Unmanned vehicle and hyperspectral imager for a more rapid microplastics sampling and analysis

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***Abstract*—In this paper, we present a proof-of-concept study aiming to improve the sampling and analysis of microplastics (MPs) by implementing a novel methodology combining an autonomous surface vehicle and a near-infrared hyperspectral imager (HSI). The field study was conducted from the 2^{nd} to the 5^{th} of August 2022 at Runde – a well-known bird preservation island on the Western coast of Norway. Over 35 samples from two different locations (*Exposed (A)* and *Sheltered (B)*), MPs concentration was at its highest (0.511 MPs/m^3) in *location A*. During the four days of sampling, at least 25 % of the data did not detect any MPs (0 MPs/m^3). Thus, we showcase an easy repeatable method towards the assessment of high variable MPs concentration using a Portable Catamaran Drones (PCD) and a near-infrared hyperspectral imager (HSI). The results from HSI were compared against Attenuated Total Reflection Fourier-Transform infrared (ATR-FTIR). No significant difference ($P > 0.05$) found at *location A* indicated that both instruments can provide accurate MPs concentration. A potential future correlation between MPs concentration and Key Environmental Variables (KEVs) could help to contribute to the modeling and policymaking world.**

I. Introduction

As the need for more healthy and sustainable food resources becomes urgent, more concerns surrounding plastics and microplastics (MPs) pollution are raised as it could potentially affect ocean resources and seafood safety [1]. MPs, defined as smaller than 5 mm in diameter [2], are ubiquitous in marine environment globally [3]–[6] and marine plastics pollution is an urgent environmental matter [7]. MPs are entering coastlines and transported in the ocean [8] either from direct input or from the breakdown of macro debris through different mechanisms [9]. Widespread dispersal of MPs makes their accumulation in the ocean "poorly reversible" and readily available for exposure due to MPs' large range of size and, as a result, have concrete geophysical, biological, and societal impacts [10].

Understanding the transport and effects of plastics over long spatial and temporal scales must be a priority in the environmental monitoring field for the years to come [11]. Knowledge about the food chain bioconcentration of MPs [12] as well as the potential transfer of hazardous substances [4], [13] will be important to assess human risk exposure [14], [15]. There is an urgent need for guidelines and monitoring framework of MPs in the marine environment [11], [16], [17]. NOAA marine MPs database [18] presents global MPs concentration change between 1972 and today. Multiple factors can be correlated to this increase, such as the increase in plastic production and release to the environment as a consequence of a growing world population [9].

The increase in marine pollution is followed by an increase in research [18] which faces challenges related to the limited throughput of monitoring campaigns of plastic debris. Although data is abundant, for some areas sampling of MPs remains mainly opportunistic with a low level of replication often due to the requirement of a boat [19]. Thus, limited spatial and temporal scales are recorded making it harder to reproduce and compare data on MPs [20].

A central challenge in determining plastic exposure is the time-consuming nature of sampling and analyzing of MPs in marine environments, restricting modelling and monitoring frameworks. Furthermore, opportunistic sampling is often not representative for the highly variable MPs concentration in the ocean as it is difficult to sample sufficiently in space and time. The lack of standardized and diverging methods for analysis can lead to inconsistency in methodologies. Missing baseline data makes comparisons quite limited [20]. For surface water sampling, common sampling equipment (manta, neuston, and plankton nets) often requires a boat, which results in a limited sampling area, contamination risks and less spatial and temporal coverage [22]. For MPs analysis, common techniques are the Raman and Fourier-Transformed Infra-Red (FTIR)

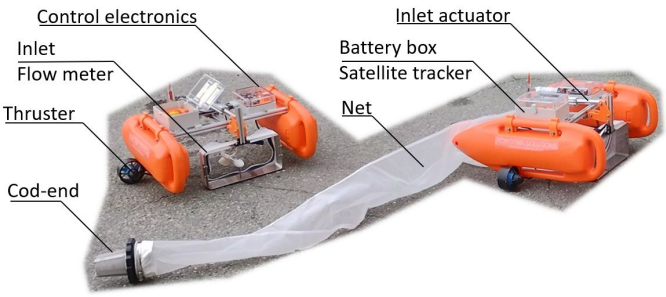


Fig. 1. Portable Catamaran Drone. Reprinted from [21]

This work was supported by the Research Council of Norway through the Centre of Excellence funding scheme NTNU AMOS (grant no. 223254).

spectroscopy [23]. These technologies are highly accurate but can introduce selection bias or limited throughput because they are time-consuming and expensive [23], [24]. Analytical challenges occur often when prior manual selection is required for spectroscopy measurements as it can underestimate MPs counts, thereby introducing selection bias [23], [25]. In order to design a high throughput monitoring method, faster sampling and analysis methods need to be implemented [23].

