Examining the erosional and depositional behaviour of cohesive sediments

Juliet Rounce[1] and Andrew J Manning[2]

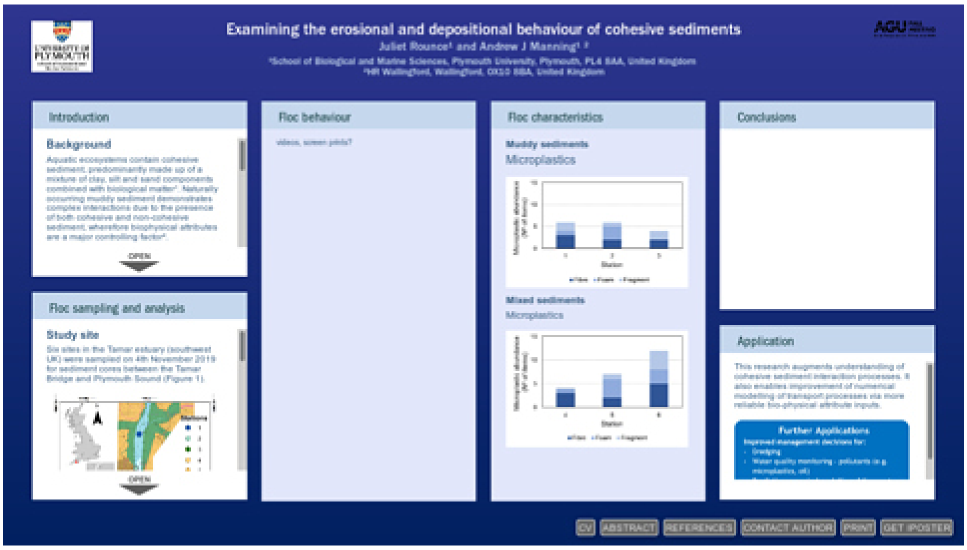
[1]Trinity College Dublin, Ireland
[2]University of Plymouth, UK

November 21, 2022

Abstract

Many aquatic environments are dominated by muddy sediments. These cohesive sediments, however, often contain a mixture of sand, mud and organic material, giving rise to complex interactional behaviour, the nature of which is often controlled by bio-physical attributes. An understanding of these complex interactions is paramount in the accurate prediction of sediment transport processes in numerical models, facilitating monitoring and management of marine environments. Calibration of such models relies on quantitative erodibility and depositional data. Muddy sediments flocculate; a process impacted by complex sedimentary and hydrodynamic interactions. The degree of sediment stability describes the degree of flocculation and depends on interactive forces (including bonding cohesion) between suspended particulate matter and turbulent shear stress, as well as mineralogy and biological composition. Erodibility and deposition properties rely greatly on the formation and break-up of these flocs, in turn impacting processes of sediment transport. This study examines, through the use and comparison of various data sets, aspects of both erodibility and deposition for several different sedimentary conditions. Collation of a range of quantitative field and laboratory-derived sedimentary and hydrodynamical data sets (e.g. sediment composition, floc properties, bed density, mass erosion rates, erosion thresholds, suspended particular matter concentration, turbulent shear stress) from a range of aquatic scenarios (including estuaries, intertidal areas, shelf seas, and lakes) are utilised to investigate the impacts of related controlling and influencing parameters on sediment transport, in particular to assess coastal erosion and sustainability. Case studies include: water quality monitoring, contaminated sediments, and dredging applications; these will be used to demonstrate / illustrate various applications of this sedimentary-hydrodynamic investigation. This research augments our understanding of the interactive processes within different cohesive sediments, providing quantitative analysis to inform and ultimately improve our mathematical representation of bio-physical sedimentary processes for implementation within predictive numerical modelling.

Examining the erosional and depositional behaviour of cohesive sediments



Juliet Rounce[1] and Andrew J Manning[1 2]

[1]School of Biological and Marine Sciences, Plymouth University, Plymouth, PL4 8AA, United Kingdom
[2]HR Wallingford, Wallingford, OX10 8BA, United Kingdom

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INTRODUCTION

Background

Aquatic ecosystems contain cohesive sediment, predominantly made up of a mixture of clay, silt and sand components combined with biological matter[1]. Naturally occurring muddy sediment demonstrates complex interactions due to the presence of both cohesive and non-cohesive sediment, wherefore biophysical attributes are a major controlling factor[2].

