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Characterising Mary River flood sediments within Hervey Bay: a pilot study

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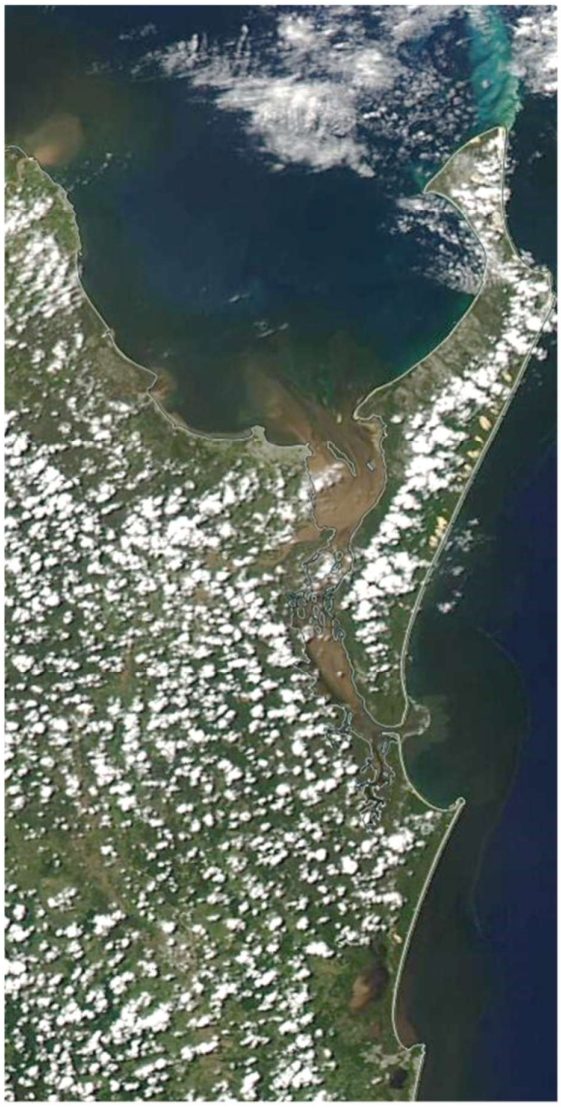

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Characterising Mary River flood sediments within Hervey Bay: a pilot study

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1. Introduction

Hervey Bay including the Great Sandy Strait is the location of the most important seagrass meadows in southern Queensland and supports populations of dugong and green turtles. Flood events in the Mary River can have devastating impacts on the extent and density of these seagrass meadows with consequent impacts on the megafauna and a wide range of other biota. Despite the importance of these seagrass meadows, historically we have had very little quantitative information on their extent and density in Hervey Bay and the effects of terrestrial runoff. A recent study has demonstrated the link between terrestrial runoff from the Burdekin River and the seagrass condition and extent in the receiving waters of Cleveland Bay (Lambert et al., 2021). A similar investigation is warranted for the Hervey Bay.

During the 2022 Mary River flood events and resulting flood plumes, the Queensland Government Department of Environment and Science (DES) collaborated with James Cook University's TropWATER to examine the flood sediment (this report), and map and monitor post-flood seagrass distribution across Hervey Bay (York et al., 2022) and the Great Sandy Strait (Bryant et al., 2023).

This report examines the dispersal of suspended sediments delivered from the Mary River across two large flood events in January and February-March 2022. Specifically, the aim of this study is to characterise the sediment particle size distributions and geochemistry from the end of catchment and in the flood plumes to determine which components travel the furthest into Hervey Bay. Further, benthic sediment samples collected across Hervey Bay were characterised to compare with the river and flood plume samples.

2. Methods

Mary River discharge and sampling events

Three sizable flow events occurred in the Mary River over the 2021/22 water year, of which the two largest events were sampled (Figure 1). The first event coincided with the rain generated by Ex-Tropical Cyclone Seth where the Mary River peaked on the 9th January 2022 at 664,000 ML/day with subsequent sampling occurring on the 12th (end of catchment) and 13th of January (flood plume). The second event peaked on the 28th February 2022 at 658,000 ML/day with sampling occurring on the 1st (flood plume), 2nd (end of catchment and flood plume) and 3rd (end of catchment) of March. The third event was much smaller and peaked on the 15th May 2022 at 202,000 ML/day; this event was not sampled (Figure 1). The total discharge of the Mary River measured at the Home Park gauge for the 2021/22 water year was 7,200,000 ML, which places it as the highest annual water year discharge on record. Indeed, on inspection of the upstream Mary River at Miva gauge record which extends back to 1910, the 2021/22 water year is the highest on record surpassing the 2010/11 water year (Figure 2). A total sediment load of 1.7 million tonnes was exported past the Mary River at Home Park site over the 2021/22 financial year (State of Queensland, Dept. of Environment and Science, 2023).

The Mary River end of catchment surface waters were sampled using 20 L buckets on the 12th January and during the subsequent event on both the 2nd and 3rd February 2022 (i.e. three samples), by the Department of Environment and Science's Environmental Monitoring and Assessment Science team. Well-mixed aliquots were taken from each sample for total suspended solids (TSS) and particle size analysis while the remainder of the samples were sieved to recover the <20 µm sediment fraction. The sieved sediment was then dried in a 60°C oven and recovered for radionuclide and trace element geochemistry analysis.

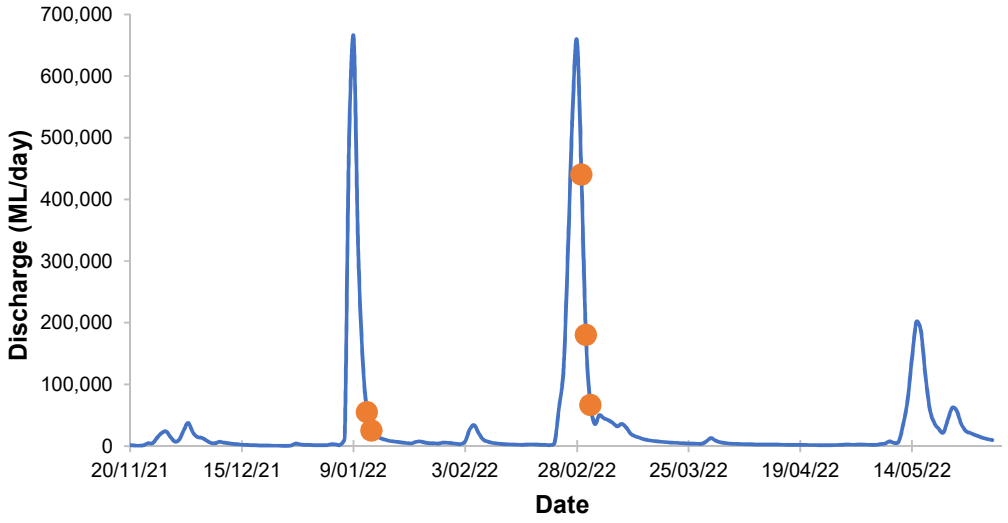

Figure 1. Discharge hydrograph for the Mary River at Home Park gauge (138014A). The orange dots represent when water samples were collected.

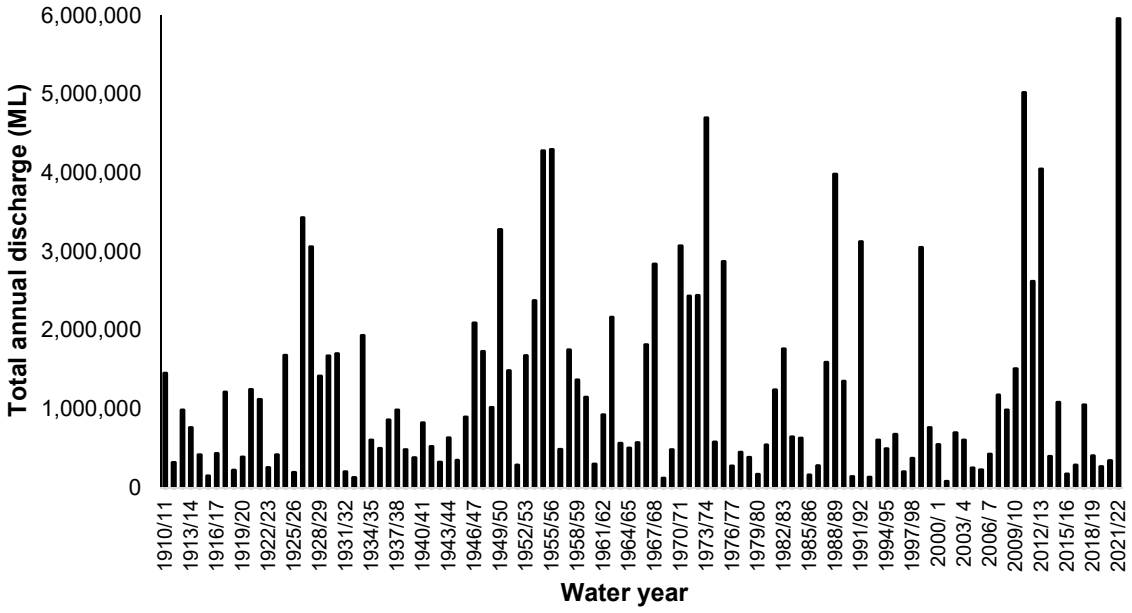

Figure 2. Total annual discharge for the Mary River at Miva gauge (138001A) from the 1910/11 to 2021/22 water years (1st October – 30th September).

Satellite image time series show the movement of the Mary River (and adjacent rivers) flood plume offshore from the mouth into Hervey Bay. The images highlight that the flood plume tightly followed the coastline during the January flood event (Figure 3) and extended a little further offshore during the February-March event (Figure 4). The Mary River flood plume samples were collected targeting the plume as it moved from the river mouth through the Great Sandy Strait and out into Hervey Bay. Only plume surface waters were targeted (i.e. top 0.5 m). Sites in Hervey Bay were targeted to capture the plume over known areas of inshore coral reefs and seagrass meadows (Figure 5). Samples were collected by the DES EMAS team as part of routine monitoring, with vessel support from Queensland Parks and Wildlife Service (QPWS) Urangan. At each sampling site, a 1 L sample was collected for TSS analysis and another 5 L sample was collected for particle size analysis. The TSS sample was analysed by standard laboratory methods (described below) to report suspended particulate matter (SPM) concentrations. The 5 L sample was decanted to reduce the sample volume (ensuring no suspended sediment was lost) before placed in dialysis tubing to remove the seawater before particle size analysis (see method description in Bainbridge et al., 2021). In addition, at each site a water column profile of salinity was taken to capture the extent of the vertical mixing of the flood waters.