In this paper, we present a proof-of-concept study aiming to improve the sampling and analysis of MPs by implementing a novel methodology combining an autonomous surface vehicle [21] (Figure 1) and a near-infrared hyperspectral imager (HSI). The study area for this vehicle was Runde, a well-known bird preservation island on the Western coast of Norway. Two locations were chosen for the fieldwork: the first one exposed to dominant currents and wind and the other protected.

Sample collection was performed by a Portable Catamaran Drone (PCD) as shown in Figure 1. The autonomous surface vehicle was used to enhance accessibility and selectivity regarding spatial and temporal coverage contrasting conventional methods. Sample preparation was carried on with a Wet Peroxide Oxidation (WPO) for the removal of organic materials and filtered for spectroscopic analysis. For sample identification and characterization, HSI was compared against Attenuated Total Reflection FTIR (ATR-FTIR) to quantify sample throughput increase and reduction of analysis time and costs.

Key contributions of that paper are: 1) a proof-of-concept of the utilization of state-of-the-art technologies (PCD, HSI), to increase the number of MPs samples collected during fieldwork; 2) Showcase how samples collected over the same path differ in concentration; 3) Reduction in samples analysis time; 4) Showcase difference in readouts of digital and traditional sensors affecting the concentration data.

Section II discusses MPs sampling and analysis methods used. Section III describes observed concentrations. Results are discussed in Section IV.

II. Microplastics sampling and analysis

Guidelines for surface water monitoring usually involve three main steps: sampling, sample processing, and particle analysis [16], [26]. For this study, we focus on testing new methods for sampling and analysis of surface water samples. Quality assurance and quality control (QA/QC) measures were taken ensuring little or no MPs contamination throughout the sampling and laboratory analysis [27], [28].

A. Fieldwork Site

The fieldwork took place on Runde Island (62°23'31.902"N, 5°38'35.6028"E), situated on Norway's northwestern coast in Møre og Romsdal county, facing the Norwegian Sea, characterized by an oceanic climate, steep terrain, and intricate currents [29]. The island's marine litter distribution is influenced by the Norwegian Atlantic and coastal currents (NAC and NCC, respectively) [30] and by freshwater runoffs from the fjords [31]. Runde is renowned for being the southernmost seabird island on Norway's coast and a crucial site for the national bird monitoring project, hosting red-listed species like the Atlantic puffin *Fratercula arctica* and black-legged kittiwake *Rissa tridactyla*. Drastic reduction of seabirds have been recorded in the last decades [32], [33]. Colonies of gannets are known to nest in its cliffs with reports of nests made of plastics litter [34]. The fieldwork was conducted at the beginning of August in 2022, during the breeding season, with sampling locations chosen due to seasonal conservation area closures. Two different locations on the island were used in this study. Situated on the South-West side of the island, *location A* is most exposed to currents with little to no influence from direct or near human disturbances. *Location B* is on the North-East side of the island, sheltered from currents but can be influenced by human runoffs.

B. Unmanned Surface Vehicle for Microplastic Sampling

While common surface water MPs collection uses a net towed by a boat, in the presented fieldwork we used Unmanned Surface Vehicles to tow the nets. A number of Portable Catamaran Drones (PCD)[21] can be deployed and they navigate automatically through a pre-planned path because of an embedded autopilot. The vehicle is controlled using an open-source QGroundControl or Mission Planner software running on Android and Windows devices. The user can communicate with PCD via WiFi or LTE connection Due to its autonomy and compact size, the PCD did not require any boat assistance during the fieldwork. At *location A*, the PCD was deployed and recovered directly from ashore whereas, at *location B*, it was sent out from a pier. Fieldwork lasted four days from the 2^{nd} to the 5^{th} of August, with eight to ten runs throughout each day. The robot carried a nylon plankton-net (300 µm) and custom, stainless steel cod-end (300 µm), designed for quick swap between runs. Cod-ends, attached at the end of the net where the environmental samples is collected, were changed after each transect and stored. The net was attached to an actuated inlet mouth of the PCD. Each mission started with the inlet above the surface of the water. The inlet was lowered by the autopilot at a pre-programmed location further from the coast to avoid any unwanted disturbances in the samples and to have a better representation of the MPs concentration of the area without too many confounding factors involved.

