INTERACTION BETWEEN MICROPLASTIC PARTICLES AND SUBMERGED VEGETATION CANOPIES IN WAVES PLUS CURRENT ENVIRONMENTS

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INTRODUCTION

The pollution of the oceans by plastic waste is one of the biggest environmental disasters of the last century. Existing studies agree that the size, shape, and density of microplastic (MP) particles significantly influence their transport characteristics (Zhang 2017, van Sebille 2020). Kerpen et al. (2020) studied the wave-induced distribution of sphere-like MPs in the surf zone on a live sandy bed. Guler et al. (2022) also investigated non-buoyant MP particle transport beneath irregular breaking waves over a live sediment bed. The focus of the present study is to experimentally examine the transport dynamics and retention of different non-buoyant MP under the effects of combined (non-breaking) irregular waves and current in coastal waters, in the presence of vegetation canopies.

MATERIALS AND METHODS

The experiments were conducted in a 28.0 m long wave and current flume at the Technical University of Denmark Hydraulics Laboratory. The flume utilized is the same as in prior coastal MP transport studies of Guler et al (2022) and Larsen et al. (2023). Irregular waves were generated based on a JONSWAP spectrum with a peak enhancement factor of 3.3, a spectral significant wave height H_{m0}=0.053 m and a peak period T_p=2 s at the paddle with water depth h=0.45 m. A sand bed (median grain size d=0.18 mm) was embedded in the middle of the flume to a depth of 0.15 m, such that the water depth at the test section is h=0.30 m. The water surface elevation in the experiments was measured with five wave gauges. Fluid velocity measurements were also made using a Laser Doppler Velocimetry (LDV), such that details of the combined waves and/or wave plus current flow velocity profiles can be determined, and compared to determine the effect of the vegetation canopy on the flow. Seven different MP groups were considered, with primary characteristics as listed in Table 1. Settling velocities are as measured by Goral et al. (2023).

Artificial vegetation canopies, originating from turf mats, were attached to weighted plates and were placed on the sediment bed. The mats were adapted to vary the canopy density i.e. the distribution and density of individual plants. Tested vegetation canopy densities (see Table 2) considered have lengths as 60 cm, 60 cm, 180 cm and 240 cm for dense, medium, sparse and very sparse, respectively.

In this table the canopy height is defined as h_v. A plant is composed of a stem (length: h_v, width: d_v). The spacing between the individual plants in the canopy is defined in the transverse ($\Delta S_{v,L}$) and wave propagating ($\Delta S_{v,C}$) directions. With using these parameters solid fraction defined by canopy density

$$\varphi = b_v d_v / (\Delta S_{v,L} \Delta S_{v,C}) \qquad (1)$$

Table 1- Description of particle characteristics of MPs

ID	shape	density [g/cm^3]	dimensions [mm]	settling velocity [m/s]
MP1	sphere	1.352	3.0	0.16
MP2	sphere	1.062	3.1	0.06
MP3	sphere	1.358	3.0	0.22
MP4	cylinder	1.195	5 x 4 x 4	0.12
MP5	plate	1.206	5 x 5 x 0.5	0.04
MP6	plate	1.197	5 x 5 x 1	0.06
MP7	cube	1.192	4.0	0.11

Table 2- Specifications of tested canopy densities

	Dense 1	Medium dense 2	Sparse 3	Very sparse 4
h_v [mm]	20.1	20.1	20.1	20.1
b_v [mm]	2.13	2.13	2.13	2.13
d_v [mm]	2.14	2.14	2.14	2.14
$\Delta S_{v,L}$ [mm]	5	10	20	30
$\Delta S_{v,C}$ [mm]	10	10	10	30
φ	0.0912	0.0456	0.0228	0.00506

Experiments with no vegetation were also conducted, as control. For each canopy density three tests were performed: irregular waves only, irregular waves with following current, and irregular waves with opposing current. At the beginning of each test, 50 particles from each MP group (Table 1) were initially released at x ≈ -17.5 cm where x=0 defines the beginning of the vegetation canopy, and the x axis points in the wave propagation direction, such that a total of 350 particles were released simultaneously (Figure 1) for waves only and waves with following current.