Estuaries

Estuarine environments are important for many reasons, including shipping, recreation and habitat provision for wildlife. The management of estuaries is therefore paramount as development occurs, from construction in harbours to reclamation of intertidal habitats[3]. For these projects, an understanding of sediment transport and interaction processes is key due to the influence of anthropogenic intervention.

Muddy sediment

Flocculation of muddy sediments relies on forces of interaction, such as bonding cohesion, between suspended particulate matter and turbulent shear stress[4]. Sediment stability gives an indication of the degree to which sediments will flocculate[5]. A further impact on sediment transport is the reliance of erosion and deposition processes on this floc formation and break-up.

Implication?

To facilitate management, quantitative data from erodibility and depositional studies helps improve delineation of bio-physical attributes in numerical modelling to enable more reliable prediction of sediment transport processes.

Aim

- Investigate floc properties in muddy and mixed sediments utilising a southwest UK estuarine case study
- Relate to water quality via microplastics supplementary data set

FLOC SAMPLING AND ANALYSIS

Study site

Six stations in the Tamar estuary (southwest UK) were sampled on 4th November 2019 for sediment cores between the Tamar Bridge and Plymouth Sound (Figure 1).

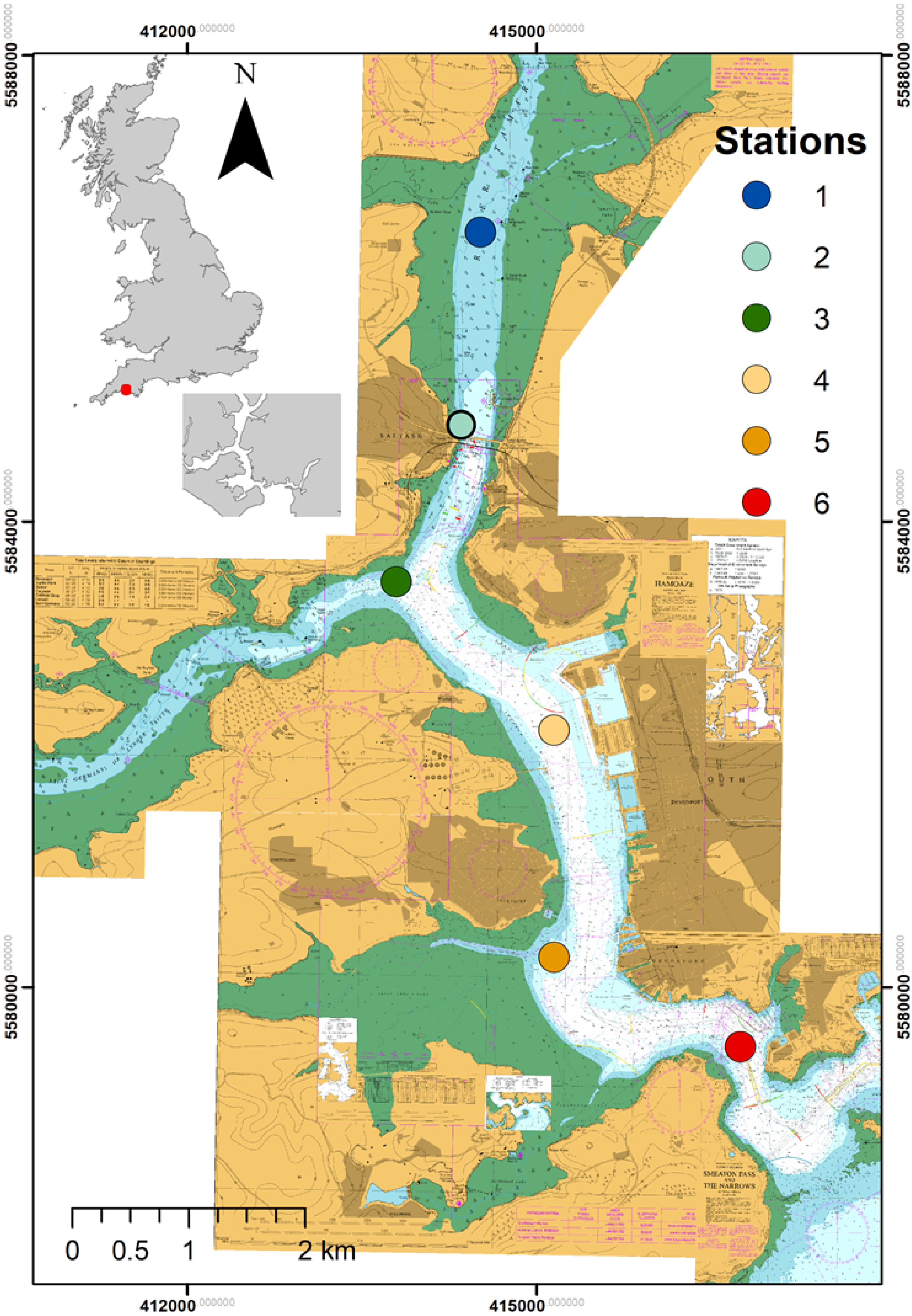

Figure 1: Floc sample stations in the Tamar Estuary: 1 - upper estuary; 2 - north of Tamar Bridge, 3 - Lynher tributary, 4 - Wilcove, 5 -Devonport and 6 - lower estuary, coordinate system WGS84[6].

Data Acquisition

The sediment samples were collected using a van Veen Grab from which cores (~10 cm depth) were taken, deployed from the research vessel at Plymouth University, UK (Plate 1).

Plate 1: The van Veen Grab, before deployment for sediment collection.

Processing

Flocs

Laboratory processing began with initial 'jar tests' to assess the interactions in a natural mud suspension, indicative of flocculation potential[4]. Subsamples were taken from the cores for each station and mixed into 0.5 L water, which was subsequently stirred to suspend the sediment. Floc characteristics could then be obtained from video observations.

Video observations of jar subsamples were obtained by the LabSFLOC-2 camera (Laboratory Spectral Flocculation Characteristics; Plate 2)[7 8].