C. Microplastics extraction and analysis

MPs are widely distributed across different matrices with distinct levels of complexity. Hence, sample processing can require several steps including density separation, digestion, and filtration [16], [35]–[37]. A simplified protocol from Liu et al. 2019 [35] was implemented for our surface water samples due to their low content of organic matter. After SDS-soaking, incubation, and ultrasonic treatment for particles removal of the stainless steel filters, the oxidation of the organic matter was done using Fenton reagent (0.05 M), hydrogen peroxide (35% H_2O_2, Sigma-Aldrich, 1.08600), and sodium hydroxide (0.1 M NaOH solution, Sigma-Aldrich, S5881). Then, all reagents were mixed with the samples in 1L beakers and

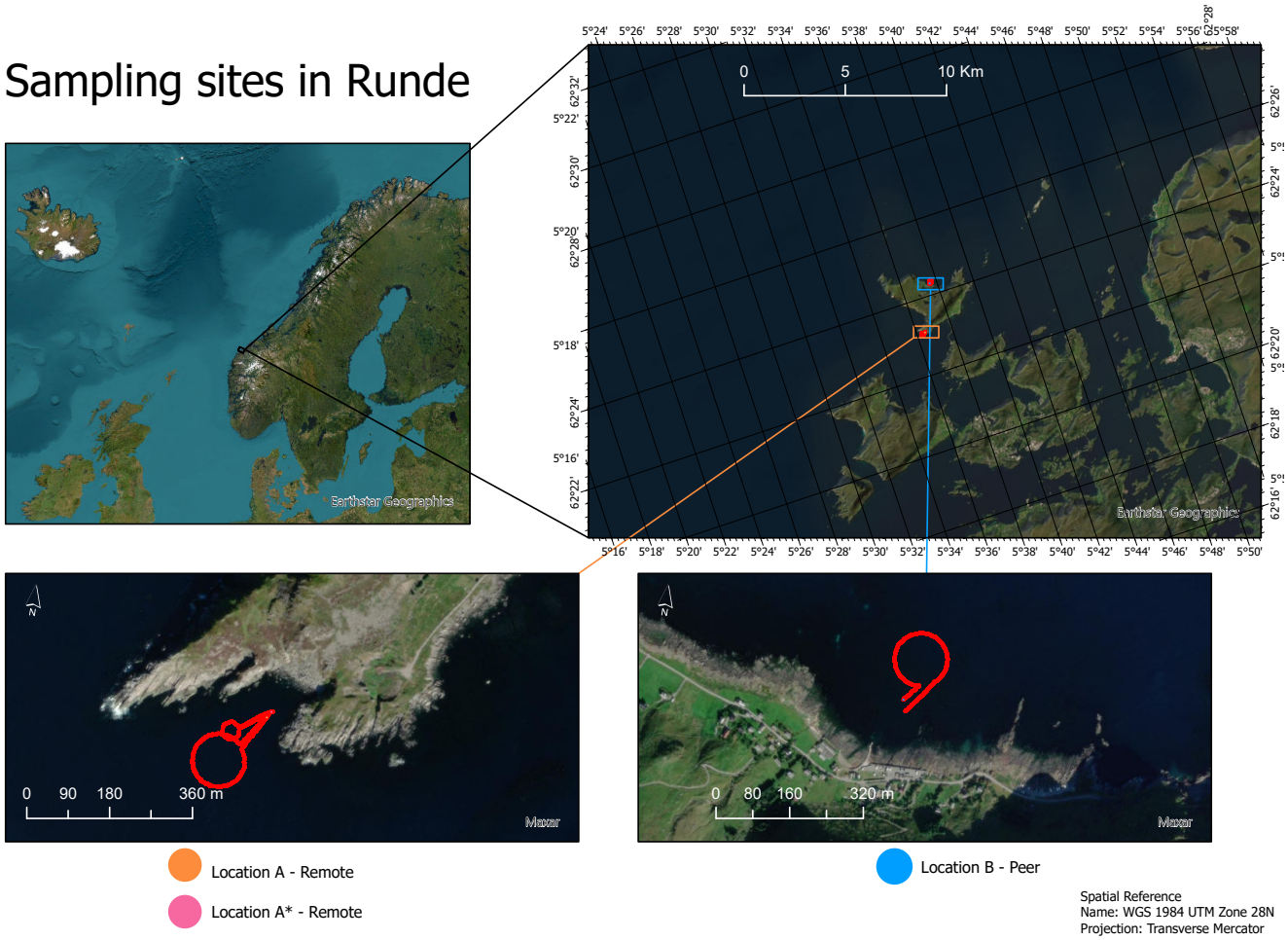
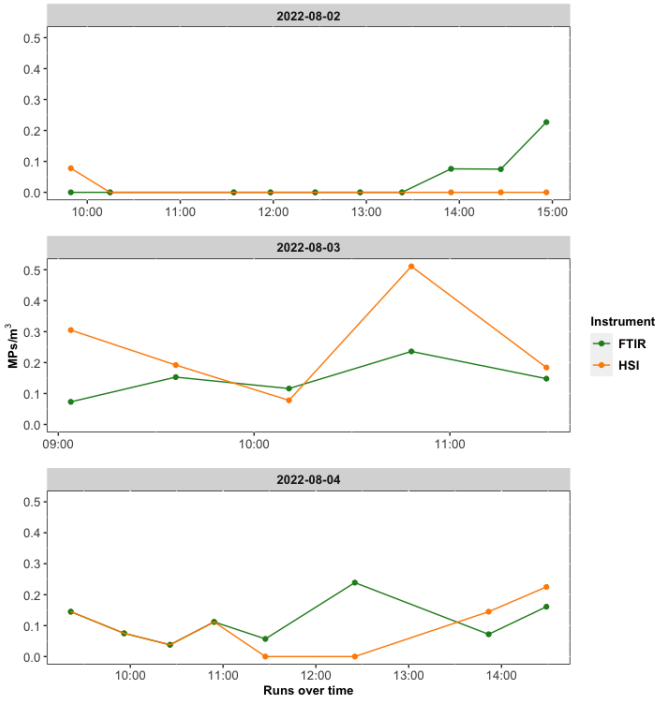


