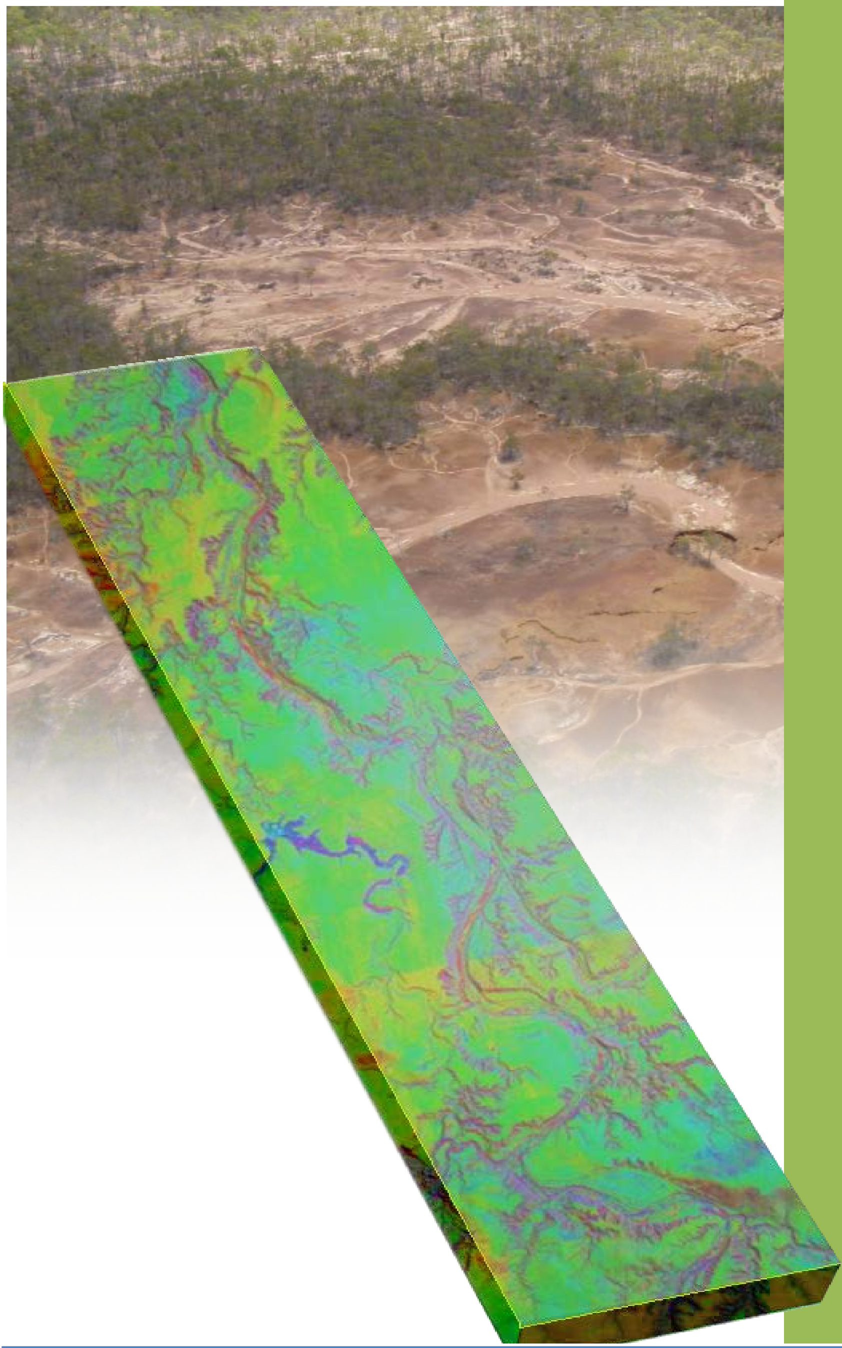

An Empirically-based Sediment Budget for the Normanby Basin

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Appendix 08: Catchment Tracing

Griffith UNIVERSITY

CARING FOR OUR COUNTRY

Appendix to the Final Report prepared for the Australian Government's Caring for our Country - **Reef Rescue initiative**

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Appendix 08: Catchment Tracing

