed to the air to the same extent as the blanks.

Color distributions in the blank samples were different from the salt samples. Mainly black, blue, transparent, and brown particles were found in the blank samples (Figure 3). It is also possible that the black and brown particles were dirt and other pollutants. This also indicates the variability of visual analysis, where errors are possible in counting microparticles.

Similar to the results of the shape distribution in the salt samples, fragments, and fiber were most abundant in the blank samples. The most significant share of the particles overall was fibers, with 94% (N=48) in Air blank 1, while in Air blank 2 the most prominent share was fragments, with 54% (N=41). In Air blank 1, most of the fibers were black, which could mean that they are not microplastics but other particles. The distribution in Air blank 2 was most similar to the other salt samples seen in Figure 4, meaning it could be a more accurate result since the color distribution was also mainly blue.

Credibility

A size assessment of the particles in the present study gives a perception of its credibility. Table 1 shows that the size ranges are different in the selected four studies compared to the present study. Compared with these studies, the present study found and analyzed particles in the range of 5-2000 µm. In this study, many small particles were counted and analyzed (Table 1), which could explain why the results showed a higher concentration than other studies. Smaller particles are harder to count, and errors like double counting, missed MPs or counting of organic material could have occurred. This study analyzed a smaller size range of particles, it is possible to assume that the results are not directly comparable to the study by Kim et al. (2018). The study was used as the foundation for the extraction and analysis methods. In that study, they found that the United Kingdom, the country in Europe with the highest MP concentration in salt, had 34 MPs in their sea salt (n/250 g). If that result is compared with the two sea salt samples (Figure 2), it is clear that the number of particles is higher, meaning the result is presumably not directly comparable. However, it is likely that if only the particles counted in the 200-1500< µm range was counted, the results would be more comparable. If that were the case, the number of particles in Salt A would be around 65 (n/250 g), which is similar to the result by Kim et al. (2018).

Table 1. Size ranges in four selected sources and the present study.
The largest range was in the studies by Kosuth et al. (2018) and Kim et al. (2018). The smallest particles counted were in this study while other studies had 45, 100 and 160 µm as their smalles particles.

References	Size range (µm)
Kosuth et al. (2018)	100 - 5000
Yang et al. (2015)	45 - 4300
Kamari et al. (2017)	160 - 980
Kim et al. (2018)	100 - 5000
This Study	5 - 2000

Other than the size range, the number of particles can be influenced by the production processes of the salts and their packaging. The production of the salts generally had the same process. The only difference was that Salt C used groundwater and firewood burning for the processes instead of geothermal energy like the other two salts from Iceland. Producing rock salt can then contribute to its high concentration of microparticles. Many particles could be coal from the firewood or MPs from the process. As seen in Figure 5, the background pollutants in the samples are different, and the brown, black, and orange particles could then be from the firewood burning in the production process. Packaging could play a role in the contamination of the samples meaning that the salt with the highest concentration, Salt A with the highest concentration of MPs found, was packaged in plastic while Salt B was in a glass container, and Salt C was stored in carton. This relevance's plausibility is low, but it could be an interesting observation for the future.

Pollution level indicator

Sea salt can potentially be used as an indicator for monitoring ocean plastic debris. They can show the magnitude of MP pollution around different cities and at-risk marine environments. However, based on the uncertainty of the results of this study, the concentration of MPs in these specific Nordic sea salts could not be directly used as indicators of microplastic pollution in the Arctic Ocean. With only the results from this study, monitoring like that could not be possible. However, they can be better used with other studies' results. Despite having limitations in quantifying MPs and other available data, plastic pollution and the discharge to the oceans and coastal regions can be important when monitoring marine and human health. Sea salt can thus be a valuable tool to monitor the number of microplastics in these specifically exposed areas to see how the waste generated in these areas is broken down and consequently continue to spread and multiply in the future (Kim et al., 2018). In the study by Kim et al. (2018), they also found a general trend with a linear relationship between MPs in sea salt and bivalves, thus supporting the idea of using sea salt to monitor MP pollution in specific areas for future management.

Alternative ways to monitor and indicate pollution levels include monitoring and investigating population density around production and extraction sites. In China, coastal areas had a density of 559 people/km^2, and the northwest, lake salts origin, had only 12 people/ km^2 (Yang et al., 2015). The population density is directly linked to higher pollution levels, including MPs, in local environments (Yang et al., 2015). This can be applied to the sea salt samples in the present study, but the correlation between population density and groundwater pollution needs to be clarified. Further, it can be discussed how relevant this is in Iceland, where the population density is low compared to China. Additionally, plastic has a slow degradation rate, meaning it can travel far from its sources (Karami et al., 2017). The MPs found in the samples could originate from another area far away and, therefore, not be associated with the population density of the area where the salt was produced. This does not mean that waste management, agricultural changes, and other measures to ensure lower plastic emissions into the marine environment should not be considered in differently populated areas. These things should globally be taken into consideration for better mitigation.