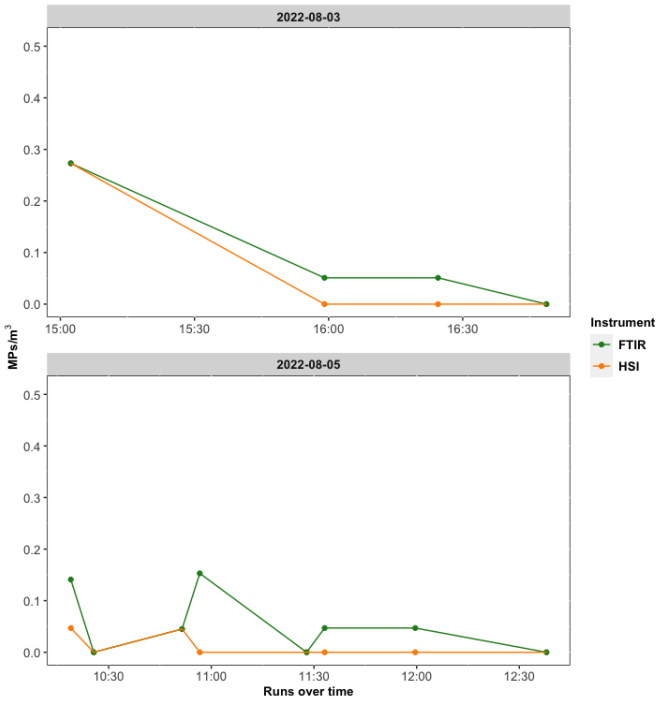
Fig. 2. Sampling sites at *A* and *B*. *Location A** emphasizes the shorter path GPS track used on Day 1(2022-08-02). Maps were created in ArcGiS Pro Version 2.8.0 using GPS coordinates of each 35 runs throughout the field campaign

aliquots of Fenton reagent were added. The reaction was monitored for a few hours to control for too high temperatures with an ice bath. The reaction was left overnight to let it slow down and complete the oxidation sufficiently. Lastly filtrating on a glass fiber filter (⌀47 mm) for HSI and ATR-FTIR analysis was performed.

HSI, HySpex Shortwave Infrared (SWIR) 320ni (HySpex by Neo, Norway), was compared against Attenuated Total Reflection FTIR (ATR-FTIR), Bruker Alpha Platinum ATR-FTIR instrument. The HSI measures a spectrum between 962 nm - 2493 nm, with a spectral resolution of 6 nm. The spectrum of light reflected by a certain plastic polymer allows the classification of pixels according to the chemical composition correlated with certain wavelengths [23], [38]. A spectral database and Soft Independent Model of Class Analogy (SIMCA) model provided an automated workflow for the production of four images, from the HSI pixel measurements, related to the four polymers implemented in the model: polypropylene (PP), polystyrene (PS), polyethylene (PE), and polyethylene terephtalate (PET)[38]. These images can then provide quantitative and qualitative data regarding size, number, and shapes through a common image analysis software [39]. For environmental comparison, manual selection of suspected MPs particles was performed under the microscope (Zeiss Axio Zoo.V16 fluorescence microscope) [40] and particles were individually transferred to ATR-FTIR for middle-wavelength-IR (MWIR) (2500 nm - 25000 nm) transmission measurements and characterized for their polymer type further using OpenSpecy [41]. Concentrations were calculated from MPs particles count per sample and sampled volume according to Table I. For the majority of runs, the PCD track – computed and saved by the autopilot – was used for volume calculation. Flowmeter volumes were used in a few runs where PCD experienced navigation quality degradation. For cases where neither the flowmeter or PCD provide realistic results, an average volume from that day at the same location was taken. MPs with longest dimension of 300 µm or higher were used for calculating the presence of MPs in the environmental samples due to the limit of detection (LOD) of the sampling equipment and SIMCA model.



(a) Location A



(b) Location B

Fig. 3. Distribution of MPs concentration (MPs/m^3) over the field campaign period comparing both locations and instruments used.