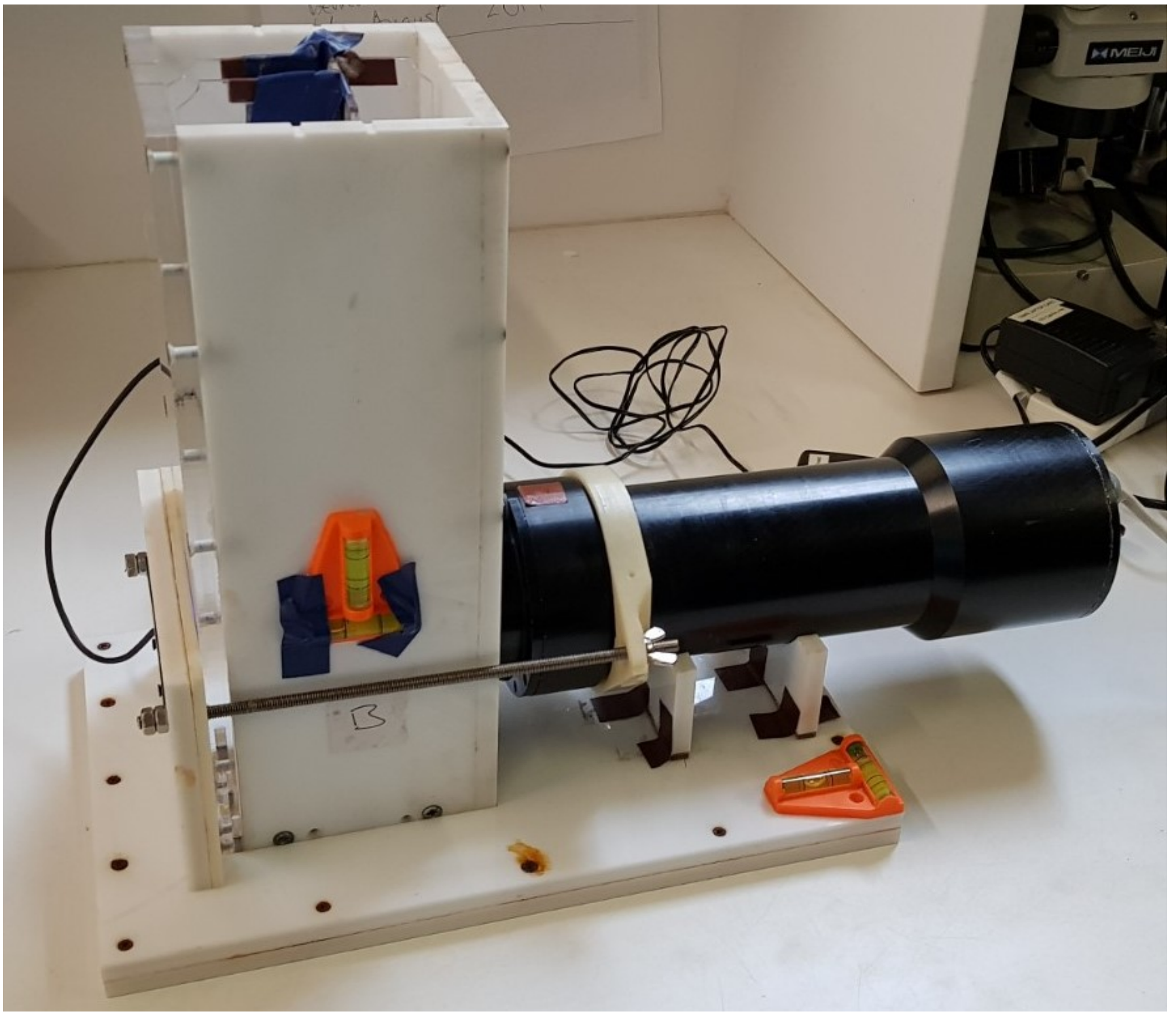

Plate 2: The LabSFLOC-2 camera set up for sediment floc processing[7].

Microplastics

Surface subsamples of sediment were taken from each core (~20 g) from the six Tamar stations and analysed for microplastics[9]. A Sediment-Microplastic Isolation unit was utilised for extraction in the laboratory, after which the sediment was sieved, rinsed and filtered through 15 μm mesh and filter paper. Microplastic concentration was represented via counting under microscopes and classification into fibre, foam or fragment.

Post-processing

Floc properties were calculated from the LabSFLOC-2 analysis using the following equations[4]:

1. Floc diameter (spherical equivalent), *D*, was estimated using:

$$D = (D_x \cdot D_y)^{0.5}$$

where *Dx* and *Dy* are major and minor axis floc dimensions from digital image stills.

2. Settling velocity, *Ws*, was estimated from the vertical distance each floc travels in a known time interval between images.

3. Effective density estimates were obtained from a modification of Stoke's law:

$$\rho_e = (\rho_f - \rho_w) = (18\mu \,.\, W_s) / (D^2 \,.\, g)$$

where the variables ρ_f and ρ_w represent bulk and water density respectively. The parameter μ is molecular viscosity, g is gravitational acceleration and D (floc diameter) and Ws (settling velocity) are measured by the LabSFLOC instrument.

FLOC CHARACTERISTICS

Muddy sediments

Floc properties in muddy sediments (Station 1) were assessed: mean D = 144 µm, ρ_e = 322 kg.m^{-3}, W_s range = ~21 mm.s^{-1} (Figure 2).