Study limitations

Uncertainties and limitations of the present method can be of significance when only analyzing 250 g salt once and not making a comparison or mean of the particles found in the different samples. Furthermore, it would have been easier to analyze and make conclusions if only fibers of different colors and sizes were counted, meaning more specific categorizations to ensure that only microplastics were being counted. The size range can be essential to compare this result with other studies. According to other studies, the size range is vital to have more comparable results between different studies. Misidentification and double counting of particles could have been avoided with easier categorization. The counting process could have been more accurate through the digital camera on the microscope with an accompanying computer system that takes photos for analysis. According to Kim et al. (2018), the particles that were not microplastics in their samples were identified as natural polymers, such as cotton and mineral particles. Other inorganic compounds can be found when analyzing salt samples. In the study by Yang et al. (2015), the particles can be identified as bentonite and calcium carbonate, which are naturally occurring.

Other uncertainties could result from inefficient particle recovery, as no hydrogen peroxide (H2O2) was used in the laboratory work to eliminate the organic particles from the samples. As mentioned in the delimitation (Introduction, 2.3), it would not have been possible to use H2O2 in the present study. Nevertheless, it would be a crucial step in future and more extensive works with microplastic recovery and quantification in salts. Furthermore, no FTRI spectroscopy was used to establish the particles' nature and determine if they were plastic for more accurate pollution level monitoring. Results that indicate that the visual analysis and quantification were not adequate only show that there are options for development. With more time and resources, the results can be developed and more elaborated.

The results in a bigger perspective

According to The World Health Organizations guideline for sodium intake (2012), the daily recommended salt intake is 5 g. Salt A contains 432 particles in 250 g of salt. Assuming all particles are microplastics, it can be concluded that the average person then consumes around 1000 particles per year only from sea salt. Through sea salt, other products can be contaminated with MPs. Seafood can also pose a risk for even more intake of MPs. Many individuals will be affected by this because table salts like sea salt are a requirement and well used in our daily lives. However, it is not known precisely what amounts of microplastics one ingests during one's lifetime and how they can accumulate and affect human health (Blackburn & Green, 2022).

The presence of microplastics in the marine environment, specifically sea salt, can pose a direct threat to food safety. Furthermore, salt from seawater can further absorb other contaminates and transfer them to other products. Contaminates can be, for example, plasticizers that can cause harm when migrating into the environment and potentially affect human health (Seltenrich, 2015).

Therefore, both other studies and the results from the present study suggest that no matter exactly how many particles different salts contain, they will contain some concentrations of MPs, meaning it is crucial to implement preventive measures to limit human exposure and the deterioration of the marine environments. Mitigation strategies must be implemented in high-risk areas to reduce the amount of mismanaged plastic waste discharged into the oceans. Reducing plastic use needs to be considered globally to ensure that no marine environment or other humans worldwide will not get harmed. That is a fundamental reason why further work and analysis of other salts from Nordic countries are needed for more knowledge and understanding of microplastic pollution around us that affect us.

Conclusion

The present study concludes that the results strongly suggest that microplastics contaminated the two sea salts and the rock salt. The distribution of MPs in the three salt samples according to color, shape, and size was as expected. The most abundant colors were red and blue, while the most occurring shape was fragment and fiber, as seen in previous studies. Size ranges varied, and the present study quantified and analyzed the smallest particles meaning that the results for the concentration of MP per salt are higher than expected and compared with the study by Kim et al. (2018). Additionally, three blank samples were tested for MP contamination in the air and water. The results showed that they were contaminated with MPs and other microparticles.

This study is limited to only visual analysis and specific laboratory methods due to time limits. Particle recovery was also limited, meaning that the results vary from other studies, and it can be hard to compare the exact numbers. Although the limitations of this study make the results less accurate, there is no doubt that the presence of MPs in the marine environment, specifically sea salts, can threaten food safety since no matter what amount is ingested, it could pose a risk to human health.

Another conclusion that can be made is that MP pollution in sea salt can potentially be an indicator to monitor plastic pollution levels in the oceans, even though this study could not with certainty indicate this due to uncertainties. Together with better coastal plastic waste management, and along with monitoring, significant improvements could be made to marine health and food safety.

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