The dominant erosion process supplying sediment to rivers draining into Princess Charlotte Bay, Australia

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DRAFT FOR PUBLICATION

Abstract

The Laura-Normanby River (24,350 km^2) which drains into Princess Charlotte Bay has been identified using catchment scale modelling as the third largest contributor of sediment to the Great Barrier Reef World Heritage Area. These previous studies identified surface soil erosion as supplying ~90% of the sediment. This was largely based on the assumptions that the open woodland vegetation that dominates the catchments, coupled with the intense tropical rainfall and seasonal burning regimes, would result in high hillslope sediment yields and that gully erosion in these tropical landscapes was limited because the channel networks were at their fullest extent. Here we use activity concentrations of the fallout radionuclides ^{137}Cs and $^{210}Pb_{ex}$ to test the hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay. River sediment samples were collected using both time integrated samplers and sediment drape deposits. We show that there is no detectable difference in ^{137}Cs and $^{210}Pb_{ex}$ activity concentrations between samples collected using these two methods. Two methods were also used to collect samples to characterise ^{137}Cs and $^{210}Pb_{ex}$ concentrations in sediment derived from surface soil erosion; sampling of surface lag deposits after a major rain-events and surface runoff traps which collected samples during rain events. While there was no difference in the ^{137}Cs activity concentrations on samples collected using these two methods, $^{210}Pb_{ex}$ activity concentrations were significantly higher in the samples collected using the runoff traps. The higher $^{210}Pb_{ex}$ concentrations are shown to be correlated with loss-on-ignition (r^2=0.79) and therefore are likely to related to higher organic concentrations in the runoff trap samples. As a result of these differences we use a three end member mixing model (channel/gully, hillslope surface lag and hillslope runoff traps) to determine the relative contribution from surface soil erosion. Probability distributions for ^{137}Cs and $^{210}Pb_{ex}$ concentrations were determined for each of the end members these were then used to estimate the surface soil contribution to each of the river sediment sample collected.

The mean estimate of contribution of surface derived sediment for all of the river samples (n=70) is 16 ± 2%. For samples collected along the main channel of the Normanby – Laura River system (n = 27) this is 13 ± 3%. Our results are consistent with channel and gully erosion being the dominant source of sediment and the hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay is rejected. This study reinforces the importance of testing model predictions before they are used to target investment in remedial action and adds to the body of evidence that the primary source of sediment delivered to tropical river systems is derived from sub-soil erosion.

1. Introduction

The Great Barrier Reef World Heritage Area (GBRWHA) extends along the Queensland coast for 2000 km. The coast adjoining the GBRWHA has a diverse range of wet and dry tropical catchments, covering an area of 423,000 km^2. Catchments draining the eastern portion of Cape York contribute continental runoff to a ~750 km stretch of the northern section of the GBRWHA. Coral reefs in this section of the marine park are closer to the coast than in the southern portion and are therefore potentially more vulnerable to terrestrial derived pollutants. The Laura-Normanby River (24,350 km^2) which drains into Princess Charlotte Bay (Figure 1) in this region has been identified using catchment scale modelling as the third largest contributor of sediment to the GBRWHA (e.g. Prosser et al., 2001; Brodie et al., 2003) and as such is a priority for erosion mitigation measures (Brodie et al., 2003). These previous studies identified surface soil erosion as supplying around 90% of the sediment. As erosion mitigation measures differ depending on the erosion process being treated it is important to correctly identify the dominant source of erosion before attempting local or catchment-wide management to control it. In this study we use activity concentrations of fallout radionuclides ^{137}Cs and $^{210}Pb_{ex}$ to test the hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay; in particular the Laura-Normanby River system and the smaller Stewart River (2500 km^2).

The fallout radionuclides ^{137}Cs and $^{210}Pb_{ex}$ have been widely used to determine the relative contribution of surface and channel erosion to stream sediments (Walling and Woodward, 1992; Olley et al., 1993; Wallbrink et al., 1993, 1998; Whiting et al., 2005; Matisoff et al., 2002; Everett et al., 2008; Caitcheon et al., 2012; Olley et al., 2012). ^{137}Cs is a product of atmospheric nuclear weapons testing that occurred during the 1950-70s. Initially the distribution of this nuclide in the soil decreased exponentially with depth, with the maximum concentration at the surface. However, due to processes of diffusion the maximum concentration is now generally found just below the surface in undisturbed soils. The bulk of the activity of this nuclide is retained within the top 100 mm of the soil profile. In subsoils recently exposed by erosion ^{137}Cs is virtually absent (Wallbrink and Murray 1993).

