ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

FINAL REPORT

CRRP2021-08MY-Zhao

2024

Impacts of river plume fronts on the distribution and the fate of plastic debris based on high-resolution observations and implications for waste recovery

Project Reference Number: CRRP2021-08MY-Zhao

Project Duration: 3 years

Funding Awarded: USD 75,000

Grant DOI: https://doi.org/10.30852/p.18776

Date of Publication: 30 April 2024

Project Leader and Contact Details: Dr. Shiye Zhao, Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan (szhao@jamstec.go.jp)

Collaborators and Contact Details:

- Dr. Roswati Md Amin, Universiti Malaysia Terengganu, Malaysia (roswati_ma@umt.edu.my)
- Dr. Tao Wang, Ocean University of China, China (taowang@ouc.edu.cn)

Recommended Citation:

Zhao, S., Md Amin, R., Wang, T. (2024). Impacts of river plume fronts on the distribution and the fate of plastic debris based on high-resolution observations and implications for waste recovery. Project Final Report. Asia-Pacific Network for Global Change Research.

1. Summary

Plastic is one of the fastest-growing materials and production is on course to double, to more than one billion tonnes a year, by 2050. With that, will come more pollution. Every year, 5.6 million to 25.4 million tonnes of plastic waste is estimated to enter the global ocean. The Asia-Pacific region has been identified as the world's largest contributor of mismanaged plastic waste (MPW). Rivers play a crucial role in transporting land-derived material (for example, ~91% of the global MPW) and freshwater to the coastal ocean, the latter creating convergent river plume fronts. Convergent frontal systems trapping suspended materials and planktonic organisms have been well documented. Whether and how plume fronts are important to the distribution, transport, and fate of plastic debris (including microplastic smaller than 5 mm) is largely unknown. Knowledge of this topic could provide insights into prioritizing riverine plastic mitigation strategies. Our study uses a combination of measurements and numerical models to determine how plastics are impacted by plume fronts. Four observational campaigns were conducted at plume fronts of the Yellow River and Terengganu River to examine plastic densities from the water and zooplankton samples in and around plume frontal zones to test the hypothesis that plastics accumulate at plume fronts, leading to a high ingestion risk in zooplankton. Plastic debris impacted by the dynamics of the Yellow River plume front were studied by performing high-resolution observations of hydrographic and biogeochemical variables. Finally, numerical simulations were carried out to predict the transport of plastics in frontal systems.

Our results clearly show that fronts play a significant role in converging microplastics floating in the estuarine environments Specifically, the average microplastic abundance (>20 µm) in fronts of Terengganu River Estuary is up to 9, 900 particles m^{-3} compared to that (2, 200 particles m^{-3}) in non-frontal waters. Similarly, the microplastic abundance/mass (>300 µm) in the fronts of Yellow River Estuary is up to 18 particles m^{-3} compared to that (0.3 particles m^{-3}) in non-frontal waters. Our observation indicates that microplastic accumulation is influenced by the intensity of fronts and the tide types. The physical simulation successfully predicts spatial and temporal variations of the Yellow River plume fronts and their effects on surface numerical particles. The

results show that the movement of Yellow River plume fronts is mainly affected by tidal currents, and numerical surface particles tend to be accumulated at fronts. These are crucial for understanding the transport of plastics and microplastics in estuarine fronts. Polyethylene, polypropylene, and polyamide are identified as the dominant polymers in both estuaries, indicating their prevalence. SEM-EDS and FTIR analysis show apparent signs of oxidative and mechanical weathering, implying their high potential of degrading into nanoplastics. Microplastics ingestion by zooplankton were detected in greater abundance in the frontal region, particularly in surface water, during high tide than in the plume and shelf regions. Two types of microplastics in zooplankton were recorded at all stations: fragments (98%) and pellets (2%), with an average size of 30 µm and 18 µm, respectively. The ingested microplastics were recorded only from copepods and gastropods, and the range of ingested microplastic was 0.008 and 0.036 particles ind^{-1}, respectively. These results, for the first time, demonstrate the converging effects of estuarine fronts via well designed observation strategy, provide a close look at the changes of fronts on plastic accumulation and help to predict plastic accumulation “hot spots” and developing mitigation strategies.

2. Objectives

There are four key objectives:

1. Quantify abundances of plastic waste in water and zooplankton samples from the plume frontal water and coastal water
2. Identifying the impacts of the complex environmental setting in the frontal systems on the distribution patterns of plastic debris at fine spatial and temporal scales
3. Exploring how plume fronts influence microplastic ingestion by zooplankton
4. Model the transport and fate of plastic debris within plume frontal systems

These objectives will help to tackle the following research questions:

1. How are the distribution and abundances of microplastics in plume frontal and ambient waters of the studied areas?

2. What potential mechanisms are influencing the distribution of plastics in the fronts?
3. What are the responses of Zooplankton in plume frontal waters and adjacent areas to microplastic?
4. What are the trajectories and the fate of plastic debris in the plume fronts of the Yellow River?

3. Outputs, Outcomes, and Impacts

Outputs	Outcomes	Impacts
- Specific strategies for observing microplastic pollution within and outside Estuarine Fronts. - Synchronous and high-resolution observation of quantify physical parameters in river plume zones - A method for semi-automated identification of small microplastic with Fourier-transform infrared spectroscopy imaging. - Distribution and concentrations of Plastic and	- Realistic approaches for observing large and small plastics and microplastics within river plume zones. - Developed methods for acquiring continuous physical dynamics concurrent with microplastic observation in river plume zones. - open-sourced algorithms for interpreting large datasets of Fourier-transform infrared	Practical strategies for monitoring both large and small plastics, including microplastics, in river plume zones are essential. The refined observation techniques for studying microplastics alongside physical dynamics in these zones will significantly benefit ongoing and further microplastics and other research in Asian-Pacific estuarine fronts. Our established semi-automated method of hyper-spectral datasets and built polymer library are also helpful to the plastic research community and move towards the