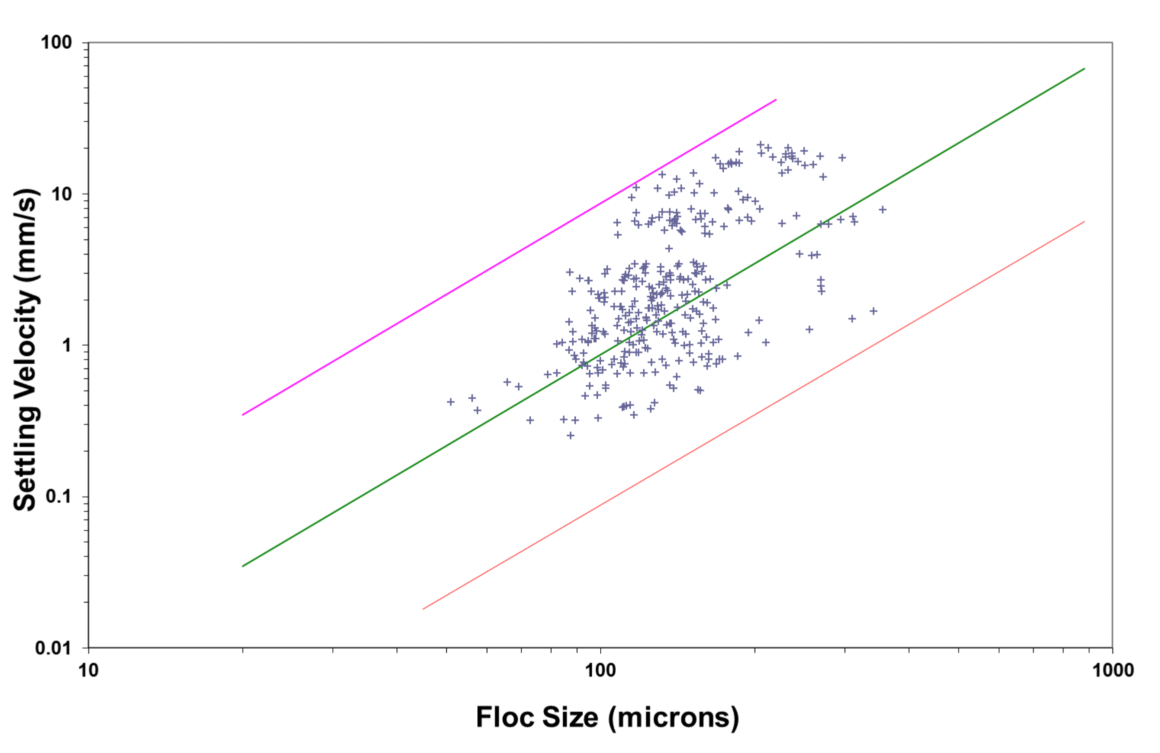

Figure 2: Upper Tamar estuary floc population (Station 1), comparing floc size and settling velocity. Floc effective density is represented by the diagonal lines: 1600 kg.m^{-3} (pink), 160 kg.m^{-3} (green) and 16 kg.m^{-3} (red).

Mixed sediments

Floc properties in mixed sediments (Station 6) were assessed: mean D = 109 µm, ρ_e = 508 kg.m^{-3}, W_s range = ~21 mm.s^{-1} (Figure 3).