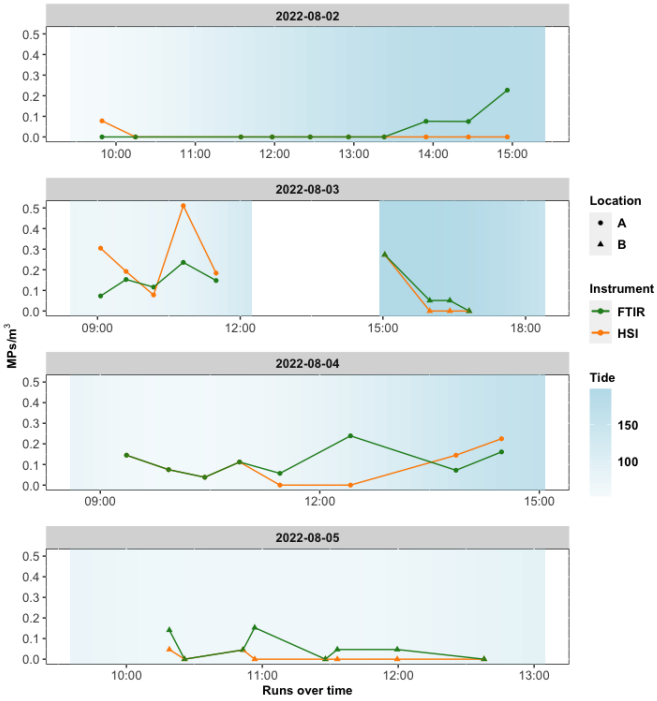


Fig. 4. MPs concentration (MPs/m^3) compared to tide levels (obtained from Kartverket.no) over the field campaign period for both locations: *A* corresponds to a circular shape; *B* corresponds to a triangular shape

III. Environmental Concentrations of Microplastics

A. Microplastic concentrations at location A & location B

Relatively low abundance of MPs surrounding Runde's waters recorded at two different locations. The mean concentration of MPs at *location A* was 0.091 MPs/m^3 ($\pm$ 0.1) for HSI and 0.087 MPs/m^3 ($\pm$ 0.08) for ATR-FTIR. At *location B*, it was 0.030 MPs/m^3 ($\pm$ 0.08)for HSI and 0.067 MPs/m^3 ($\pm$ 0.08) for ATR-FTIR. However, concentrations per transects throughout the field campaign were highly variable (Figure 3).

For samples collected over three days at *location A*, HSI measurements resulted in concentration values ranging between 0.000 and 0.511 MPs/m^3 for total MPs' count of 47 particles. The FTIR measurements resulted in concentration values ranging between 0.000 to 0.239 MPs/m^3 with 41 particles. For samples collected over two days at *location B*, both instruments' concentration values ranged between 0.000 - 0.273 MPs/m^3 with HSI detecting a total amount of five MPs particles, whereas, for FTIR measurements detected 12 MPs particles. As shown on Figure 3, a MPs concentration at *location A* is higher than at *location B*. Moreover, the correlation and causation of tides levels was investigated to see if it has any influence on MPs concentration and distribution. No apparent effects were observed shown (Figure 4).

A Shapiro-Wilk test in RStudio (2023.03.0+386) was performed to assess the normal distribution of the concentrations. For both locations with respect to the instrument used, the data

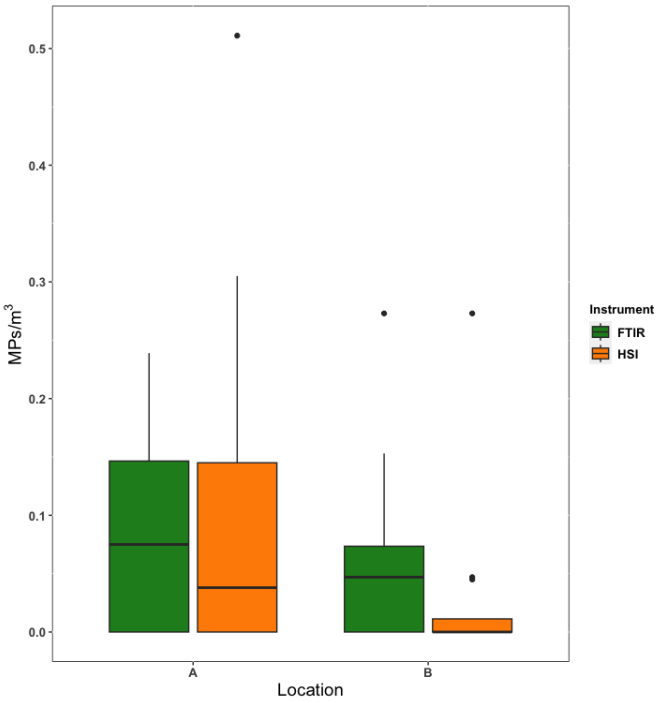


Fig. 5. Boxplot of MPs concentration variability per location and instrument used showing Interquantile Range, minimum and maximum values, and potential outliers.

are not normally distributed, but more positively or negatively skewed (Figure 5).