Outputs	Outcomes	Impacts
Microplastics in the frontal and non-frontal zones in the Terengganu River Estuary, Malaysia and the Yellow River Estuary, China. - Microplastics ingestion by Zooplankton in the frontal and non-frontal zones in the Terengganu River Estuary, Malaysia. - Synchronous and high-resolution observations of physical parameters and plastics in the plume zones of the Yellow River. - Modelling microplastics redistribution and fate in the plume zones of the Yellow River, with an emphasis on the role of frontal processes.	spectroscopy imaging, as well as a spectral library. - Identified the role of estuarine fronts in the accumulation of plastic debris. - Discovered the effect of estuarine fronts on microplastic ingestion by Zooplankton. - Unraveled how the converging effect of plastics are affected by physical dynamics of the river plume zones. - Simulated microplastics transport process in the plume zones of the Yellow River.	standardized analysis procedure. The measurements of plastic and microplastic debris in the fronts of two significant Asian estuaries clearly confirm that estuarine frontal regions are hotspots of plastic pollution. Our simulation results offer firsthand information on how physical dynamics in fronts impact the fate of microplastics. Furthermore, the observed microplastic ingestion by zooplankton in these frontal areas, where microplastics are significantly more abundant compared to other ocean regions, provides insights into the environmental risks of microplastics in the further ocean, given the continuous input of plastics.

4. Key facts/figures

- Methods to observe plastics and microplastics in the frontal and non-frontal regions.
- Python code of the automated algorithm for analyzing FTIR imaging datasets
- Polymer library based FTIR library

- One journal article published and two manuscripts under review in journals
- Newspaper Feature
- Six presentations on the conference have been done
- One master's thesis and two PhD dissertations are being conducted based on this project

5. Publications

- Wang Tao; Zhao Shiye*; Zhu Lixin; McWilliams James C.; Luisa Galgani; Roswati Md Amin; Nakajima Ryota; Jiang Wensheng; Chen Mengli; Accumulation, transformation and transport of microplastics in estuarine fronts, *Nature Reviews Earth & Environment*, 2022, 3: 795-805.

- Chen Zhixing; Wang Tao*; Xu Dan; Jiang Wensheng; Bian Changwei ; Observations of the near-field Yellow River plume and fronts and their biogeochemical effects, *Journal of Geophysical Research-Oceans*, 2024, under review.

- Thaarshini Paramasivan, Roswati Md Amin*, Shiye Zhao, Tao Wang, Daoji Li, Nurhidayah Roseli, Idham Khalil, Yuzwan Mohamad Microplastic in Surface Water of Tropical Estuarine Front at Kuala Terengganu River, Malaysia. (Submitted)

6. Media reports, videos, and other digital content

- Feature on UTUSAN Malaysia: Pencemaran mikroplastik tinggi di muara. https://repository.seafdec.org.my/browse?type=author&value=Dr+Roswati%2C+Md+Amin&locale-attribute=ms Published on 30 June 2023
- Python code of the automated algorithm for analyzing FTIR imaging datasets

- Polymer library based on FTIR spectra

7. Significant citations

The published paper has received 37-time citations. Selected significant quotes are listed here.

- *"Fronts are related to strong convergence currents at surface waters that form visible lines of foam and debris, promoting lateral gradients of MP concentration (Wang et al., 2022)"* By Defontaine & Jalon-Rojas from Univ. Bordeaux, CNRS, Bordeaux INP, EPOC, UMR 5805, F-33600 Pessac, France, in their paper (doi.org/10.1016/j.marpolbul.2023.114932)
- *"Estuaries facilitate the formation of aggregates due to water mixing and the inflow of abundant freshwater that contains many microalgae (Wang et al., 2022)"* By Lim et al. from Ecological Risk Research Department, Korea Institute of Ocean Science and Technology (KIOST), Republic of Korea, in their paper (doi.org/10.1016/j.marpolbul.2023.115961)
- *"The distribution and transport of MPs in estuaries are subjected to interplayed hydrodynamic forces and anthropogenic activities, which may further complicate the assessment of MPs in estuaries (Wang et al., 2022)."* By Feng et al. from Department of Building, Civil and Environmental Engineering, Concordia University, Canada, in their paper (doi.org/10.1016/j.envpol.2023.122014)

8. Acknowledgments

We extend our sincere gratitude to the Asia-Pacific Network for Global Change Research (APN) for their funding support for this project, and we appreciate the assistance provided by the APN Secretariat during this project. Additionally, we wish to express our sincere appreciation to Dr. Shiye Zhao from the Japan Agency for Marine-Earth Science and Technology, Dr. Roswati Md Amin from Universiti Malaysia Terengganu, Malaysia, and Dr. Tao Wang from Ocean University of China, China. We are deeply thankful to our colleagues at the administrative office of the Japan Agency for Marine-Earth Science and Technology for their meticulous work on project documents throughout this endeavor. Our special thanks also go to the numerous researchers from Japan, Malaysia, and China who directly and indirectly contributed to this project. This project was also co-funded by the National Natural Science Foundation of China (42076006) and the International Partnership Research Grant sponsored by UMT (UMT/IPRG-2022) with Grant Vot. 55379.

9. Appendices

Appendix 1: Sample collection of plastics, microplastics and zooplankton in the Kuala Terengganu Estuary, May and August, 2022.

Four cruises were organized to conduct the sample collection in the Kuala Terengganu Estuary. Sampling took place during the southwest monsoon season, chosen due to the dry conditions and low precipitation that aid in locating and observing estuarine fronts. The sampling occurred during daylight hours (9:00 am to 5:00 pm) from May 16th to 17th, 2022, and August 16th to 18th, 2022 (**Figure 1**). Initially, sampling targeted the frontal region, identified using drones, followed by the plume and shelf waters. Samples from all three regions were collected during ebb tide, with an additional high tide sample taken as a representative of the frontal estuary. High tide sampling was conducted within 1 hour of the highest recorded water tide, while ebb tide sampling occurred 2-3 hours after high tide.

To measure physical data from surface to bottom at each station, we used Acoustic Doppler Current Profiler (ADCP), conductivity, temperature, and depth (CTD), and Hydrolab equipment. Rainfall data during sampling periods were obtained from the Malaysian Meteorological Department.Plastics and microplastics were collected using a manta net (350 µm) and a calibrated 10 L stainless steel bucket. The manta net was horizontally towed at the surface (~0.5 m) in a transect method, collecting water samples for 20 minutes at a boat speed of 1.9 knots. Following this, a 500 L surface water sample was retrieved using the 10 L stainless steel bucket at the endpoint after towing and sieved using a series of nets with a mesh size of 20µm. The water samples were then stored in a freezer at 4ºC for further laboratory analysis.