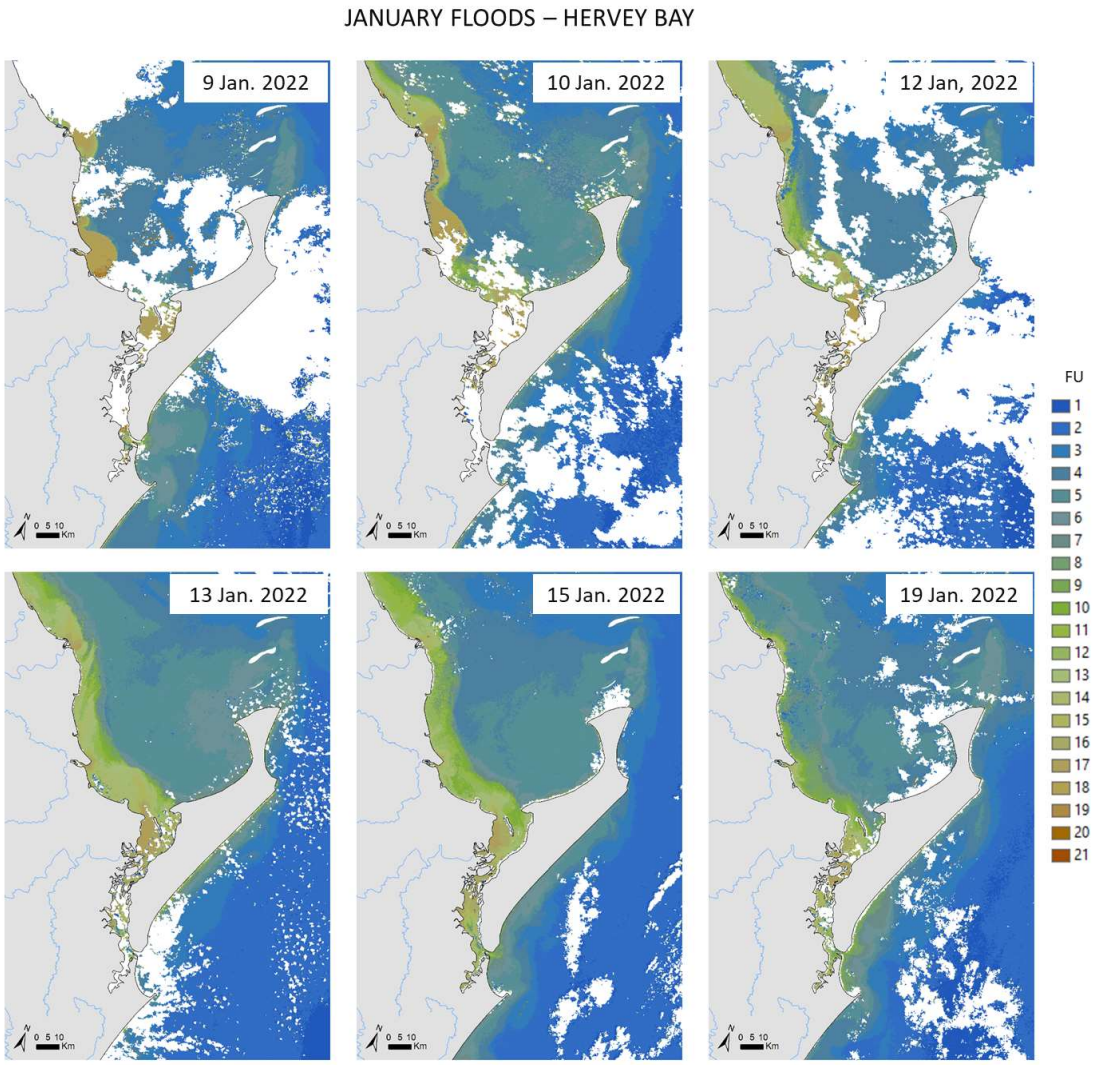

Figure 3. Processed satellite image time series (to the Forel Ule (FU) colour classes) of the January flood event off the Mary River-Hervey Bay region. The time series show the flood plume from the Mary and adjacent rivers were tightly constrained along the coastline.

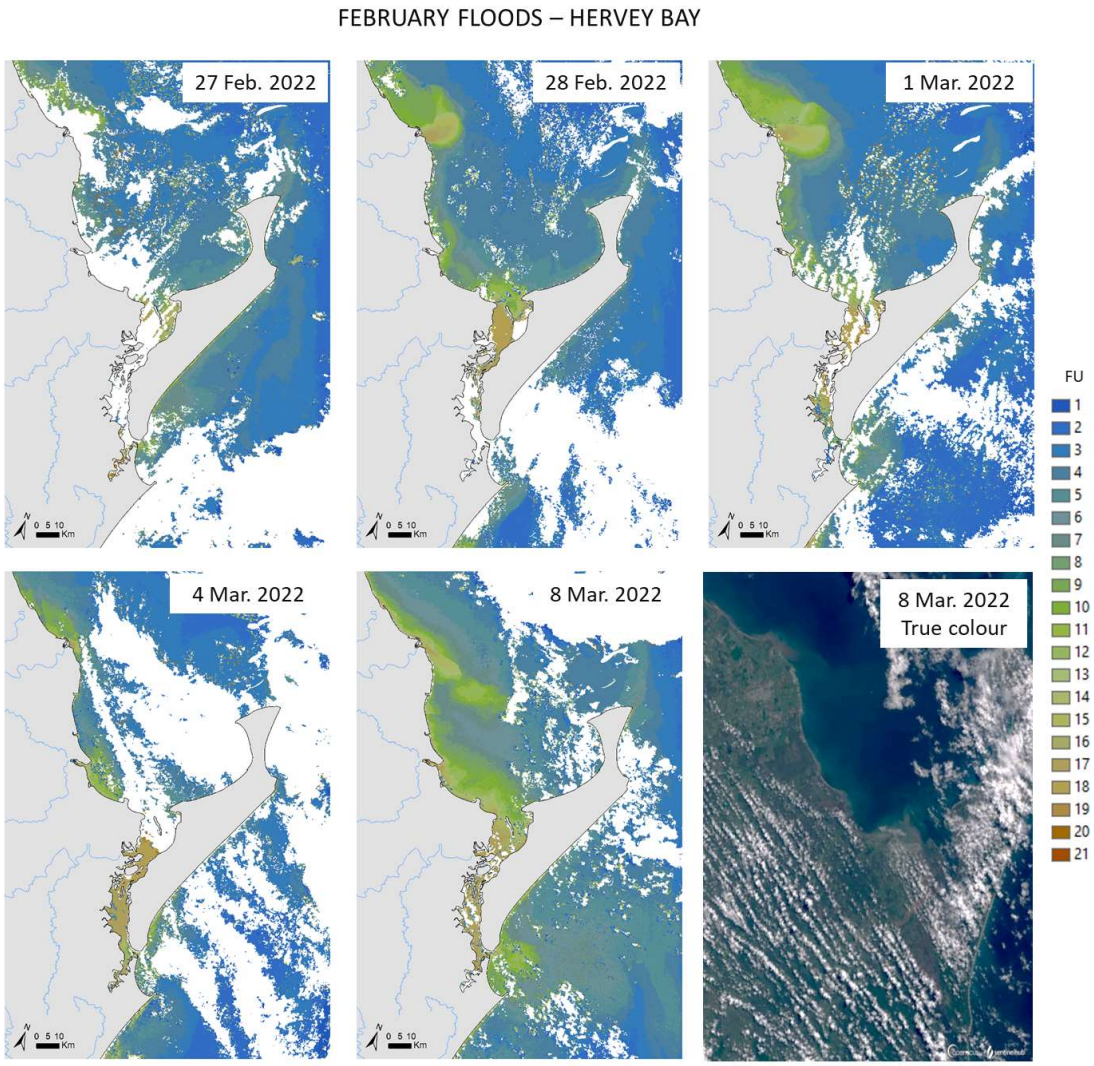

Figure 4. Processed satellite image time series (to the Forel Ule (FU) colour class) of the February-March flood event off the Mary River-Hervey Bay region. The time series show the flood plume from the Mary and adjacent rivers moving out into Hervey Bay and covering a larger area relative to the January event.

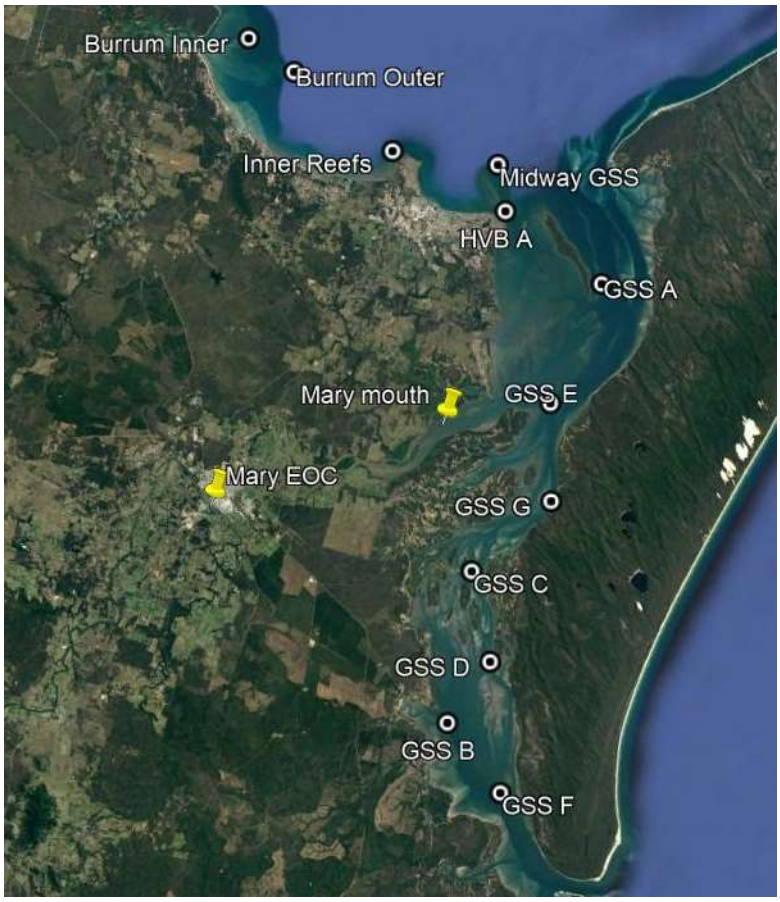

Figure 5. Mary River flood plume sites sampled over the January and February-March 2022 events. The yellow pins represent the Mary River end of catchment monitoring sites and the black dots represent flood plume samples from the Great Sandy Straits and Hervey Bay.