FTIR and HSI measurements were then tested for each location using a Kruskal-Wallis test in RStudio (2023.03.0+386). At *location B*, MPs concentrations between both instruments were found to be significantly different ($P < 0.05$). This might be due to limitations from the HSI as it has been known to have false negatives related to transparent films and narrower fragments as well as darker, or black, particles [23], [38]. At *location A*, no significant difference was found ($P > 0.05$) between instruments implying that both instruments could have been used to measure MPs concentration at that location. The standard deviation (SD) for HSI is higher ($\pm$ 0.1) than the SD for FTIR ($\pm$ 0.08) could indicated that the spread of MPs concentration per sample around the mean is greater and could result in more variable concentrations. However, since the concentrations correspond to a non-Gaussian distribution, the relative variability can not be fully defined by SD especially when outliers are present and the distribution is positively skewed. This can be better visualize in Figure 5. For simplicity, the rest of the discussion will use HSI measurements of MPs concentration.

High variation per day of MPs concentration is indicating that different physical drivers are responsible for the highly dynamic distribution of MPs. A slight trend comparing the windward *location A* to the leeward *location B* was observed with a higher abundance of MPs and more variable MPs concentrations related to a more exposed site for wind, waves and currents disturbances. Geological, hydrological, biological, and meteorological factors can influence the high variability and heterogeneity of coastal marine environmental concentrations and distribution of MPs. Hence, surface MPs are known to have long-range transport and settling on coastlines and ocean gyres [42], [43]. Transport mechanisms in the coastal seas of Runde are governed by the bathymetry of the island, the tidal transport, the wind drift, Ekman circulation, and wave/wind direction. These factors can explain the variability of MPs in the samples collected at the same location, following the same path at different time (Figure 3)[8]. The highest variability of MPs concentration was at *location A* suggesting that, from the North Atlantic to the Norwegian seas, NAC transports MPs from more polluted areas to the Norwegian coast by interacting with the NCC [29]–[31]. Other factors that might influence this variability are the gentle slope, sheltered bay where *location B* was sampled restricting the mixing and Strokes drift effect resulting in lower variability of MPs concentration. However, a Kruskal-Wallis test was also performed between locations where no significant difference was observed. This might be explained by the low concentration of particles found in the water compared to the large volumes sampled resulting in the low abundance of MPs in the waters. As seen in (Figure 5), 25% or more of the values correspond to a non-presence of MPs for each location. Nonetheless, visual inspection confirmed the presence of plastics particles in some samples indicating the high variability of MPs concentration at Runde, where at a certain time no MPs are collected whereas at another time concentrations are much higher. This is proving the need of higher sampling frequency. Moreover, potential outliers could explain the non-significant difference (Figure 5). For instance, Run #16 (Table I) at *location B* corresponds to the first run at that location on August 3^{rd}, 2022. That same morning, vehicle #3 was used for *location A*. We might have forgotten to rinse the net used at *location A* when we moved to *location B*. This suggests that MPs from the net from *location A* might have been washed down the cod end when starting run #16 at *location B*.

In the North and Norwegian Seas, several studies have looked at the MPs concentration along the Norwegian coast [18]. From the NOAA database [18], our MPs concentration (0-0.511 MPs/m^3) at *Location A* is well within the observed concentrations along the coast ranging from very low (0-0.0005 MPs/m^3) to medium (0.005-1 MPs/m^3). Although most samples from the database are from opportunistic sampling, one MPs concentration was located at Runde where [18], [44] reported 0.366 MPs/m^3. Moreover, a study in Danish waters (Kattegat/Skagerak) [45] has shown higher concentrations ranging from 11-87 MPs/m^3. This indicates that transports mechanisms varies greatly from open coastlines to semi-enclosed seas. More limited water circulations in the Kattegat/Skagerrak can retain MPs [46], resulting in higher MPs concentration. Moreover, the authors also reported calm weather during the cruise compared to strong winds and rain for our field campaign, indicating the potential effect of extreme weather events during fieldwork. Overall, data