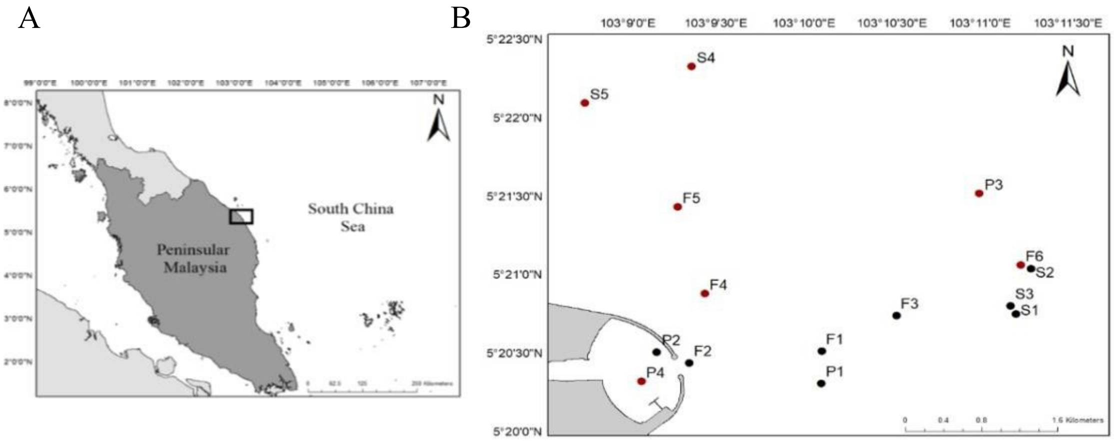


Figure 1. A) A map of Peninsular Malaysia with the sampling location indicated by a box. B) Sampling stations within the Kuala Terengganu estuary for both May 2022 (black) and August 2022 (red), covering all regions (P: Plume, F: Front, S: Shelf).

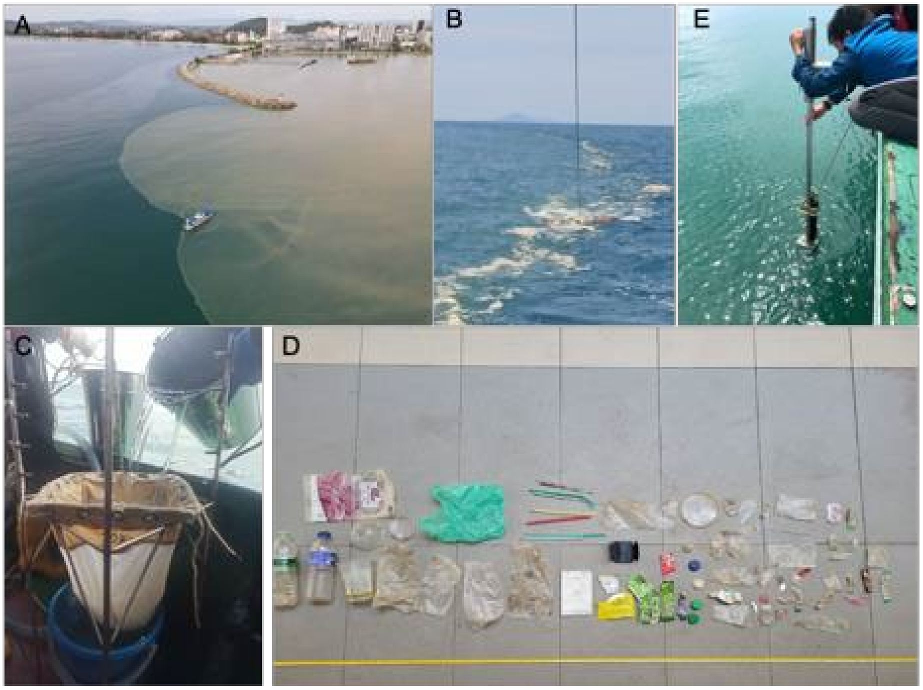


Figure 2. Images of A) the tidal front in the Kuala Terengganu estuary; B) A manta net being towed along the estuarine fronts to collect plastic and microplastic samples; C) surface seawater filtered for accounting for small microplastics; D) macro-plastics collected during the cruises; E) the concurrent measurement of hydrodynamics.

Figure 3. Reduced surface seawater samples on filters for small microplastics collected in the Kuala Terengganu estuary.

Appendix 2: Three field observation campaigns to collect plastics and microplastics and characterize physical dynamics of fronts in the Yellow River Estuary, August 16-17, 2021, July 31-August 6, 2022, and September 25-27, 2023.

In the Yellow River Estuary, plastic collections and physical dynamics were conducted during three cruises (in total 12 days), from August 2021 to September 2023 (Figure 4-8). Samples of plastics and microplastics were collected during the cross-front ship-track observations to determine the impacts of the dynamic nature of plume fronts on the distribution of plastics and microplastic. Concurrently, three types of physical observation were conducted to identify the characteristics of the estuarine fronts.

Briefly, the Manta net (300 µm mesh cod end) were deployed to collect the floating plastics in the front during the cross-front ship-track observation, which will track the instantaneous accurate frontal location (Figure 5). The net was towed along the plume front for 20-30 minutes at 2 knots at each manta net tow station. The volume of water filtered will be generated from the readings of a flowmeter at the center of the manta net mouth. Plastic collection were done in 2021 and 2023.

Three types of physical observation were performed: the cross-front ship-track observations, fixed station observations, and GPS drifter observations.

1) Fixed-station observation: To observe the structures of temperature, salinity, currents, turbidity, and micro-plastics with high temporal resolutions in the cross-frontal direction during full tidal cycles, two mooring stations on the two sides of the main plume front were set up in August 2021. In each station, a base tripod equipped with ADCP (Acoustic Doppler Current Profiler), ADV (Acoustic Doppler Velocimeter) and OBS (Optical Backscatter point Sensor) and a mooring with a series of CTD (Conductivity-Temperature-Depth profiler) was set to observe the temporal variations of the vertical temperature, salinity and velocity profiles on the two sides of the front (Figure 4).