A total of 10 benthic sediment samples from Hervey Bay were collected with a Van Veen grab sampler in May 2022 (Figure 6), by the TropWATER seagrass and QPWS Urangan teams, during a post-flood seagrass assessment survey of the bay. An additional two sediment grab samples were collected from the Marine Monitoring Programs intertidal seagrass monitoring sites at Urangan (UG) and Burrum Heads (BH) in March 2022, immediately following the larger flood event (collected by L.Mckenzie, TropWATER). All samples were transported to the TropWATER laboratory (Townsville) and stored in 10 L buckets in a 4°C coldroom.

For each sample a well-mixed aliquot was taken and wet sieved to 1.4 mm before placed in dialysis tubing to remove the saltwater associated with the sample. This aliquot was then treated and analysed for particle size (descriptions below). The remainder of the sample was wet sieved through a series of 1.4 mm to 20 µm sieves, to recover the fine (<20 µm), terrigenous component. The excess RO water used to sieve the sample was evaporated in a 60°C oven. The concentrated <20 µm sample was then placed in dialysis tubing to remove the saltwater and the sample then dried in a 60°C oven and recovered for trace element geochemistry analysis.

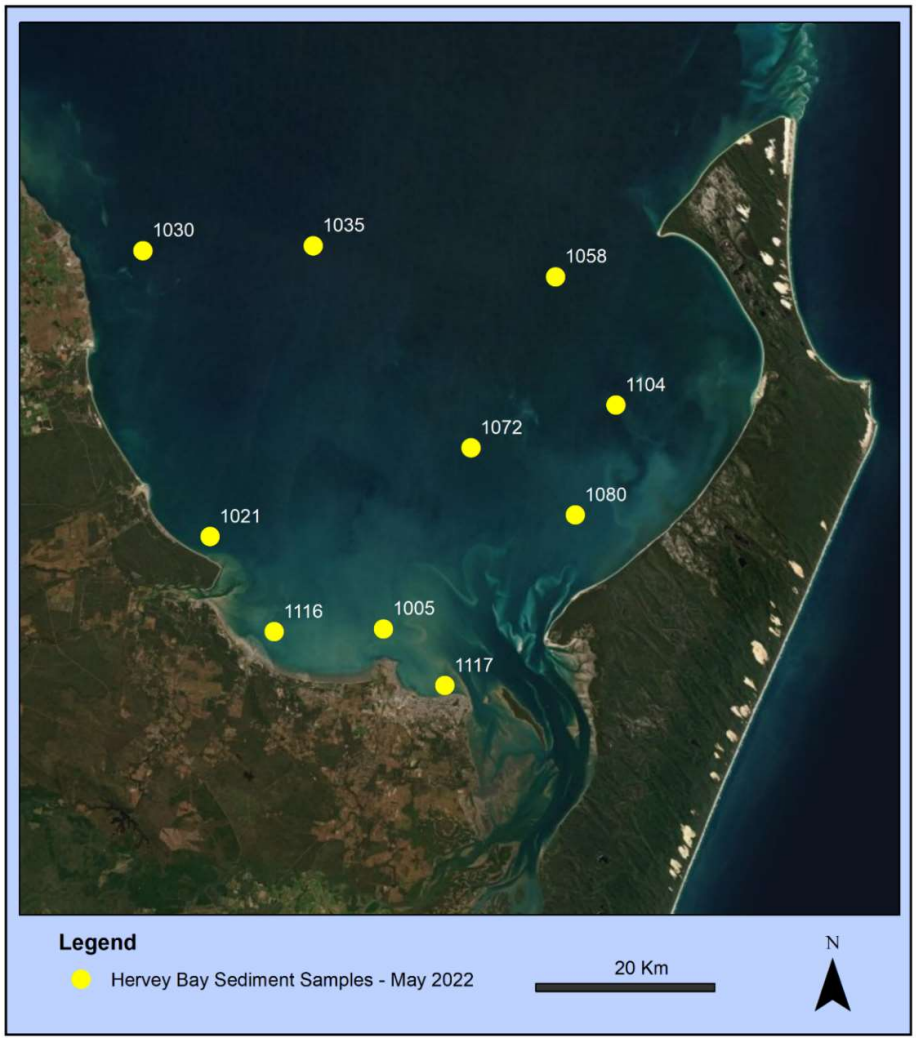

Figure 6. Sediment grab sample sites collected from Hervey Bay in May 2022.

Analytical Methods

TSS analysis

The 1 L TSS samples were filtered using pre-weighed 0.4 µm polycarbonate filter papers using standard gravimetric methods. Each filter paper was then well-flushed with milli-Q water to remove salts before being dried in a 105°C oven for 24 hours and weighed. The weight difference between the dried and pre-weighed filter paper was reported as the SPM concentration (in $mg.L^{-1}$). A separate method was conducted to quantify the organic component of the SPM. Here, an aliquot of each sample was filtered for TSS analysis as previously described with the only difference that a GF/C filter paper was used (nominal size 1.2 µm). Once the SPM concentration was determined on this sample, the GF/C filter paper was placed into a 550°C furnace for 4 to 5 hours and the paper was reweighed. The

material lost on ignition represents the volatile suspended solids (VSS) which is a measure of the organic component of the sediment (see method in Bainbridge et al., 2021). This proportion was then applied to the SPM concentration measured with the 0.4 µm polycarbonate filter paper.

Particle size analysis

The sample aliquots for particle size were spilt into an untreated (salt-removed) and treated sample before being analysed on a Malvern Mastersizer 3000 following the methods outlined in Bainbridge et al. (2021). Briefly for the treated samples, approximately 100 ml of the sample aliquot from the Mary River end of catchment (i.e. freshwater) samples and the salt-removed sample aliquots from the flood plume sites were poured into a glass beaker and 100 ml of hydrogen peroxide (H_2O_2) was added. The beakers were then placed into an 80°C water bath for ~ 8 hours to remove all organic material from the sample. Subsequently, around 4 to 5 rinses of each sample in double distilled water in the 80°C bath occurred to flush the H_2O_2 from the samples before these treated (along with the paired untreated) samples were analysed on the Malvern Mastersizer 3000.

The salt removed benthic grab sediment samples sieved through 1.4 mm were treated with H_2O_2 as described above but these subsequent ~ 100 ml samples were then treated with HCl acid in an 80°C water bath for ~ 6 hours to additionally remove the carbonate component. The treated samples were then rinsed 4 to 5 times (and decanted) with double distilled water to remove the residual HCl before being analysed with calgon dispersant (with the paired salt-removed sample) on the Malvern Mastersizer 3000 (Bainbridge et al., 2021).

Radionuclide analysis

The <20 µm fraction of the three end of catchment Mary River samples were analysed for ^{210}Pb, ^{226}Ra and ^{137}Cs by high-resolution gamma-ray spectrometry following the procedures of Leslie (2009). Approximately 3 g of each sample were counted for seven days on a high resolution germanium gamma detector at Griffith University. The $^{210}Pb_{ex}$ activity concentrations were calculated as the difference between the ^{210}Pb and ^{226}Ra activity concentrations for each sample (Olley et al. 2013). Samples were corrected for organic matter content.

Geochemistry analysis

The <20 µm fraction of the three end of catchment Mary River samples, 10 benthic grabs in Hervey Bay and the Urangan intertidal sample were analysed for trace element geochemistry at the Queensland Government Department of Environment and Science (DES) Chemistry Centre (Brisbane, Australia). The dried <20 µm samples were fused with lithium metaborate flux at 975°C and analysed on an Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) for the major element concentrations (Al, Ca, Cr, Fe, K, Mg, Mn, P, K, Na, Si, Ti, Zr and Zn) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for the trace and rare earth element concentrations. These instruments are calibrated with certified commercial single- and multi-element standard solutions (9 for ICP-OES and 10 for ICP-MS). The measured major element concentrations were converted to weight percent oxides and summed. The summed weights were then normalised to 100%

(i.e. exclude the loss on ignition). The same correction factors were then applied to the trace and rare earth element data.

3. Results

SPM and particle size end of catchment and flood plume samples

The SPM concentration of the Mary River end of catchment samples averaged 120 mg.L^{-1} for the sample collected on the 12th January while SPM concentrations were higher in the samples collected in the February-March event on the 2nd (220 mg.L^{-1}; Figure 6) and 3rd (200 mg.L^{-1}; Figure 7) February. The sampling in the January event coincided with the tail end of the event while the sampling in March coincided with more elevated flows (see Figure 1). The flood plume samples from the January event show much lower SPM concentrations which were mostly <10 mg.L^{-1} by the 20 PSU salinity zone. In general, the salinity and SPM concentrations were similar at the sites measured across the January and February-March event with a couple of notable exceptions (Figures 7 and 8). Specifically, the Urangan Jetty site (HVB A) had much lower salinity (4.5 versus 16.8 PSU) and much higher SPM (61 versus 14 mg.L-1) in the February-March event compared to the January event. Similar differences were also measured at the Stewart Island (GSS D), East Woody Island (GSS A) and Yellow Beacon (GSS E) sites (Figures 7 and 8). However, once the plume moved out of the Great Sandy Strait into Hervey Bay (i.e. Inner Reefs and Burrum Inner and Outer sites see Figure 5) the plume salinity's were >25 PSU and SPM values were mostly <10 mg.L^{-1}. Indeed, Figures 7 and 8 show that once seawater mixing >15 PSU occurs the SPM concentrations consistently remain <15 mg.L^{-1}.

The particle size data for the Mary River end of catchment and mouth samples show that the suspended sediments are dominated (~ 80%) by the fine <20 µm fraction with some coarse silt (20 to 63 µm) and a minor sand (>63 µm) component (Figures 7 and 8). In general, there is a reduction of the coarse silt and sand fractions along the salinity gradient, although occasionally at some sites >10 PSU salinity there is an apparent increase in coarse silt or sand that occurs relative to the adjacent samples from the lower salinity zones. These instances almost certainly indicate the production of phytoplankton in the plume which is not removed by the H_2O_2 digestion (see Bainbridge et al., 2021).