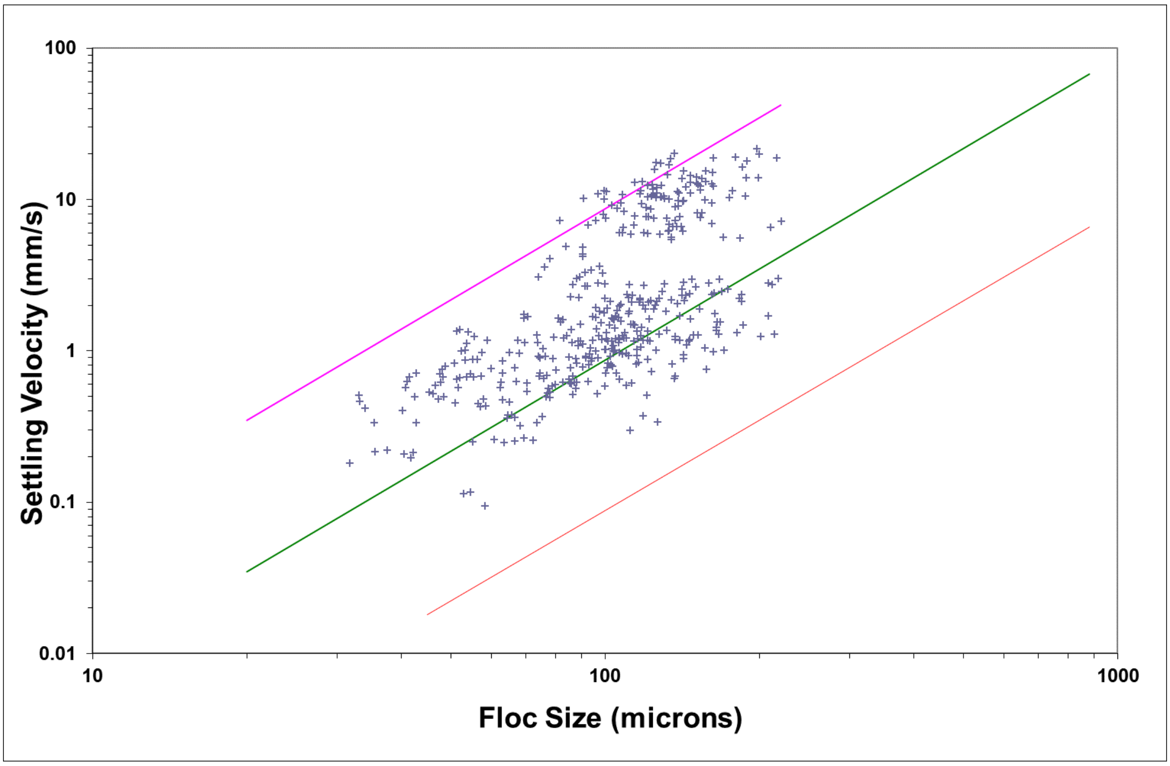

Figure 3: Lower Tamar estuary floc population (Station 6), comparing floc size and settling velocity. Floc effective density is represented by the diagonal lines: 1600 kg.m^{-3} (pink), 160 kg.m^{-3} (green) and 16 kg.m^{-3} (red).

MICROPLASTICS

Muddy sediments

Microplastics abundance in the upper estuary was more constant than more seaward stations, with counts varying around 5 items (Figure 4). At Station 1, microplastics count was lowest at 6 items, with fibre the most abundant type at 50%.

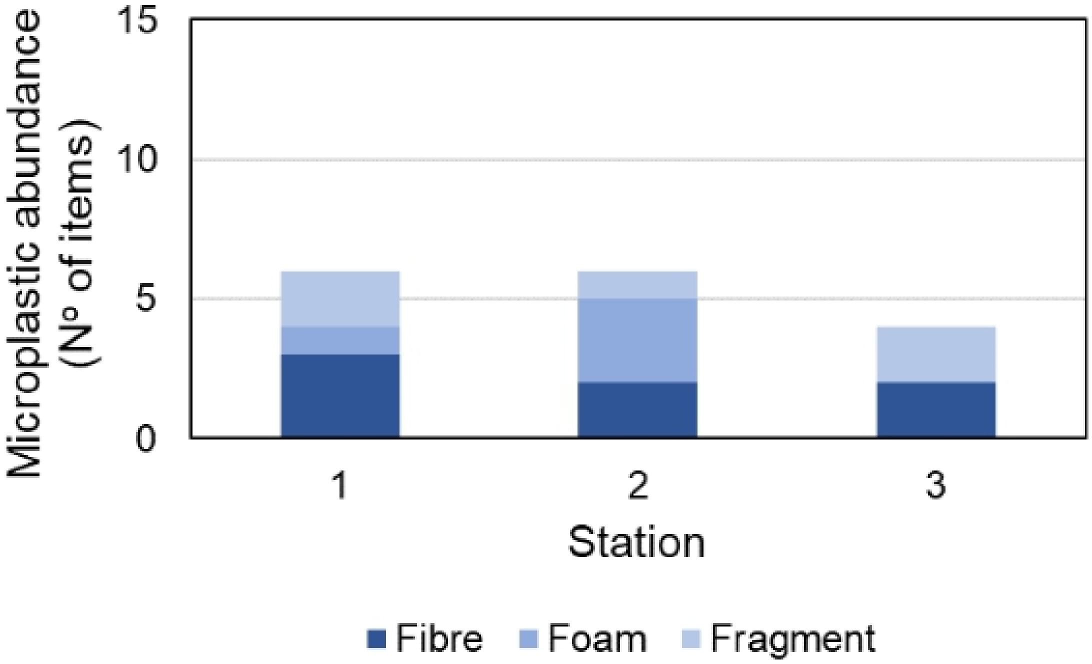

Figure 4: Abundance of microplastics in muddy surface sediment at three stations along the upper Tamar estuary, moving seaward from Station 1[9].