2) Ship-track observation: To observe the high-resolution structures of the front during different tidal phases, ship-track observations were conducted from 2021 to 2023. Before the observations, the location of the main front was determined via small quadrotor drones. When the ship was close to the front, its speed was slowed down to about 1 m s^{-1}, and went across the front. Meantime, a winch was used to control a frame equipped with RBR-620 and LISST to loop up and down inside the water. An ADCP was equipped on one side of the boat and measure the velocity profiles across the front (Figure 4).

3) GPS-drifter observations: Surface GPS drifters were deployed around the front during the ship-track observations in 2021 and 2023. Their real-time GPS positions were recorded, which support to understand the influence of the currents around the front on the surface material transport (Figure 6).

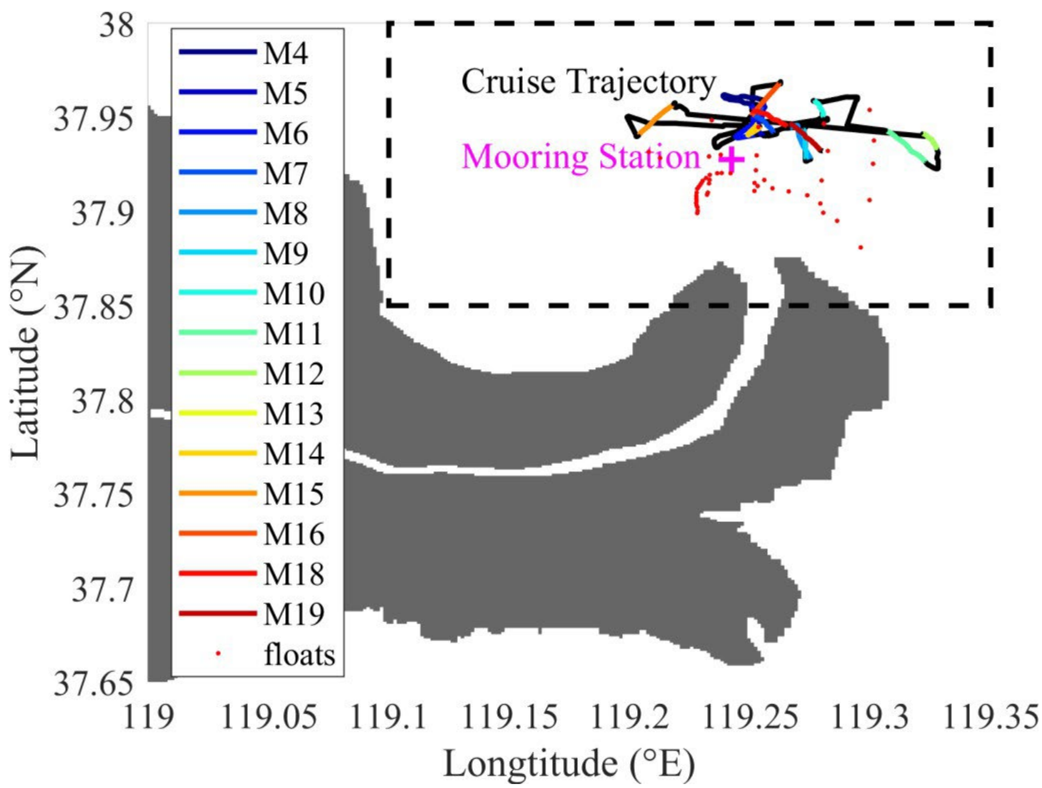


Figure 4. The plastic collection, moored and shipboard observations in the Yellow River Estuary.

Colored lines indicate the ship trajectories for collecting plastic and microplastic samples and the cross-front measurement of physical dynamics. '+' in purple shows where the fix-station observation was conducted. Red dots were the real-time positions of Surface GPS drifters released in 2021 and 2023.

Figure 5. Observational Images of the fixed-station and ship-track observations and the trawl of Manta net from the Yellow River Estuary

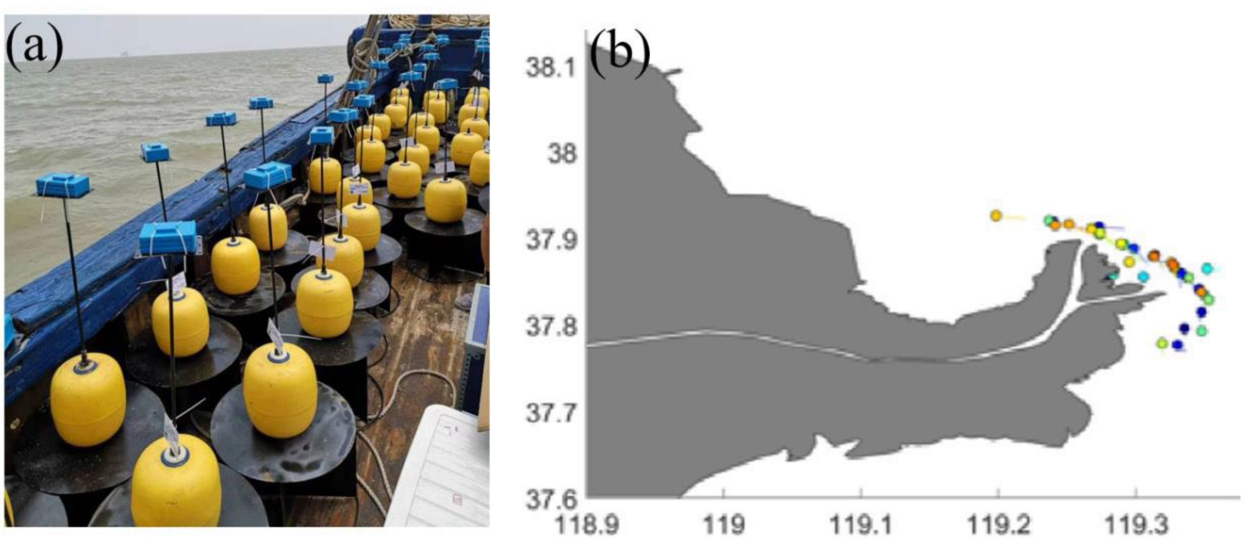


Figure 6. (a) Photo of the drifters deployed in the Yellow River plume; (b) A snapshot of the drifters' locations.

Figure 7. Selected images of plastics and microplastics collected in the Yellow River Estuary.