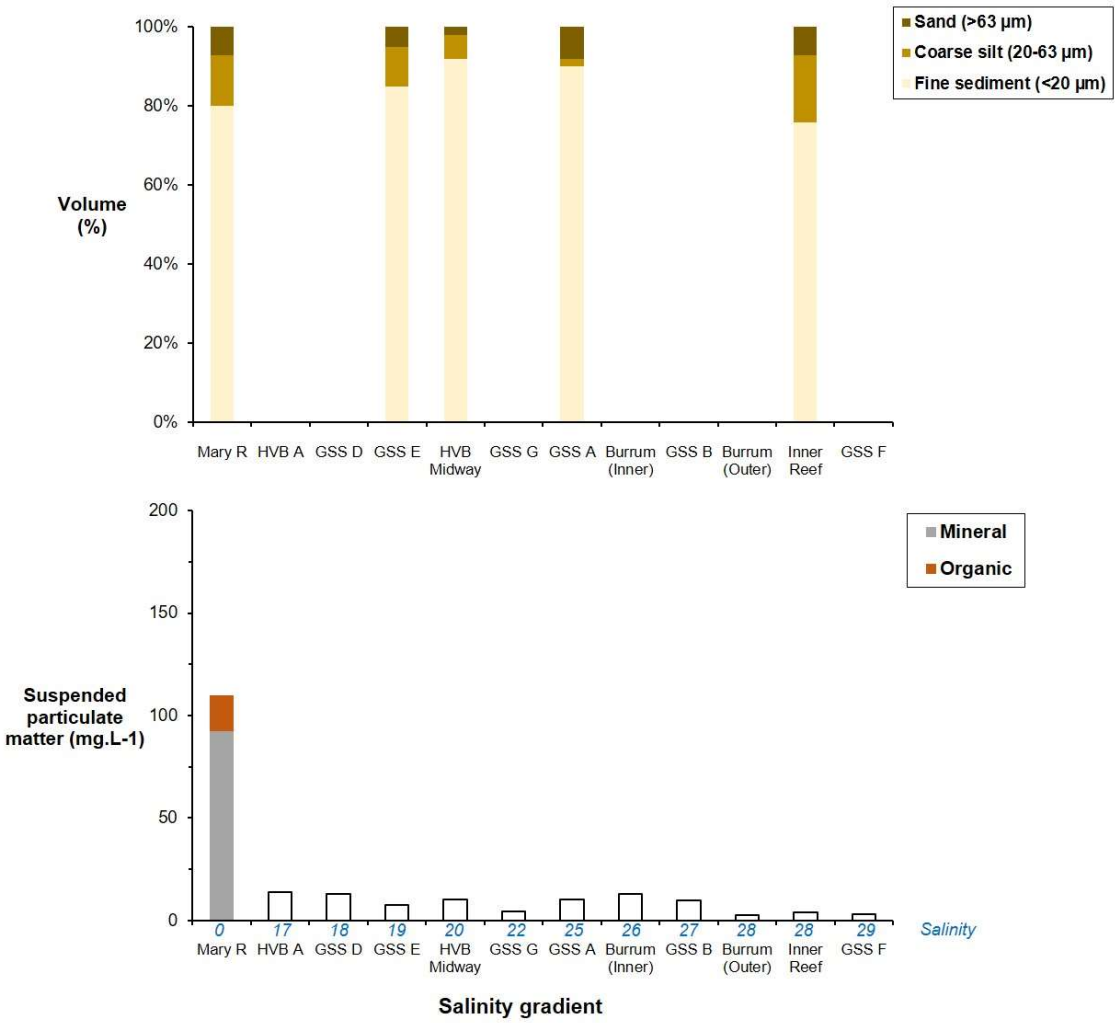

Figure 7. Suspended particulate matter concentrations (mg.L^{-1}) measured across the Great Sandy Strait and inner Hervey Bay in the January flood plume event (13/01/22). The Mary River (freshwater) EoC sample was collected on the 12th January.

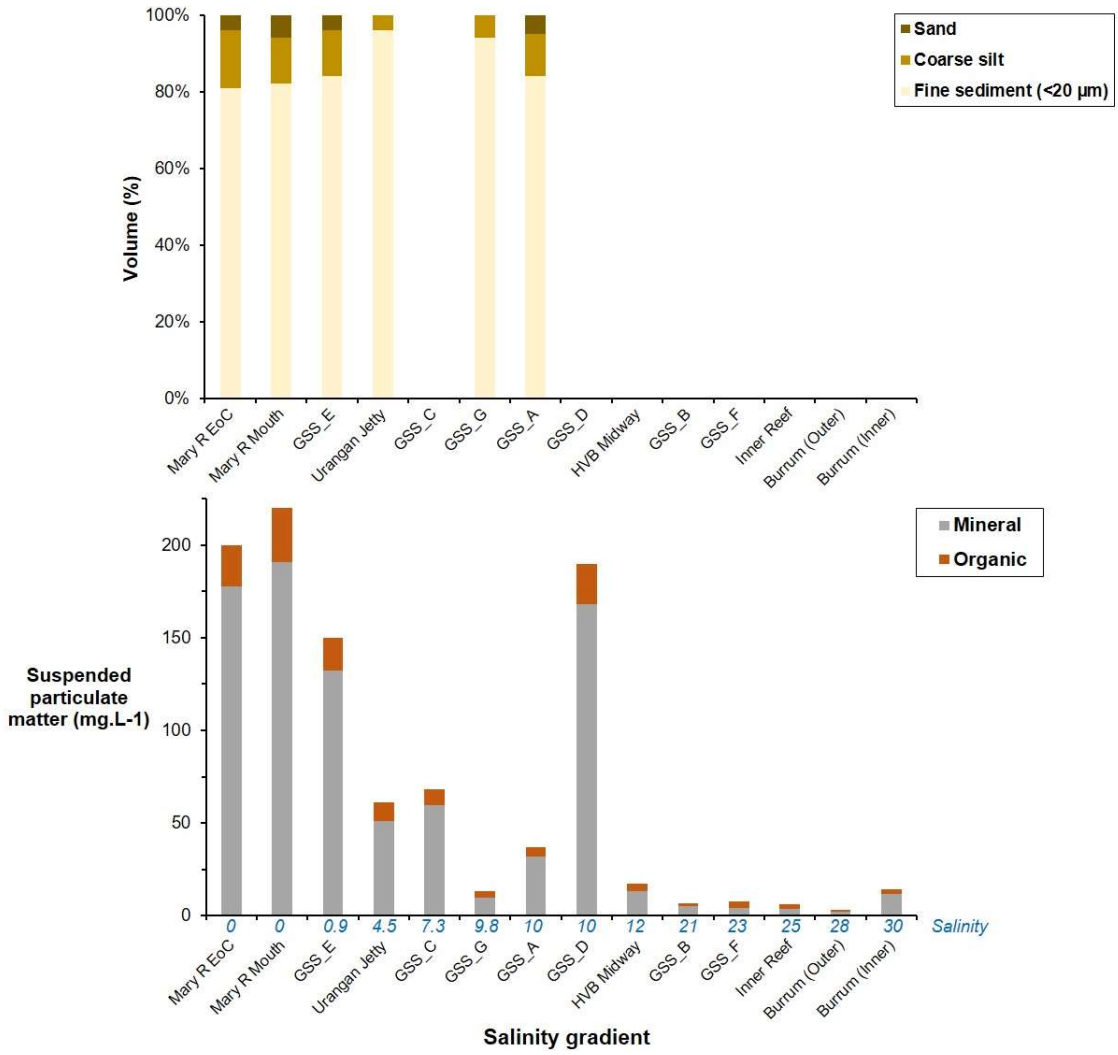

Figure 8. Suspended particulate matter concentrations (mg.L^{-1}) measured across the Great Sandy Strait and inner Hervey Bay in the March flood plume event (1-2/03/22). Freshwater samples collected along the Mary River EoC and at the mouth are also included.

Particle size – intertidal seagrass site sediment samples

The sequence of particle size analyses shown on the intertidal sample from the Urangan seagrass site highlight the intricate and subtle details of the sediment composition at this location (Figure 9). The first analysis on the 1.4 mm wet sieved salt-removed sample show it has a general unimodal pattern dominated (~ 93.5%) by sand size (>63 µm) particles with little (~ 0.5%) coarse silt (20 – 63 µm) and clay and file silt (~6% <20 µm). The organic and carbonate removed sample treated with H_2O_2 and HCl reveals a general shift towards the finer particles, although this treated sample continues to exhibit a unimodal pattern and is still dominated by sand (71%) with increased amounts of fine silt (10%) and clay and fine silt (19%). When the fine suspended sediment component of this treated sample is magnified by wet sieving through a 38 µm sieve, then this material exhibits a bimodal pattern with a sizable colloidal (<1 µm) fraction (13%) with a peak ~ 0.4 µm and a larger fraction peaking around 5 to 6 µm (Figure 9). Interestingly, the particle size distributions closely match when this <38 µm treated sample is plotted with the Mary River end of catchment and mouth samples (Figure 10).

The particle size analysis of the Burrum Heads intertidal sample show similar trends to the Urangan sample between the untreated and treated sample (Figure 11). However, there was much less fine sediment (<63 µm) in the Burrum Heads sample compared to the Urangan sample even with the organic and carbonate removed treatments (i.e. 6.5% compared to 29%). Due to the relatively low amounts of fine sediment in the Burrum Heads intertidal sample, not enough material could be recovered for the major and trace element geochemistry analysis.