TABLE I
SUMMARY OF SAMPLING AND RESULTS OF ATR-FTIR AND HSI ANALYSIS

Run No	Date	Sampling start time	Location	Vehicle	Distance travelled [m]	Volume [m^3]	FTIR		HSI	
							MPs abundance	MPs/m^3	MPs abundance	MPs/m^3
1	02/08/2022	09:49:23	A	2	289	13	0	0.000	1	0.078
2	02/08/2022	10:14:42	A	2	284	13	0	0.000	0	0.000
3	02/08/2022	11:34:30	A	1	315	14	0	0.000	0	0.000
4	02/08/2022	11:58:12	A	1	290	13	0	0.000	0	0.000
5	02/08/2022	12:26:59	A	1	294	13	0	0.000	0	0.000
6	02/08/2022	12:56:00	A	1	233	10	0	0.000	0	0.000
7	02/08/2022	13:23:00	A	1	NA	13	0	0.000	0	0.000
8	02/08/2022	13:54:39	A	1	296	13	1	0.076	0	0.000
9	02/08/2022	14:26:44	A	1	298	13	1	0.075	0	0.000
10	02/08/2022	14:56:09	A	1	297	13	3	0.227	0	0.000
11	03/08/2022	09:03:50	A	3	309	14	1	0.073	1	0.305
12	03/08/2022	09:36:00	A	3	NA	26	4	0.153	5	0.192
13	03/08/2022	10:10:42	A	3	580	26	3	0.116	2	0.078
14	03/08/2022	10:48:12	A	3	572	25	6	0.236	13	0.511
15	03/08/2022	11:29:34	A	3	610	27	4	0.148	5	0.184
16	03/08/2022	15:02:20	B	3	493	11	3	0.273	3	0.273
17	03/08/2022	15:59:04	B	1	437	19	1	0.051	0	0.000
18	03/08/2022	16:24:28	B	1	438	19	1	0.051	0	0.000
19	03/08/2022	16:48:43	B	1	447	20	0	0.000	0	0.000
20	04/08/2022	09:21:32	A	1	6	21	3	0.145	3	0.145
21	04/08/2022	09:56:01	A	1	599	27	2	0.075	2	0.075
22	04/08/2022	10:25:41	A	1	588	26	1	0.038	1	0.038
23	04/08/2022	10:54:11	A	1	602	27	3	0.112	3	0.112
24	04/08/2022	11:27:19	A	1	1202	18	1	0.057	0	0.000
25	04/08/2022	12:25:10	A	1	374	4	1	0.239	0	0.000
26	04/08/2022	13:51:40	A	1	623	28	2	0.072	4	0.145
27	04/08/2022	14:29:01	A	1	699	31	5	0.161	7	0.225
28	05/08/2022	10:18:57	B	1	480	21	3	0.141	1	0.047
29	05/08/2022	10:25:39	B	2	474	21	0	0.000	0	0.000
30	05/08/2022	10:51:27	B	1	503	22	1	0.045	1	0.045
31	05/08/2022	10:56:38	B	2	620	7	1	0.153	0	0.000
32	05/08/2022	11:27:51	B	1	488	22	0	0.000	0	0.000
33	05/08/2022	11:33:07	B	2	477	21	1	0.047	0	0.000
34	05/08/2022	11:59:35	B	1	482	21	1	0.047	0	0.000
35	05/08/2022	12:37:55	B	1	500	22	0	0.000	0	0.000

reported from studies around the world are not always comparable because there are no standardized methods for surface MPs research emphasizing ounce more the importance of a more repeatable combination of methods with regards to MPs sampling and analysis.

In coastal waters surrounding Runde Island, tidal fronts or tidal mixing are a dominant dynamic force especially in the summer when the fieldwork took place. Tidal fronts occur when buoyancy fluxes are triggered by sea surface temperature increases, which is resulting in strong tidal currents from a stratified region [47], [48]. For instance, Figure 4 shows how water level or tide cycles could impact the distribution of Runde MPs concentrations. Data collection was only performed through out full tide cycles on August 2^{nd} and 4^{th}, 2022 at *location A*. However, transects on August 2^{nd} were shorter not allowing the robot to go outside the bay where it was launched (Table I). The highest concentration (0.225 MPs/m^3) was recorded at high tide on August 4^{th}. Hence, when considering only August 4^{th} and the high variability of MPs concentration, no conclusions could be drawn between tide levels and concentrations. The importance of recording Key Environmental Variables (KEVs) is essential for understanding patterns in a highly dynamic ocean. In order to connect KEVs and MPs concentration, a high-throughput data collection needs to be done encompassing different tide cycles. As oceanographic dynamics and mechanisms surrounding an island are quite complex, interactions and effects amongst several KEVS needs to be investigated [49]. Winds speed, water level, currents, and chlorophyll are all important KEVs that should be measured alongside MPs concentration. Fossum et al. 2018 [50] investigated coastal ocean processes by coupling autonomous sampling and ocean models at the coast of mid-Norway and, then, further linked KEVs to phytoplankton distribution [51], [52]. Incorporating MPs concentration into these research would be a goal to achieve in MPs research. Overall, no correlation can be made between hydrological and biological factors and MPs concentration reported at Runde at *location A* and *location B*. However, implementing these new methods on larger temporal and spatial scales will help understand what drives MPs concentration in coastal waters and more specifically surrounding a biodiversity-rich island like Runde.