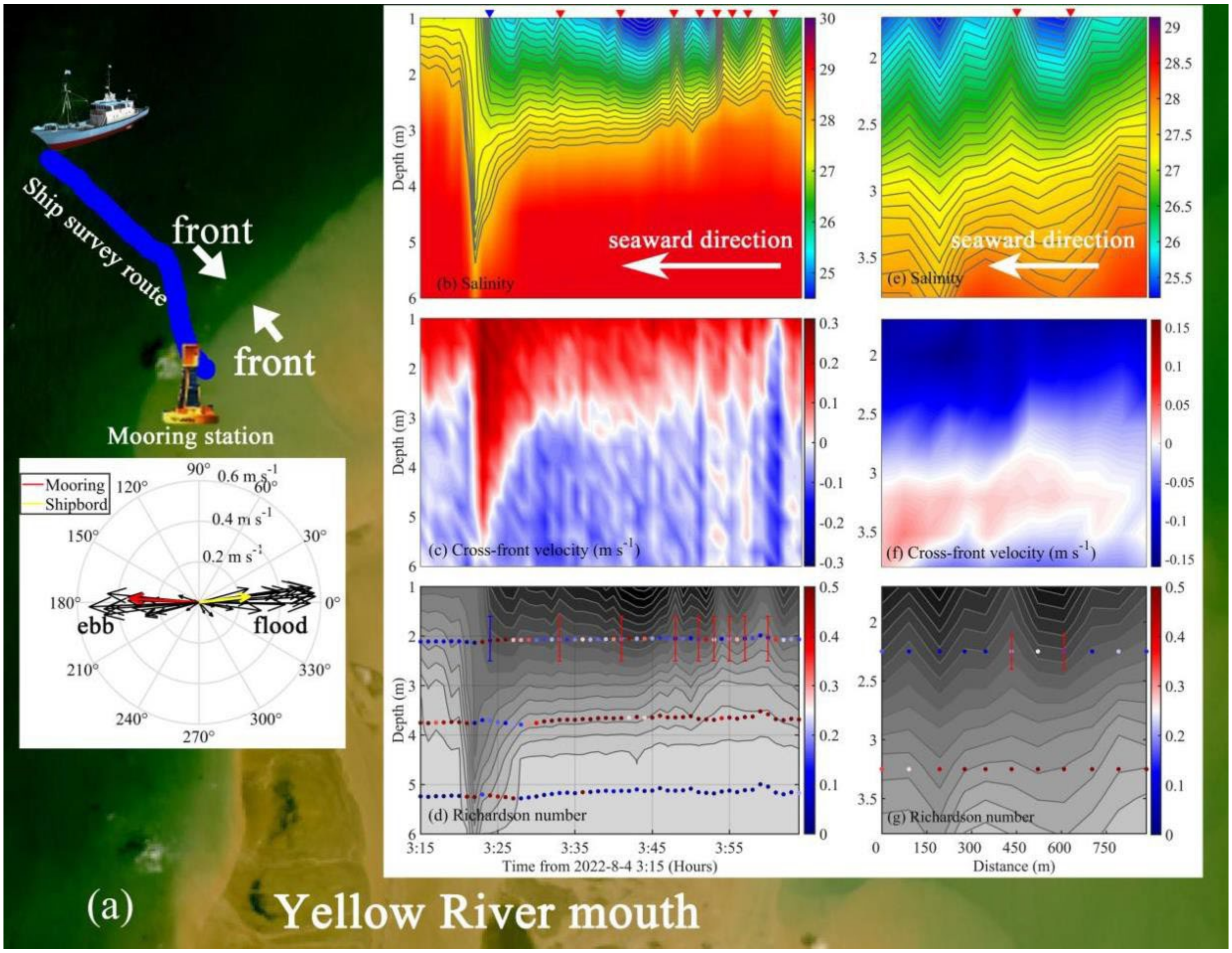


Figure 8. Multiple fronts observed by the moored and shipboard observations. Panel (a) indicates a snapshot of the RGB composite image observed on 2 July 2022 by Landsat-9. There is no clear satellite image in the observation date, so we apply the satellite image in July as a background to show the observation locations. This date of the satellite image was with similar ocean, tide and wind conditions as the observation date. Panels (b-d) represent a time series of salinity, cross-front velocity, and Ri observed at the mooring station. Positive values of cross-front velocity indicate seaward direction. In panel (b), blue and red triangles indicate the leading front and sub-fronts, respectively. In panel (d), to show the relationship between Ri and fronts clearly, the time of fronts is noted with vertical lines in the first layer of Ri. Panels (e-g) are similar to panels (b-d), but represent the results from the shipboard observations.

Appendix 3: Simulation of the dynamics of the Yellow River plume fronts and its effects on plastic transport

To simulate the dynamics of the Yellow River plume and the associated fronts, we have conducted a high horizontal resolution (~150m) numerical model based on the Regional Ocean Modelling Systems (ROMS) and validated it with in-situ observations (Figure 9). Simulated currents and surface elevations are roughly consistent with the observed results (Figures 9a-c). Time interval of the model outputs was 1 hour, so the observed salinity was selected with 1-hour interval to validate the simulated results (Figure 9d). Primary variations of the hourly observed salinity in every tidal cycle were similar. To state the tidal variations clearly, one tidal cycle was chosen to test whether the numerical model captured the tidal salinity variations and to clarify the effects of tidal currents on the plume transport. As shown in Figures 8d and 8e, the primary tidal variations of the simulated salinity were similar to the observed results. The difference between the observed and simulated results was perhaps attributed to several factors, including more complicated topography in reality, non-steady realistic river discharge and some small-scale dynamical processes not resolved by the model. Nevertheless, the numerical model results were reluctantly applicable in the present study because they were only used to help interpret the tidal variations.