RESULTS

Three experimental cases were completed, for four different vegetation canopy densities (Table 2). The results showed different behavior as the configuration changed. For the three highest density canopies, most of the MP stopped in the first 10-15 cm of the vegetation canopy. For the lowest density (canopy 4) configuration, mobilization of all samples deeper into the vegetation canopy was observed. Example histograms are depicted in Figure 2, from experiments utilizing the lowest vegetation canopy density considered, for a case involving only waves. Figure 2 shows, MP distribution for different particles under same test condition after 90 min of testing. The MP2 (see Table 1) sample distributes along the entire length of the channel (even passing the vegetation zone), whereas the MP4 and MP7 groups are completely retained within the vegetation patch.

Figure 1 – Pictures of the beginning times of each test, with placement of MP

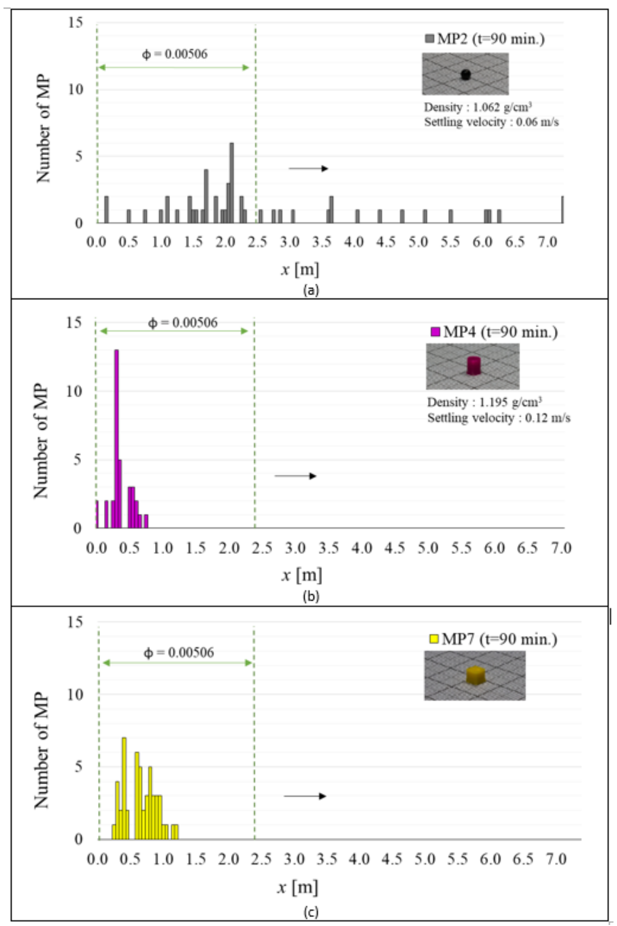

Figure 2 – Particle distribution along the wave channel under wave action with low vegetation density after 90 min test for a) MP2 b) MP4 c) MP7. Beginning of the vegetation canopy at x=0.

CONCLUSIONS

MP retention in vegetation canopies seems strongly influenced by the particle settling velocity. The present experiments demonstrate quantitatively that MP particles with larger settling velocity are much more easily retained by vegetation than those with low settling velocity when same shaped MPs are compared. Results will be further analyzed to investigate how various physical and geometric characteristics of MP influence their potential retention by submerged vegetation. Based on these results, the investigation of the dynamics of MP in the coastal environment, and their interaction with marine vegetation, is interesting and should be further investigated to identify potential nearshore accumulation zones for MP pollutants.

ACKNOWLEDGEMENTS

This research has been financially supported by the Independent Research Fund Denmark project MPCOAST: MicroPlastic transport processes in the COASTal environment, grant no. 0136-00227B. The first author additionally acknowledges financial support from The Scientific and Technical Research Council of Turkey (TUBITAK) under the 2219 International Postdoctoral Research Fellowship Programme.

REFERENCES

Goral et al. (2023): Settling velocity of microplastic particles having regular and irregular shapes, Environ. Res., vol. 228, 115783.

Guler et al. (2022): Experimental study of non-buoyant microplastic transport beneath breaking irregular waves on a live sediment bed, Mar. Pollut. Bull., vol. 181, 113902.

Kerpen et al. (2020): Wave-induced distribution of microplastic in the surf zone, Front. Mar. Sci., vol. 7, 590565.

Larsen et al. (2023): Experimental investigation on the nearshore transport of buoyant microplastic particles, Mar. Pollut. Bull., vol. 187, 114610.

Zhang (2017): Transport of microplastics in coastal seas. Estuarine, Estuar. Coast. Shelf Sci., vol. 199, pp. 74-86.

van Sebille (2020): The physical oceanography of the transport of floating marine debris, Environ. Res. Lett., vol. 15, 023003.