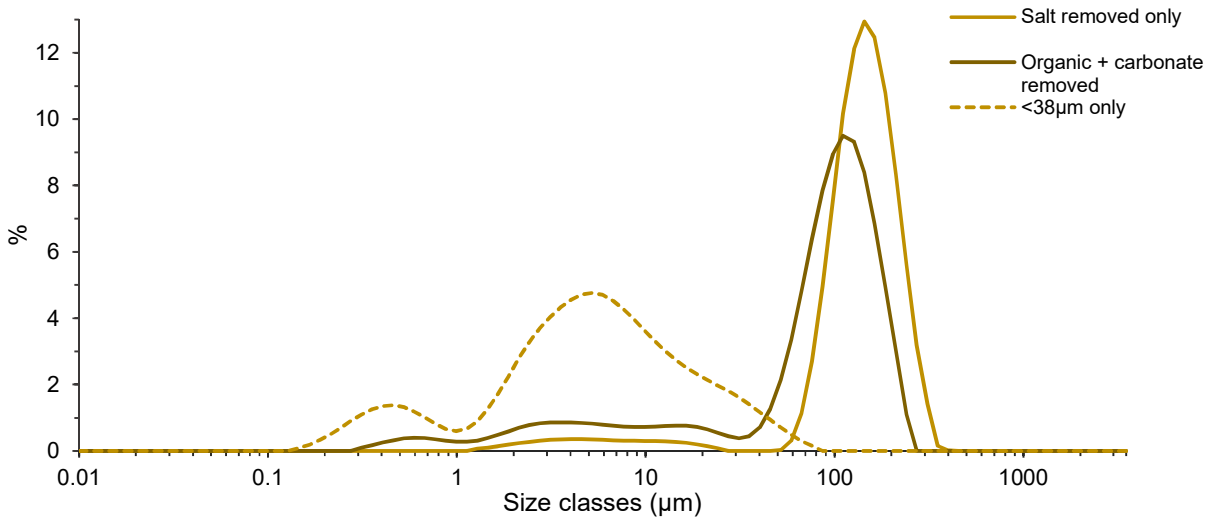

Figure 9. Grain size distribution of foreshore sediment collected at the Marine Monitoring Program's Urangan intertidal seagrass site, on 20th March. Grain size distributions represent the same sample, first treated to remove salts, treated to remove organic and carbonate components (i.e. shell fragments, plankton), and the <38µm component following sieving, to better highlight the bi-modal distribution peaking at 0.5 and 5 µm.

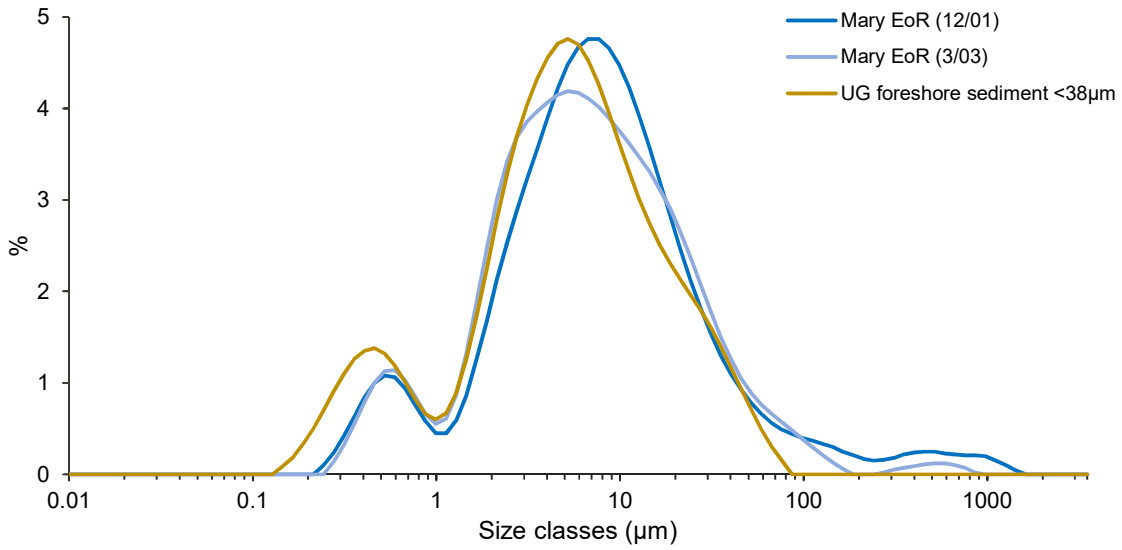

Figure 10. Grain size distribution of the Mary River (end of catchment) suspended sediment during January and March flooding events, and foreshore sediment collected from the Urangan intertidal seagrass site on the 20th March, immediately following the March river flood peak.

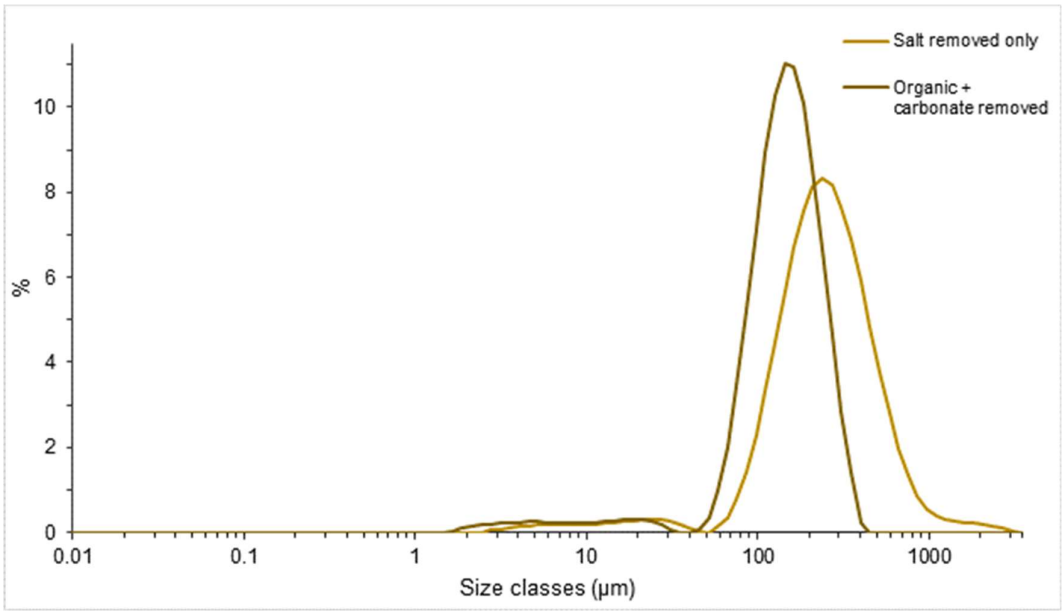

Figure 11. Grain size distribution of the foreshore sediment collected from the Marine Monitoring Program's Burrum Heads intertidal seagrass site on the 21st March, immediately following the March river flood peak.

Particle size – Hervey Bay benthic sediment samples

Due to the study focus on terrigenous sediment transport and in particular, tracing the potential extent of the Mary River source into Hervey Bay, only the finer component (<38 µm sieved fraction) of the benthic sediment samples were analysed for grain size, following organic and carbonate component removal. We note this component represents a relatively

small proportion (~ < 5%) of the total benthic grab sample collected, but this is the fraction that has an enhanced ability to reduce light through the water column when resuspended.

Similarly to the Urangan intertidal seagrass site, the benthic sediment samples collected close to the coastline (inshore samples, Figure 6) displayed a close match to the bimodal grain size distribution exhibited by the Mary River samples (Figure 12). The benthic sediment samples collected in the north-western part of Hervey Bay still contained the Mary River colloidal peak (0.5 µm) but had a less clear distribution around the clay and fine silt components (Figure 13).

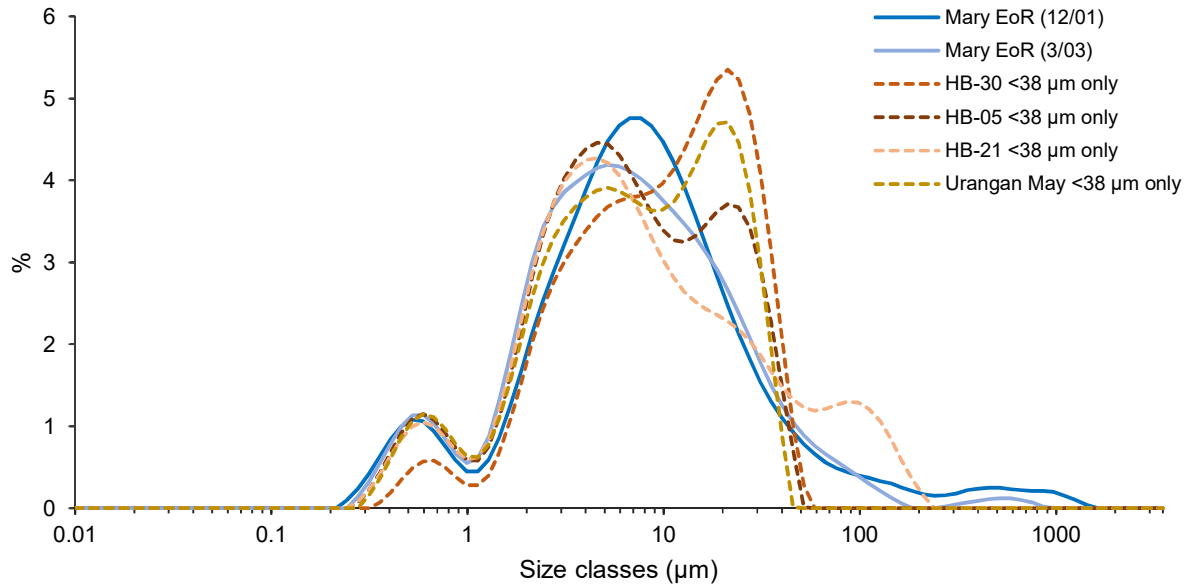

Figure 12. Grain size distribution for the benthic sediment samples (organic-carbonate removed and <38µm fraction only) collected at Hervey Bay inshore sites close to the coastline in May 2022, compared to the distributions from the Mary River (end of catchment) suspended sediment collected during January and March flooding events. Note, despite the coarser component (>40 µm), both the colloidal (0.5 µm) and fine silt/clay (~5 µm) peaks are evident in these benthic sediment samples.