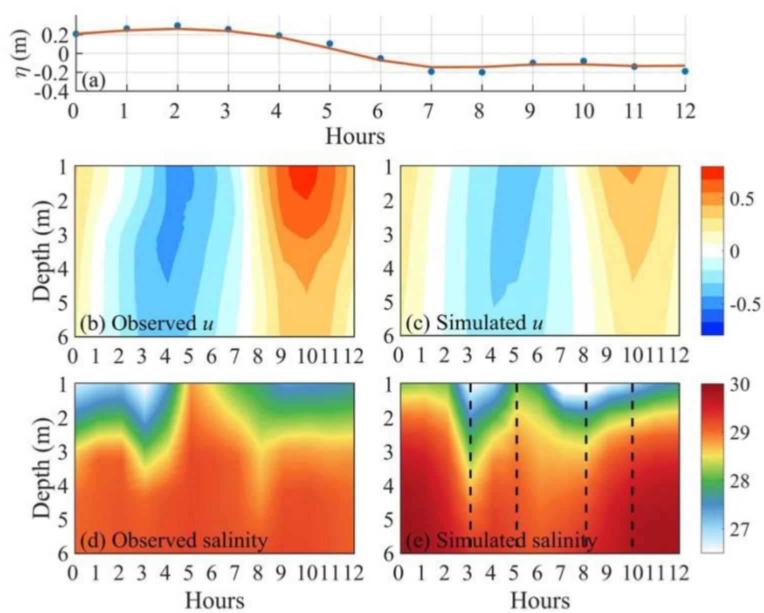


Figure 9. Time series of the hourly averaged observed and simulated (a) surface elevations, (b)-(c) east component of velocity and (d)-(e) salinity in one tidal cycle. The red lines and blue dots indicate the simulated and observation results, respectively in panel (a). The black dash lines in panel (e) indicate the corresponding moments of Figure 10.

According to the simulated results (Figures 10a-d), a time-dependent jet plume is formed in the near-field region under the effects of tidal currents. At middle ebb, the main body of the plume was transported eastward under the effects of tidal currents, resulting in low-salinity water at the mooring station (Figure 9a). At late ebb, ambient seawater on the east of the plume passed the mooring station, leading to high salinity at the mooring station (Figure 9b). At middle and late flood, the plume was transported to the east, resulting in low salinity at the mooring station again (Figure 9c and 9d). Therefore, salinity fronts mainly varied with semidiurnal tidal cycles due to periodical east-west movement of the near-field river plume under the effects of tidal currents.

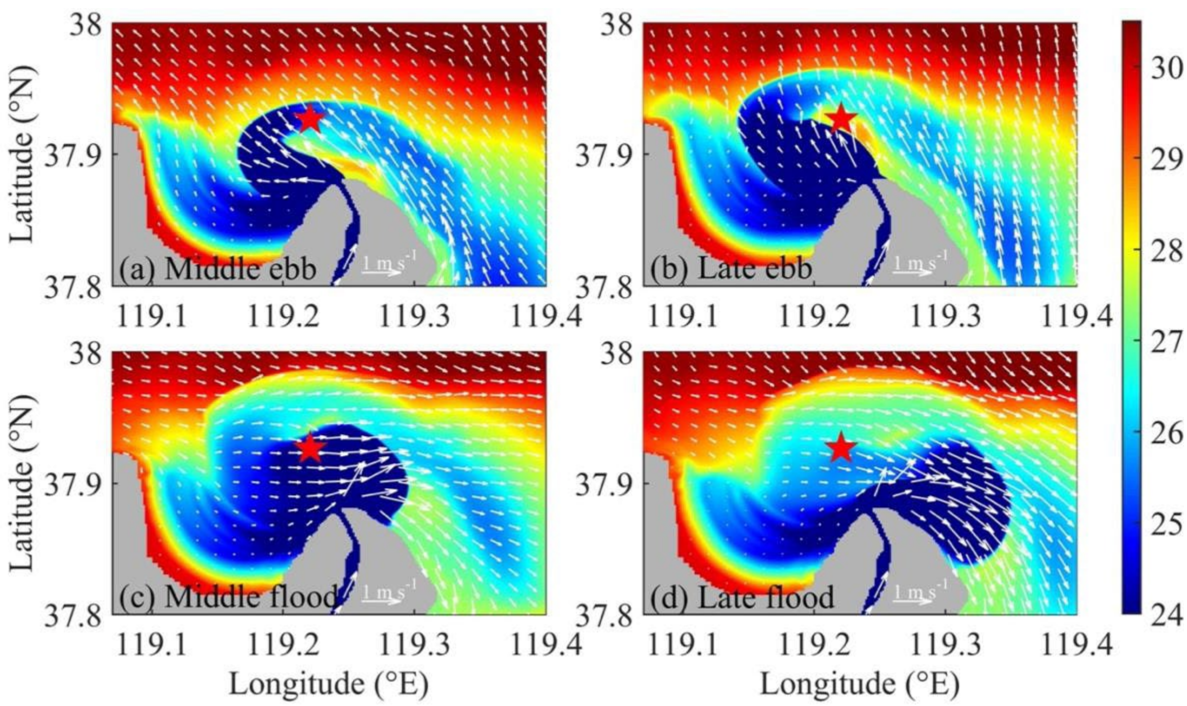


Figure 10. Simulated Yellow River plume transport in one tidal cycle. Panels (a)-(d) indicate the simulated surface salinity (color) and velocities (arrows) during middle ebb, late ebb, middle flood

and late flood, respectively. Red star indicates the location of mooring station for validation in Figure 9.

The spatial and temporal variations of the plume fronts and numerical particles released from the Yellow River (representing plastics) have also been simulated successfully (Figure 11). Surface fronts were quantified with local maximum magnitudes of horizontal surface salinity gradients. Numerical surface particles were found to be trapped by surface fronts after they are transported out from the river mouth (Figures 11b and 11d). These findings are crucial for understanding the effects of river plume fronts on the transport of plastics and microplastics.