Fallout $^{210}Pb_{ex}$ is a naturally occurring radionuclide, formed through the radioactive decay of ^{222}Rn gas. The parent of ^{222}Rn is ^{226}Ra, part of the ^{238}U decay series. These radionuclides are present in all soils. Some ^{222}Rn gas escapes from the soil into the atmosphere where it decays to ^{210}Pb. This ^{210}Pb is then deposited on the soil surface, primarily by rain. The maximum concentrations of fallout $^{210}Pb_{ex}$ (known as 'unsupported' or 'excess') in soils are found at the surface. Concentrations then generally decrease over depth to detection limits at about 100 mm depth.

As fallout radionuclides are concentrated in the surface soil, sediments derived from sheet and rill erosion will have high concentrations of both radionulcides, while sediment eroded from gullies or channels have little or no fallout nuclides present. By measuring the concentration in suspended sediments moving down the river, and comparing them with concentrations in sediments produced by the different erosion processes, the relative contributions of each process can be determined.

As part of this study we have used two methods to characterise ^{137}Cs and $^{210}Pb_{ex}$ concentrations in sediment derived from surface soil erosion i) sampling of surface lag deposits after a major rain-events (eg. Caitcheon et al., 2012) and surface runoff traps which collected samples during rain events. We also use two sampling techniques to determine the ^{137}Cs concentrations in river sediments i) time-integrated samplers (Phillips et al., 2000) and ii) sediment drape deposits. We first compare these sampling techniques and then we then use activity concentrations of the fallout radionuclides to estimate relative contribution of surface soil erosion to the river systems draining into Princess Charlotte Bay. We focus on the <10 μm fraction which has been recently shown, during flood plume sampling on the Burdekin River which drains into the Great Barrier Reef Lagoon to the south, to be the size fraction being transported into the Lagoon (Bainbridge pers comm.).

2. The Study area

The Laura-Normanby Catchment area covers approximately 24,350 km^{2}and lies between Latitude 14° 15' to the north and 16° 15' in the south, and Longitude 143° 45' and 145° 20'; the Steward River 2500km^2 is located just to the north (Figure 1). The catchments are located in the dry tropics where climate is characterised by extreme rainy (summer) and dry (winter) seasons with 95% of its annual rainfall occurring between the months of November and April. Mean annual rainfall varies from 800 mm to 1600mm across the catchments with higher rainfall occurring in the mountains along the eastern and southern borders of the catchment. Mean maximum monthly temperatures in the region range from approximately 29°C in June to 36°C in November. Mean minimum monthly temperatures ranging from approximately 17°C in August to 24°C in February.

The Laura and Normanby Rivers originate in the mountains in the east and south of the catchment area and flow to the north, discharging into the Coral Sea at Princess Charlotte Bay. Major tributaries include the East and West Normanby Rivers and the Jack River to the southeast and east, and the Hahn and Kennedy Rivers in the south and southwest (Figure

1). The majority of the catchment area is of relatively low relief with a gentle slope towards Princess Charlotte Bay. Topography in the upland areas ranges from undulating rises to steep mountain ranges, with deeply dissected sandstone plateaus and intervening plains. Mean Annual Run-off between 1986 – 2009 is estimated from this study at 4,600 GL/year (± 3400 GL – 1 stdev).

The resident population for the entire catchment area is believed to be less than 500. Outside of the conservation areas, grazing is the most extensive land use in the catchment. Cattle properties tend to be large, with low cattle density compared to other regions. Cattle tend to roam freely across the catchment. Mining is not currently a major industry in the Laura-Normanby Catchment. Most of the mines recorded with the Department of Natural Resources and Mines are abandoned gold mines. There are several small active gold mines that have been operating in the upper reaches of the Normanby and Laura Rivers for the last 15-20 years.