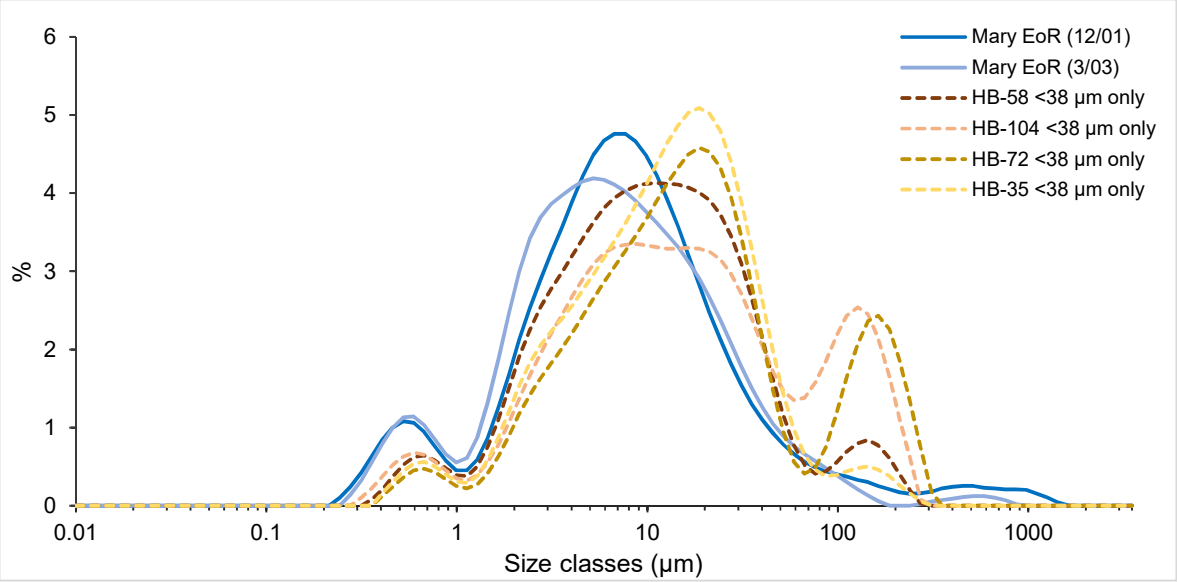

Figure 13. Grain size distribution for the benthic sediment samples (organic-carbonate removed and <38µm fraction only) collected at Hervey Bay north-west offshore sites in May 2022, compared to the distributions from the Mary River (end of catchment) suspended sediment collected during January and March flooding events. Note, despite the coarser components (>40 µm), the colloidal (0.5 µm) peak and some clay and fine silt fractions are evident in these benthic sediment samples.

Fallout radionuclides on Mary River samples

Here we compared activity concentrations of $^{210}Pb_{ex}$ and ^{137}Cs in suspended sediment samples collected from the Mary River (end of catchment) with hillslope surface soil and subsoil source samples from studies on the Burdekin Catchment to the North (Wilkinson et al., 2015) and similar source data from the Brisbane River catchment to the South (Olley et al., 2013); note in each case the surface soil and subsoil source sample concentrations of ^{137}Cs have been decay-corrected to 2022.

Activity concentrations of $^{210}Pb_{ex}$ and ^{137}Cs for the three samples collected from the Mary River were plotted along with Burdekin catchment hillslope surface soil and subsoil source samples from Wilkinson et al. (2015) in Figure 13. The vertical and horizontal dashed lines, respectively, indicate the range of ^{137}Cs and $^{210}Pb_{ex}$ activity concentrations in subsoil sources. The ^{137}Cs activity concentrations for the sediment samples are also reported in Table 1. The ^{137}Cs activity concentrations were consistent with the concentration range of the sub-surface source samples (<2.7 Bq kg^{-1}) at one standard error for all of the sediments samples (Figure 14).

Table 1. Measured concentrations of ^{137}Cs (Bq kg^{-1}) in the Mary River flood sediment including associated analytic uncertainties (one standard error on the mean), and the estimated percent contribution of surface soil to each sample using the Burdekin and Brisbane surface soil source data. The less than percentage contribution at one standard error on the mean are also presented.

Sediment sample	^{137}Cs		Surface soil contribution estimated from Burdekin source data (Wilkinson et al. 2015)			Surface soil contribution estimated from Brisbane source data (Olley et al. 2013)		
	Bq kg^{-1}	se	%	se	< than (at 82.5% confidence)	%	se	< than (at 82.5% confidence)
Mary R #1	0.07	0.98	-2	17	14	-29	18	0
Mary R #2	1.52	1.03	22	18	40	-5	19	14
Mary R #3	-0.27	0.99	-8	17	9	-35	18	0

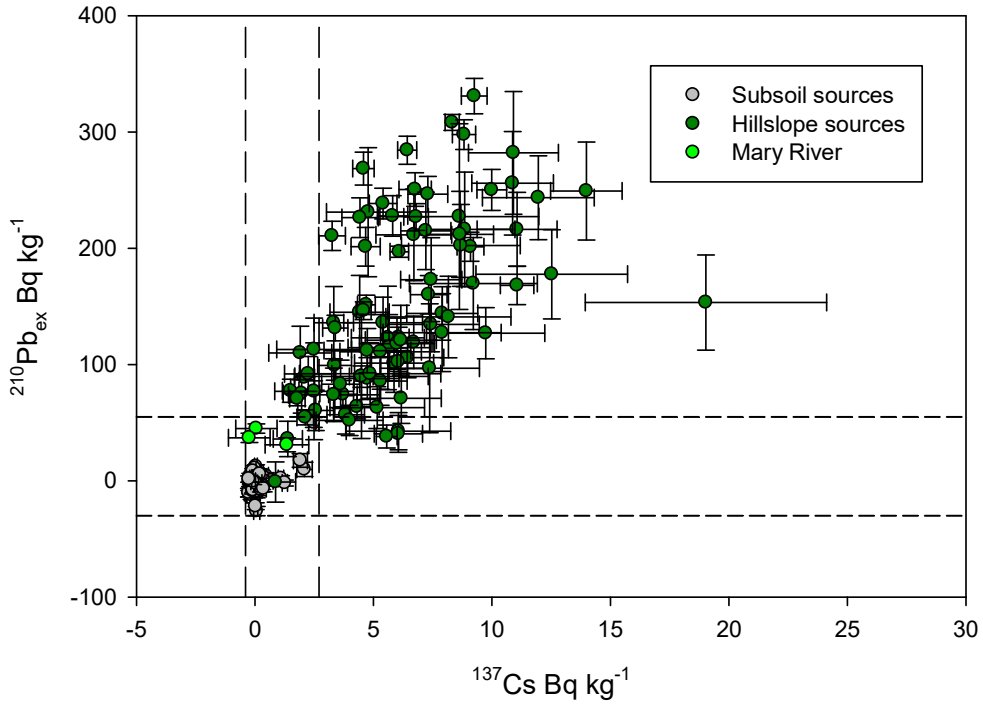

Figure 14. Activity concentrations of $^{210}Pb_{ex}$ and ^{137}Cs in Mary River suspended sediment samples together with the decay-corrected hillslope surface soil and subsoil source samples from Wilkinson et al. (2015) study in the Burdekin catchment. The vertical and horizontal dashed lines, respectively, indicate the range of ^{137}Cs and $^{210}Pb_{ex}$ activity concentration in subsoil sources. The error bars are equivalent to one standard error on the mean and are derived from the analytical uncertainties.

We have made the assumption that individual sediment samples represent a discrete mix of surface soil and sub-surface derived material such that the surface soil derived proportion is x, and 1-x the proportion derived from sub-soil erosion, with $0 \leq x \leq 1$. Such that

$$Ax + B(1-x) = C, \qquad \text{(Equation 1)}$$

where A is the ^{137}Cs activity concentration in the surface soil, B is that of the sub-surface sources and C is the resultant concentration. We have used the values of 6.1 ±0.6 Bq Kg^{-1}, and 0.2 ±0.1 Bq Kg^{-1} for A and B respectively (after Wilkinson el al. 2015) to estimate the proportion of surface soil contributing to each sample (Table 1). The weighted average contribution across all samples is 3 ± 9%. For each sample we have also calculated, using the reported uncertainties, the maximum surface soil contributions at the 82.5% confidence limit these range from 9 to 40%, with an average of 21%.

Similarly, the activity concentrations of ^{210}Pb$_{ex}$ and ^{137}Cs for the three samples collected from the Mary River were plotted along with Brisbane catchment hillslope surface soil and subsoil source samples from Olley et al. (2013) in Figure 15.

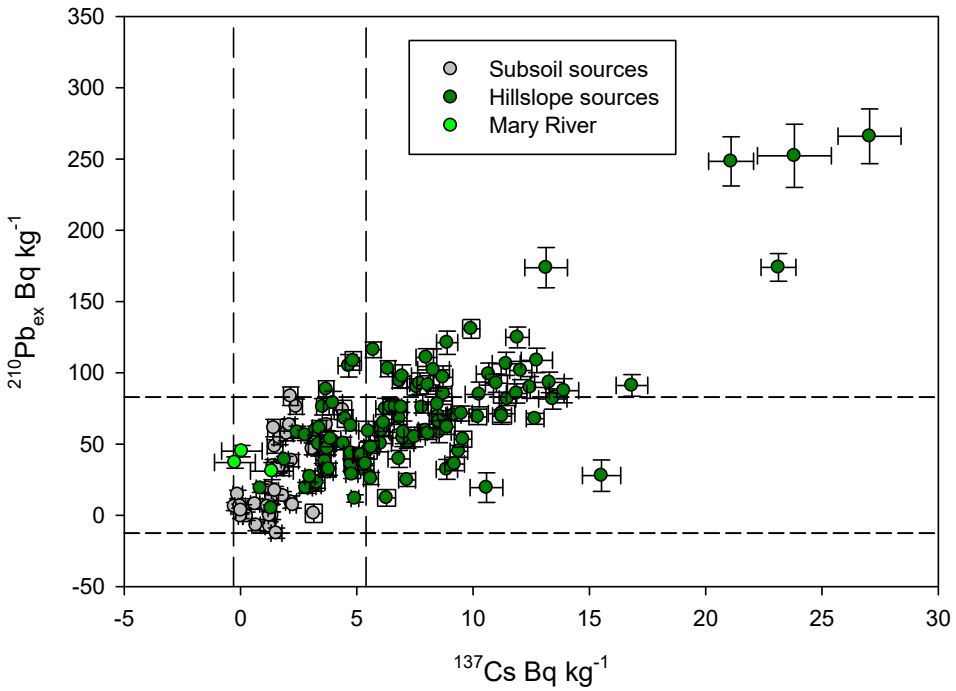

Figure 15. Activity concentrations of ^{210}Pb$_{ex}$ and ^{137}Cs in Mary River sediment samples together with the decay-corrected hillslope surface soil and subsoil source samples from Olley et al. (2013) study in the Brisbane River catchment. The vertical and horizontal dashed lines, respectively, indicate the range of ^{137}Cs and ^{210}Pb$_{ex}$ activity concentration in subsoil sources. The error bars are equivalent to one standard error on the mean and are derived from the analytical uncertainties.