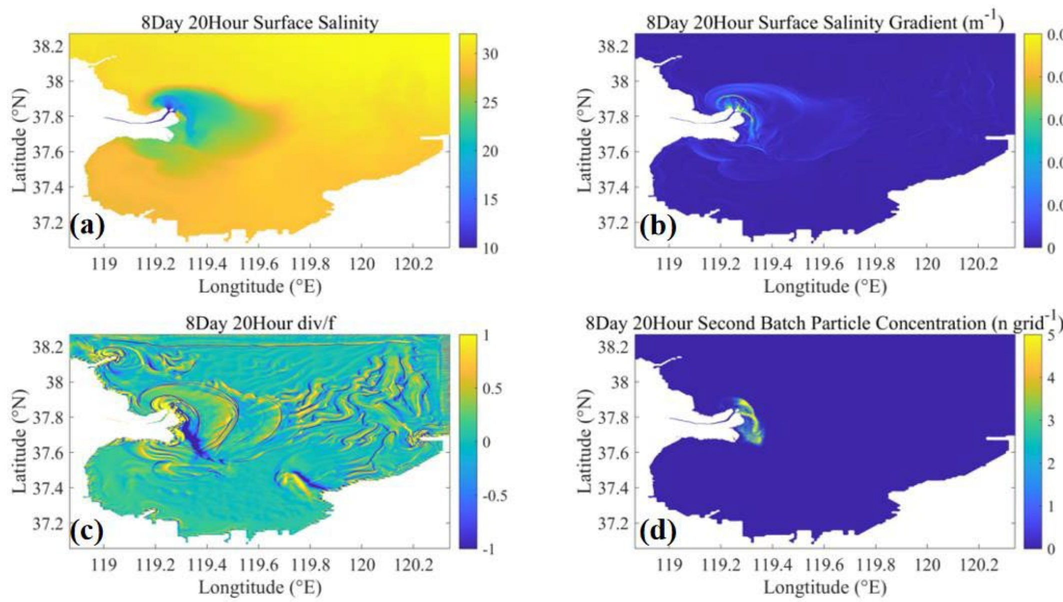


Figure 11. Snapshot of numerically simulated (a) surface salinity, (b) horizontally salinity gradient, (c) divergence normalized with Coriolis parameter f, and (d) particle concentration in the Yellow River plume.

Appendix 4: Python code for automated analysis of FTIR imaging datasets and polymer library

They are can be accessed via the link below.

DOI: 10.6084/m9.figshare.25661520

Appendix 5: Journal Articles

1. Accumulation, transformation and transport of microplastics in estuarine fronts (Published in Nature Reviews Earth & Environment, IF 47.3)

Abstract

Millions of tons of riverine plastic waste enter the ocean via estuaries annually. The plastics accumulate, fragment, mix and interact with organisms in
these dynamic systems, but such processes have received limited attention relative to open-ocean sites. In this Perspective, we discuss the occurrence and convergence of microplastics at estuarine fronts, focusing on their interactions with physical, geochemical and biological processes. Microplastic transformation can be enhanced within frontal systems owing to strong turbulence and interactions with sediment and biological particles, exacerbating the potential ecosystem impacts. The formation of microplastic hotspots at estuarine fronts could be a target for future plastic pollution mitigation efforts. Knowledge of the mechanics of plastic dispersal, accumulation and fate in frontal zones will, in turn, improve our understanding of plastic waste along the land–sea aquatic continuum.

Keywords

estuary, fronts, microplastics, plastic accumulation

2. Observations of the near-field Yellow River plume and fronts and their biogeochemical effects (Under review in *Journal of Geophysical Research-Oceans*, IF 3.6)

Abstract

The near-field Yellow River plume, fronts and their biogeochemical effects are investigated through moored, shipboard, and remote sensing observations in the present study. The near-field Yellow River plume is generally advected back and forth in the east-west directions under the effects of tidal currents. Numerous fronts are found to be formed and have non- negligible biogeochemical effects. Leading fronts are formed along the boundaries between the plume and ambient oceanic water. At leading front, a turbulent bore is observed to be generated and transport the near-surface water with low turbidity and high dissolved oxygen into the water column. The moored, shipboard, and remote sensing observations all show that a series of sub-fronts with distance of *O*(10-100m) are formed inside the river plume. The generation mechanisms of the sub-fronts following the leading front are suggested to be related to internal shear instabilities. Under the effects of cross-front shear currents and vertical mixing near the sub-fronts, a three-layer structure of turbidity and surface low-turbidity stripes are formed behind the leading front. In addition to the leading fronts, sub-fronts inside the plume are also found to accumulate surface materials.

Keywords

Yellow River, fronts, plume, biogeochemistry, dissolved oxygen

3. Thaarshini Paramasivan, Roswati Md Amin, Shiye Zhao, Tao Wang, Daoji Li, Nurhidayah Roseli, Idham Khalil, Yuzwan Mohamad Microplastic in Surface Water of Tropical Estuarine Front at Kuala Terengganu River, Malaysia. (Submitted)

Abstract

Estuarine fronts are formed due to the sharp density discontinuities due to the different water masses converged. This study, conducted in May and August, 2022 during the Southwest monsoon season, focuses on assessing the role of the frontal region in accumulating microplastics in surface seawater. Microplastic samples were collected from three main areas: the plume, front, and shelf, utilizing two methods—manta net (>350µm) and bucket water sampling (>20µm). Results indicate that the estuarine front consistently exhibits higher microplastic concentrations compared to the plume and shelf regions throughout the study period, with bucket water sampling contributing significantly. Specifically, peak concentrations occurred during the ebb tide at the frontal region in both months, reaching 5,211.67 particles m^{-3} and 12,687.44 ± 2,821.51 particles m^{-3}, respectively. Microplastics, predominantly transparent fibers with a size range less than 1000µm, and mostly showed signs of oxidative and mechanical weathering through SEM-

EDS analysis, providing insights into their fate in estuarine surface waters. FTIR spectroscopy revealed polypropylene, polyethylene, and polyamide as the dominant polymers, indicating anthropogenic sources within the estuary. These findings establish a baseline for microplastic abundance at the estuarine front of the Kuala Terengganu estuary, informing future strategies for mitigating and recovering microplastic contamination in aquatic environments.

Keywords
estuary, estuarine front, microplastic, plume, South China Sea

Appendix 6: Thesis Articles

Microplastic bioavailability and ingestion by zooplankton in tropical estuarine fronts of Terengganu River (Master thesis)