Mixed sediments

Stations in the lower estuary were more variable in microplastic abundance (Figure 5). At Station 6, microplastics count was highest at 12 items, with fibre the most abundant type at 42%, followed by fragments at 33%.

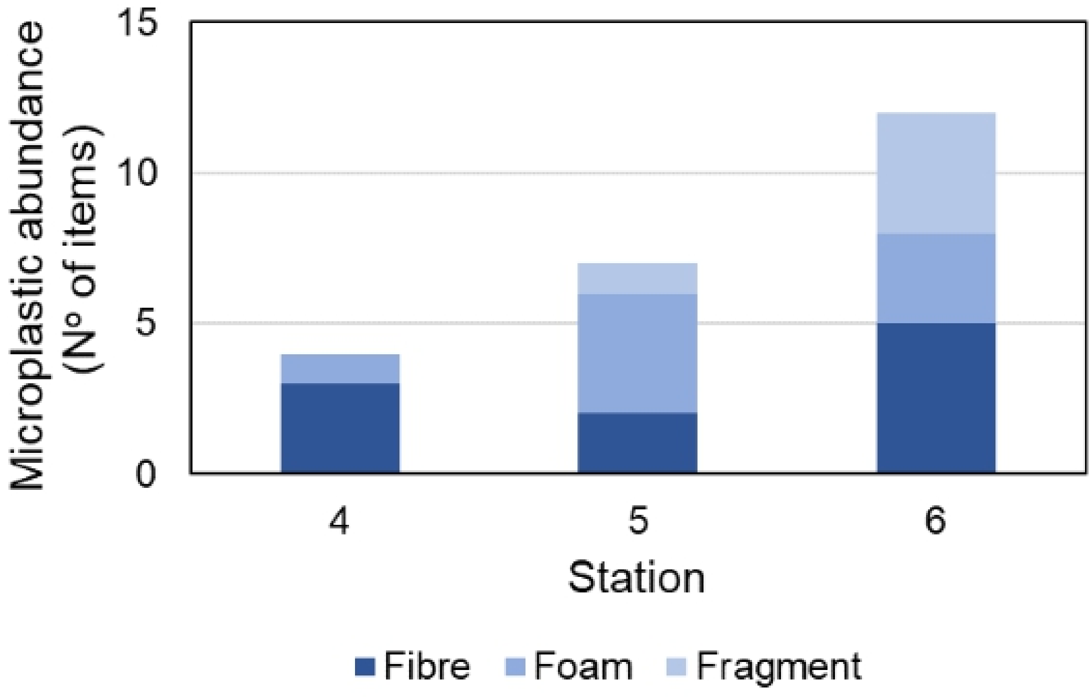

Figure 5: Abundance of microplastics in mixed surface sediment at three stations along the lower Tamar estuary, moving seaward from Station 4[9].

CONCLUSIONS

Key findings:

- Smaller floc diameter and larger effective density seaward, at Station 6, compared to inland, at Station 1
- Wide range of floc diameters and effective densities for constant settling velocity
- Wide range of settling velocities and effective densities for constant floc diameter
- Largest abundance of microplastics found at the most seaward station

This poster presents preliminary results from an ongoing MSc study.

APPLICATION

This research augments understanding of cohesive sediment interaction processes. It also enables improvement of numerical modelling of transport processes via more reliable bio-physical attribute inputs.

Further Applications

Improved management decisions for:

- Dredging
- Water quality monitoring - pollutants (e.g. microplastics, oil)
- Predictive numerical modelling of the coast

AUTHOR INFORMATION

First author:

Juliet Rounce, MSc Applied Marine Science student

juliet.rounce@postgrad.plymouth.ac.uk

juliet.rounce@gmail.com

Co-author:

Andrew J Manning

A.Manning@plymouth.ac.uk

andymanning@yahoo.com

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