Again the ^{137}Cs activity concentrations were consistent with the concentration range of the sub-surface source samples (<5.4 Bq kg^{-1}) at one standard error for all of the sediments samples (Figure 15). Note that the higher maximum value for ^{137}Cs in the subsoil from the Brisbane catchment is likely due to the smaller channels being sampled. We have again

used the average values for surface soils, this time for the Brisbane catchment 7.8 ±0.4 Bq Kg^{-1}, and subsoils 1.8 ±0.1 Bq Kg^{-1} for A and B respectively in equation 1 to estimate the proportion of surface soil contributing to each sample (Table 1). The weighted average contribution across all samples is -23 ± 10%, and <14% at 82.5% confidence. Hence, using either source data set to estimate the surface erosion contribution clearly indicates the dominance of subsoil sources.

Activity concentrations of $^{210}Pb_{ex}$ in the Mary River samples ranged from 45±4 to 31±6 Bq kg^{-1}. The maximum concentration in the subsoil samples was 55 Bq kg^{-1} for the Burdekin and 83 Bq Kg^{-1} with mean values of -1 and 26 Bq kg^{-1} $^{210}Pb_{ex}$, respectively. All of the Mary River samples exceeded the mean values for the subsoil sources. Given that the ^{137}Cs data indicate that the sediments were predominantly derived from subsoil sources, this additional $^{210}Pb_{ex}$ can have arisen in three possible ways:

i) the sediments were derived from areas such as scalds or gully floors, which have previously lost most of the material labelled with ^{137}Cs but have subsequently been exposed to $^{210}Pb_{ex}$ fallout.

ii) the sediments were derived from channel and gully walls that have been in transit within the catchment for a period of time long enough to accumulate the additional $^{210}Pb_{ex}$ (i.e. eroded and temporarily stored within a gully floor or exposed river bed prior to wet season runoff and remobilisation downstream).

iii) or a combination of both of the above.

Additional research within the Mary catchment is required to distinguish between these possibilities.

Major and trace element geochemistry

Due to the limited number of samples collected at the Mary River (end of catchment) site, the geochemical analysis and interpretation across the freshwater-marine interface was restricted and needs to be treated with caution. Additional geochemical sampling efforts should focus on the representative capture of the flood rising and peak stages in the freshwater/end of catchment site. Nevertheless the results provide some interesting initial observations and clearly highlight the influence of the Mary River sediment source within Hervey Bay. Despite the limited freshwater flood samples (n=3), the geochemical bi-plots reveal a potential river mixing and fractionation line for the Mary River freshwater and Urangan Pier intertidal sediment samples (Figure 16), with the Urangan sample most enriched in clay minerals (aluminium-rich) due to the preferential transport of the finer clay and colloidal sediment fractions within the estuarine zone.

The Hervey Bay benthic sediment sites separated into two tight clusters across Hervey Bay, one an “inshore” cluster hugging the coastline which experienced the turbid primary plume, and the second NE “offshore” cluster which only experienced secondary plume conditions (Figure 6). Samples in this offshore cluster have lower aluminum-clay contents, with the material dominated by marine carbonates (i.e. enriched in CaO and MgO) in this area of the bay (Figure 16). Interestingly, both Ba and Mn also plot on distinct mixing/fractionation lines with lower concentrations associated with increasing aluminum

oxide (Al_2O_3) contents along the Mary River mixing line and then even lower concentrations in the marine zone due to desorption from clay minerals (Ba) and UV oxidation (Mn) processes as well as by dilution with marine carbonates (Figure 16). In all cases, the Urangan intertidal sample sits as the “intersection” between the freshwater and marine samples.

For this pilot project the samples were only recovered to the <20 µm fraction, and there is an influence of the coarser minerals in the >10-20 µm component, with quartz and feldspar minerals diluting the clay fraction geochemical trace. To overcome this dilution issue, as well as desorption and oxidation processes that affect some elements in the estuarine mixing zones, the ratio of rare earth elements (REE) to thorium (Th) can be used as a stable trace for examining sources and sinks (Figure 17). Despite varying aluminum-clay content of the samples (as represented by Al_2O_3 along the x-axis), these ratios highlight that the inshore cluster sediments, and many of the offshore cluster sediments all fall within the bounds of the Mary River sediment ratio trace and hence strongly suggest a Mary River source within Hervey Bay.

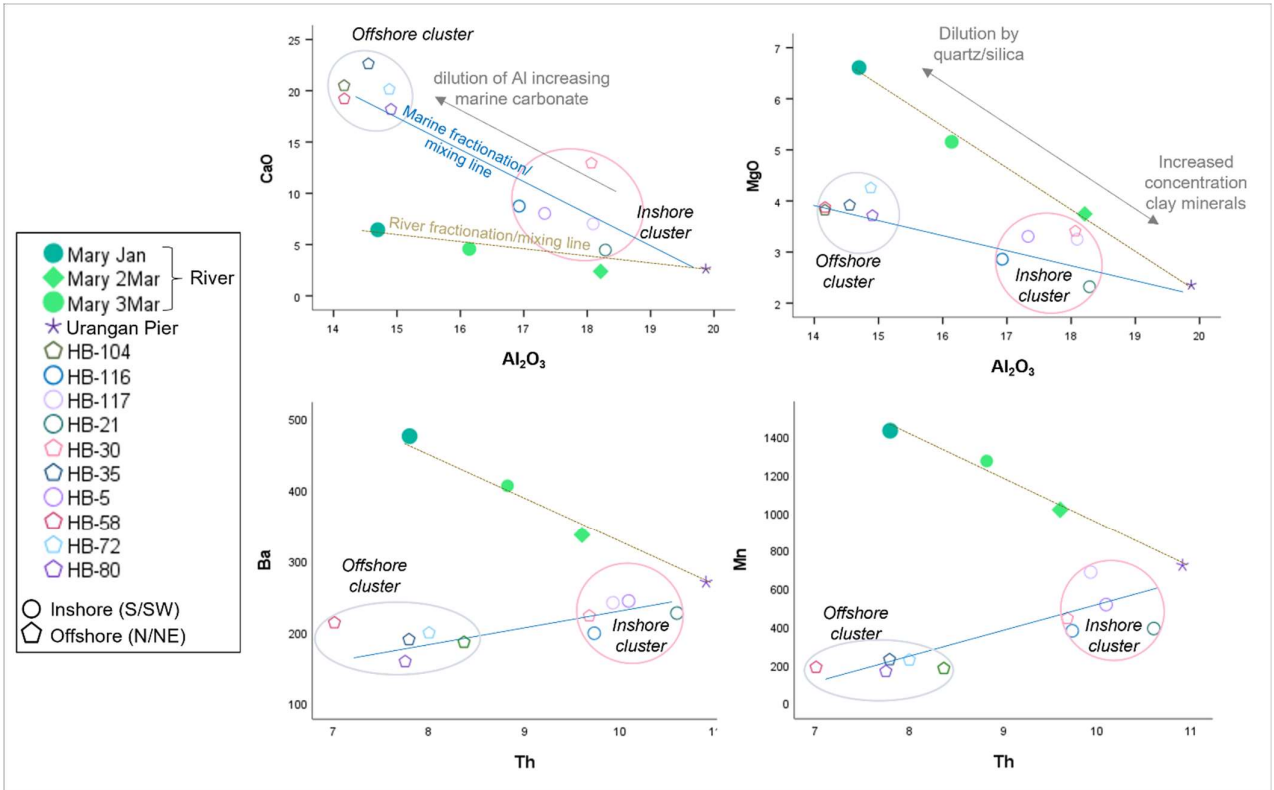

Figure 16. Selected major oxides (wt%) and trace element (mg/kg) bi-plots for the Mary River freshwater, Urangan Pier intertidal and Hervey Bay benthic sediment samples. The inshore and offshore sample clusters are identified, and the potential river and marine fractionation/mixing lines.