Estuarine front has high entrapment properties concentrates microplastic debris that risk the feeding ground of aquatic organism. Microplastic debris was collected at three main regions of estuary that were plume, front and shelf in May and August, 2022 during the southwest monsoon. Microplastic recorded according to two methods—manta net (>350 µm) and bucket water sampling (>20µm) conclude that estuarine front has high concentrations of microplastic compared to plume and shelf region with bucket water sampling contributing significantly. Highest concentrations occurred during the ebb tide at the frontal region in both months, reaching 5,211.67 particles m^{-3} and 12,687.44 ± 2,821.51 particles m^{-3}, respectively. Contrastingly, estuarine front yield's greater density of zooplankton during high tide with tide height greater than 1.5m in both surface and mid waters. The average density of zooplankton recorded in the month of May and August 2022 was 5422.18 inds. m^{-3} and 8496.6 inds. m^{-3} respectively. In both sampling events, copepod group yield higher abundance which was 81.6 % and 90.1% respectively. The dominant genus recorded for the month of May, 2022 was *Oithona* sp., *Paracalanus* sp. and *Microsetella* sp. and significant shift to *Oncaea* sp., *Microsetella* sp. and *Paracalanus* sp. in the month of August, 2022. In term of ingestion, higher ingestion was recorded at frontal zone during high tide with ingestion rate of 0.032 and 0.013 particles ind^{-1} in both

months. Fragments were commonly ingested by the zooplanktons and mostly ingestion incidence was recorded from copepod group with 50% size <20µm. The concentration of ingested microplastic varied from 0.002 to 0.032 particles ind^{-1} across all the regions for both months. These findings establish a baseline for microplastic abundance and ingestion in zooplankton at the estuarine front of the Kuala Terengganu estuary, indicating a preliminary measure on the risk of microplastic pollution at the frontal regions.

Keywords

estuary, estuarine front, microplastic, zooplankton, ingestion, South China Sea,

Appendix 7: List of young researchers

Name	Institute/University	Country	Email
Thaarshini A/P Paramasivan	Universiti Malaysia Terengganu	Malaysia	Shini1298@gmail.com
Dan Xu	Ocean University of China	China	danxu@stu.ouc.edu.cn
Zhixing Chen	Ocean University of China	China	2420186039@qq.com

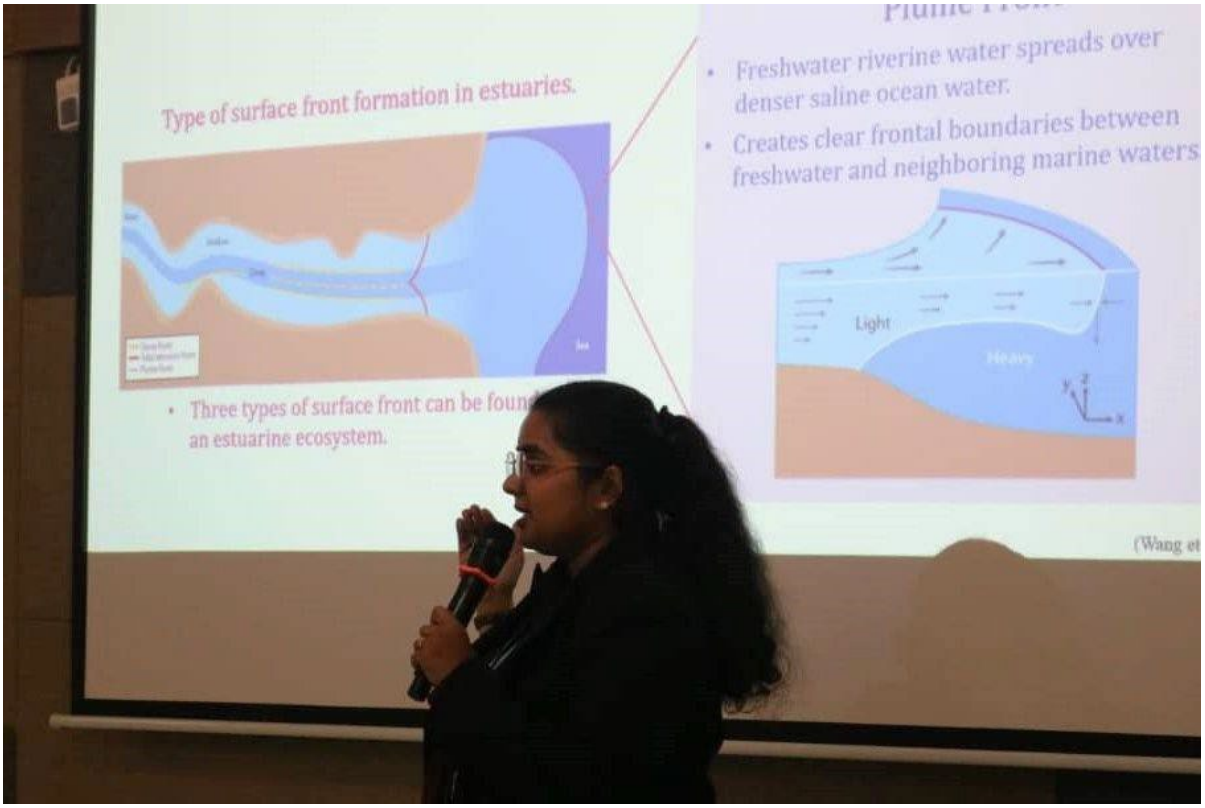
Appendix 8: Conference Presentation

Topic	Author	Conference	Year
Estuarine surface fronts	Tao Wang	7th International Conference on Estuaries and Coasts (online due to COVID-19)	2021
Bathymetric controls on estuarine surface fronts	Tao Wang	Physics of Estuaries and Coastal Seas (online due to COVID-19)	2022
Estuarine frontal dynamics and its	Tao Wang	Environment Forum of 2022	2022

implications on plastic pollution		(Qingdao) Conference on International Cooperation for Future Production, Education, Research and Application of the Ocean Industry (online due to COVID-19)	
Microplastics in the tropical estuarine fronts: A case study in Terengganu River, Malaysia	Roswati Md Amin	Westpac-ECNU International Workshop "Stem the Tide of Asia's Riverine Plastic Emission into the Ocean	2023
Composition of zooplankton in estuarine plume front at Kuala Terengganu estuary, Malaysia	Thaarshini a/p Paramasivan	10th National and 6th International Marine and Fisheries Symposium.	2023
Microplastic in zooplankton from tropical estuarine front of Kuala Terengganu River during Southwest monsoon	Roswati Md Amin	ICES/PICES 7th Zooplankton Production Symposium	2024

Dr Roswati Md Amin: Presenting her finding on microplastics in seawater at WESTPAC_ECNU workshop.

Dr Roswati Md Amin: Presenting her finding on microplastics in zooplankton at 7th Zooplankton Production Symposium.



Thaarshini A/P Paramasivan: Presenting her finding on zooplankton composition at estuarine front at International Marine and Fisheries Symposium.