Adverse effects from MPs pollution is an emerging concern for the health of marine ecosystems like Runde [53]. Endocrine

disrupting chemicals (EDCs) [54], additives on plastics and often present with MPs, can leach into the environment and rapidly metabolized in organisms inducing reproductive deficits [55]. The reported MPs concentration in our study are lower than what is tested in toxicological laboratory studies on adverse effects of EDCs calling for more environmental relevant research [56]. However, as concentrations are likely to increase, more stressors on already endangered species in Runde could affect the population dynamics. Indeed, Biamis et al. 2021 [53] has reviewed several studies that were reporting different species of seabirds where EDCs were found in different tissues only assessing physical ingestion effects. MPs from the Norwegian coast were tested for MPs ingestion causing sublethal size-effects in the a Japanese Quail populations [57]. Overall, reported environmental concentrations at higher spatial and temporal scale in biodiversity-rich island like Runde can help preserve marine ecosystems. Hence, there is a call for further research on linking these adverse effects and the environmental MPs concentration in seabirds-nesting islands.

B. PCD and HSI performance

PCD and HSI methods combined presented in this study provide a step toward more standardized and repeatable methods for measuring surface MPs concentration.

Using PCD for high-frequency sampling throughout a day and over multiple days brings several advantages to MPs research. Avoiding the use of a boat and its crew reduced tremendously the cost of sampling allowing it to be relocated for a more extended field campaign. Moreover, the PCD could access remote areas otherwise harder to reach with a boat. Table I presents the overview of the different transects including distance of path and volume of water sampled. It should be noted that during the fieldwork a few PCD runs were aborted for reasons related to navigation performance degradation, kelp entanglement or operator error as discussed in Zolich et al [21].

The PCD sampling path was designed to limit the impact of currents on total volume measurements. Runs 30-35 were tested using two PCD at the same time in *location B* as described in [21]. Running this kind of experiment simultaneously at the two different locations on Runde Island would have helped to provide a better holistic understanding of MPs concentration, especially during extreme weather events, and allow better comparison of their relationships to tide level (Figure 4).

Last but not least, the use of HSI for MPs analysis allow time and cost reduction when compared to ATR-FTIR as shown in Table II.

Further investigation is needed regarding the accuracy of the HSI and SIMCA model [38]. It seems when there is a higher count of MPs, HSI results is close to the ATR-FTIR results as *location A* MPs counts were much higher than *location B* MPs counts for both methods, and significantly different. An additional day of sampling was also done at *location A*, suggesting that a higher frequency of sampling

TABLE II
COMPARISON OF COST AND ANALYSIS TIME FOR ATR-FTIR AND HSI METHODS

		Visual Selection and ATR-FTIR	**HSI**
Time	Instrument	∼100 hours	∼5 hours
	Data Processing	∼32 hours	∼12 hours
Cost	Instrument	∼800 USD	∼150 USD

can also help the accuracy of MPs characterization with HSI and a SIMCA model. Indeed, during August 4^{th}, the first four samples resulted in the same concentration for both instruments (Table I) as well as a similar increase during high tide (Figure 4). Overall, this proof-of-concept combining PCD and HSI as new methods for MPs sampling and characterization guide a path towards higher temporal and spatial MPs research allowing MPs experts to concretely correlate MPs concentration and coastal ocean processes and dynamics. For instance, MPs variations are known to occur seasonally [58], [59] and spatially [18], [45], [60] Modellers are asking for more ground truth data [61]–[63] to visualise MPs distribution and help guide policymakers for the implementation of the monitoring framework and guided solutions to reduce MPs in the ocean [16], [20], [64], [65].

IV. CONCLUSIONS

Overall, a low abundance of MPs was observed. A highly variable MPs concentration was observed on the exposed sites in Runde compared to a lower variability on the protected side. Hence, PCD enable an easy repeatable sampling method for higher spatial and temporal variability to correlate to environmental factors and to facilitate comparison between studies. To reach a high sample throughput, HSI analysis should be included in the environmental monitoring of MPs since the very low processing time of approximately one minute per sample.

V. FUTURE WORK

A SIMCA model in R, provided quantitative and qualitative data about the polymer type, size, number, and shape. Environmental comparison with a common practice FTIR spectroscopy method of the HSI results is part of the ongoing work of this study. Linking MPs concentration and KEVs should be further investigated for understanding MPs distribution in coastal waters.

ACKNOWLEDGMENT

The authors would like to thank Runde Miljøsenter for their warm welcome during the field work and to let us use the laboratory facilities as we pleased; Staff at NTNU for the help in the laboratory; Biotox group at the Department of Biology at NTNU; IEEE, MTS, and ONR for offering us a grant for the publication of this work as part of OCEANS 2023 conference

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