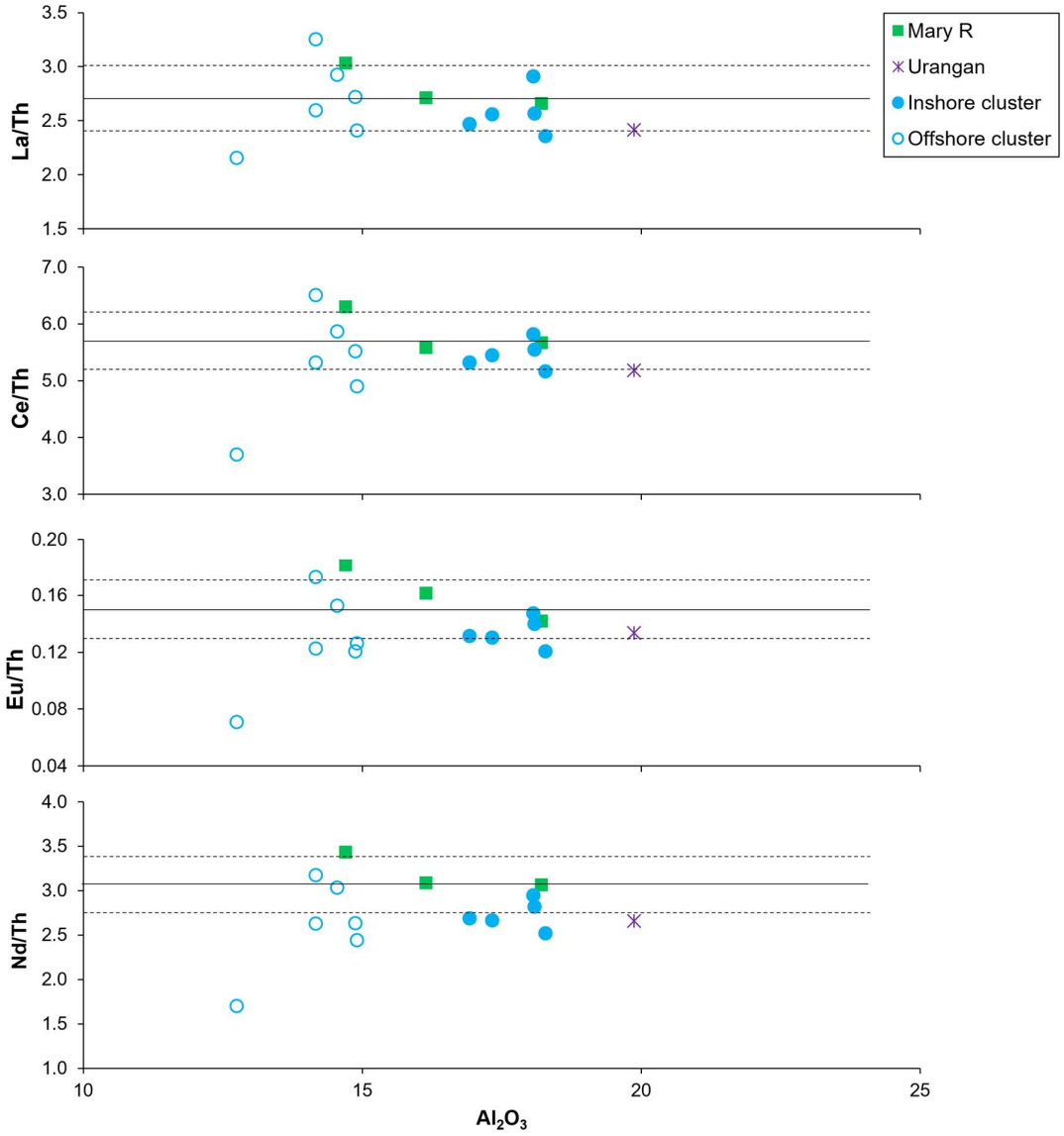

Figure 17. Plots of selected REE/Th ratios (La/Th, Ce/Th, Eu/Th and Nd/Th) vs Al_2O_3 (wt%). The solid and dashed lines represent the mean (±SD) of the Mary River freshwater and Urangan Pier intertidal samples.

4. Discussion and Conclusions

This study aimed to document the movement and dispersal of suspended sediment in flood plumes from the Mary River into the Great Sandy Strait and Hervey Bay and to characterise the suspended sediments in the Mary River and plume through particle size analysis, fallout radionuclide analysis (Mary River samples only) and major and trace element geochemistry. The particle size and geochemistry characterisation were then compared to benthic sediment samples taken throughout Hervey Bay to examine the potential extent of influence of the suspended sediment delivered from the Mary River on seagrass meadows.

The analysis of the composition of the Mary River suspended sediment samples show that the samples taken from both the major January and February-March events were dominated (~ 80%) by the <20 µm fraction. This fraction becomes further enriched in the flood plume SPM where the terrigenous coarse silt and sand fractions are likely almost completely removed by the ~ 10 PSU salinity zone. The coarser fractions measured in the higher salinity reaches likely reflect the growth of marine phytoplankton within the plume waters. Once the plume waters are funneled through the narrow Great Sandy Strait and out into Hervey Bay, the salinity greatly increases and the SPM concentrations generally fall below 15 $mg.L^{-1}$. However, these SPM concentrations (as low as 2.4 $mg.L^{-1}$) measured in the flood plume within Hervey Bay still result in greatly turbid waters and would completely block light reaching the seafloor (e.g. Figure 18). The dispersal of the Mary River plume SPM across the salinity zone is consistent with previous studies from other river plumes examined in the GBR lagoon (e.g. Devlin and Brodie, 2005; Bainbridge et al., 2012, 2021).

Importantly, the Mary River SPM particle size fingerprint appears to be embedded in the sample from the Urangan intertidal seagrass site. The treated sediment sample from Urangan represents the removal of the coarser carbonate fraction (i.e. mostly shell hash) as well as likely the disaggregation of the flocculated sediment to reveal the character of the finer sediment fraction. While this finer sediment fraction represents a much smaller component of the bulk sample, this material may be more easily resuspended and stay in suspension for longer periods, resulting in reduced light conditions for benthic autotrophs such as seagrass. Indeed, the bulk particle size analysis largely misses this important sediment fraction. A novel component of this study was the method development that highlighted that the <38 µm organic and carbonate removed sample provided the key tracing component for particle size analysis. We recommend this work be developed further for other rivers in the GBR.

The fallout radionuclide analysis of the Mary River suspended sediment samples consistently highlighted the dominance of sub-surface erosion sources (Figure 19). This finding supports modelling data from the Mary catchment (although suggests that subsurface may be much higher) and provides another line of evidence that subsurface erosion management should be prioritised (Figure 20). Hence our findings support the current remediation investments. However, additional study is required to help distinguish the most important subsurface erosion sources such as scalds, gully floors, gully walls and channel banks.

The major and trace element geochemistry of the <20 µm fraction of benthic sediment samples support the particle size data that the Mary River exerts a considerable influence within the terrigenous sediments within Hervey Bay. While the benthic sediments from the

offshore areas of Hervey Bay (Figure 19) were relatively diluted with marine carbonates, the geochemical signature of the terrigenous fine (<20 µm) sediments were consistent with the suspended sediments exported from the Mary River. We encourage future tracing work to be conducted within the Mary River catchment to determine key sediment sources for management prioritisation as well as to confirm the consistent sediment source at the end of catchment.

Overall, our study highlights that the fine (< 20 µm) terrigenous sediment fraction exported from the Mary River is embedded within the seafloor sediments of Hervey Bay (Figure 19). In particular, newly delivered fine terrigenous sediment delivered from the Mary River is likely to be highly prone to resuspension in the marine environment for several months following export and hence likely to reduce light availability to seagrass meadows within Hervey Bay (Figure 19). Targeted monitoring of benthic light within Hervey Bay would provide an important test of this hypothesis. Indeed very low seagrass density and aerial extent were observed following the extreme flow events in 2022 (York et al. 2022) and aerial surveys of dugongs conducted in the post 2022 flood plume documented the lowest numbers recorded in this region (Cleguer et al. 2023). These findings highlight the vital importance of better understanding the link between seagrass health and delivery (and sources) of suspended sediments from the adjacent catchment so that on-ground management can be better targeted.

Figure 18. The turbid Mary River flood plume (1st March 2022) during the February-March event (photo taken by DES staff from the Midway GSS sampling point looking south to the Urangan Jetty).

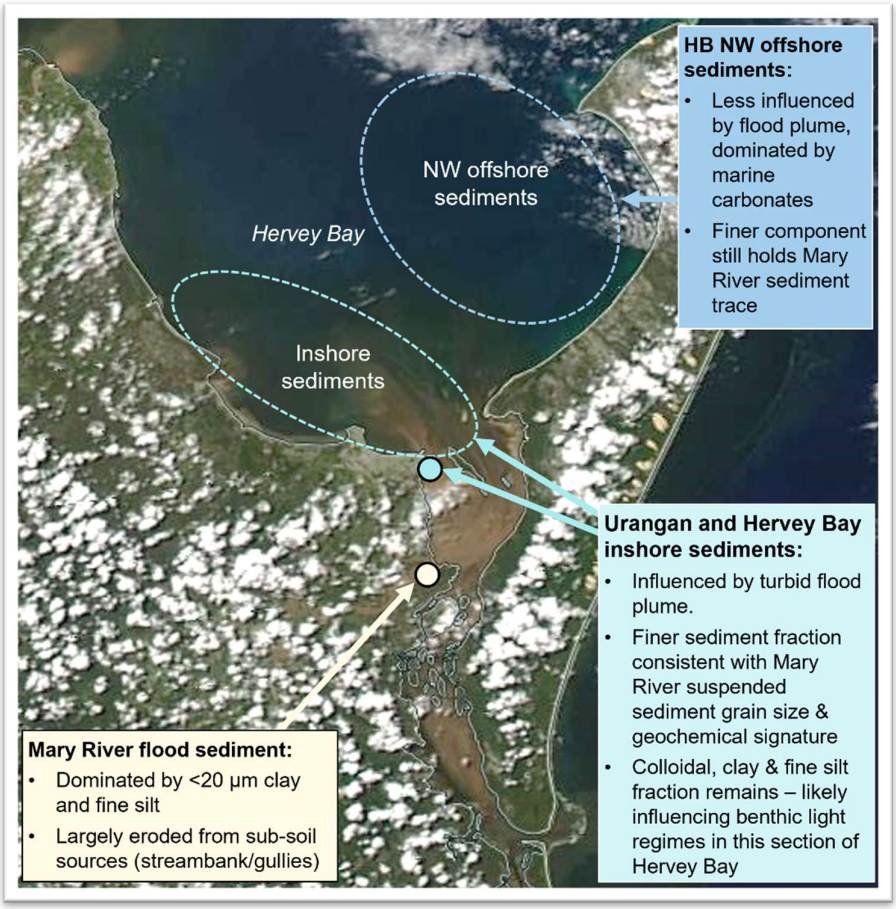

Figure 19. Conceptual summary of Mary River flood sediment characteristics and influence within Hervey Bay.

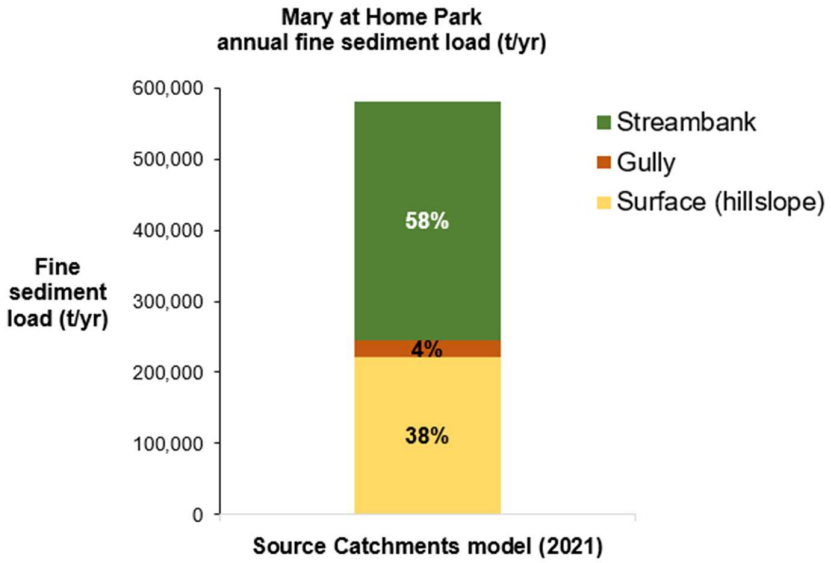

Figure 20. Mary River at Home Park average annual fine sediment load and associated erosion source contributions, as modelled by the Paddock to Reef Program's Source Catchments model (McCloskey et al. 2021).

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