3. **Methods**

3.1 Sediment and source characterisation

River sediment samples: Two groups of samples were collected to characterise the fallout radionuclide concentrations in the fine (<10μm river sediments):

(i) Time-integrated samplers (Phillips et al., 2000) were used to collect samples of suspended sediment during flow events in each of the sub-catchments. These samplers have been widely adopted in sediment tracing research (Collins et al., 2010; Walling et al., 2008;Hatfield and Maher, 2008). The samplers effectively trap a representative sample of sediment with an effective particle size of <63μm (Phillips et al., 2000); sampling through the hydrograph including the rising and falling limbs. The samplers were deployed ~0.5 metre above the low water level for the entire wet season and collected at the beginning of the dry season. At most locations of the twenty one locations (Figure 1) two samples were collected over two wet seasons.

(ii) Draped sediment deposits - fine sediment that appeared to have been recently deposited (e.g. mud drapes on channel-bed sand) was sampled at each of the time-integrated sampling sites when the integrated samplers" were retrieved. Drape sediment deposits have been widely used in Australia to characterise river sediment in regions in which it is difficult to sample during high flow conditions due to poor access and remoteness (eg. Olley and Caitcheon 2000; Wallbrink, 1994; Caitcheon et al., 2012; Wilkinson et al., 2012).

Hillslope sediment samples: To characterise the fallout radionuclide concentrations in the surface-soils two groups of surface soil samples were collected i) surface lag deposits collected after major rain-events and ii) sediments collected using surface runoff traps. Lag deposits have been widely used in Australia to characterise sediment derived from hillslopes (see for examples Wallbrink, 2004; Caitcheon et al., 2012; Olley et al., 2012). In this approach surface soils eroded from hillslopes are collected from along drainage lines in small drainage basins where there was no defined channel and no evidence of sub-soil erosion. This alluvium sampling strategy is aimed at collecting material that is, or has recently been, in-transit and therefore more likely to be transported to streams than in-situ hillslope soil. The assumption being that these lag deposits will have the same radionuclide concentrations as the material that is transported to the stream line. For comparison we collected samples of sediment in transit during rain events using hillslope runoff traps. These traps consist of a v shaped earth dam lined with plastic sheeting which directed flow into a collection tube. Care was taken during construction to ensure that there was no soil disturbance upstream of the collection point. In total 65 samples were collected to characterise the hillslope sources (sampling sites are shown in Figure 1); 22 of these were paired hillslope lag and hillslope sediment trap samples.

Channel/gully erosion: To characterise the fallout radionuclide concentrations in the channel/gully erosion end member (80) samples were collected from channel banks and inchannel benches at 14 location. The channel bank and gully samples sampled had concentrations which ranged from −0.3 ± 0.2 to 1.6 ± 0.1 Bq kg^{-1} for ^{137}Cs and −26 ± 4 to 12 ± 2 Bq kg^{-1} for ^{210}Pb. These concentrations are comparable to data from other Australian tropical and sub-tropical systems (Table 1) and the Mitchell catchment is the closest of these to the rivers draining into Princess Charlotte Bay.

Table 1: Activity concentrations for ^{137}Cs and $^{210}Pb_{ex}$ in sediment samples collected to characterise channel and gully erosion in Australian tropical and sub-tropical systems. Numbers in the brackets are equivalent to one standard deviation on the mean.

	^{137}Cs Bq kg^{-1}	^{210}Pb Bq kg^{-1}	Publication
Bowen and Broken Rivers	Mean 0.15 ± 0.13	Mean -3.4 ± 3.4	Wilkinson et al., 2012
Keelbottom and Thornton Creeks	Mean 0.27 ± 0.12	Mean 6.6 ± 0.41	Wilkinson et al., 2012
Herbert River	0.0 ± 0.3 to 4.5 ± 0.8 Mean 2.4 ± 0.3		Bartley et al., 2004
Johnson River	Mean 0.8 ± 0.1		Bartley et al., 2004
Theresa Creek	Mean 0.0 ± 0.4	Mean −6.9 ± 5.0	Hughes et al., 2009
Mitchell River	−0.2 ± 0.2 to 2.3 ± 0.4 Mean 0.9 (0.8)	−10 ± 4 to 89 ± 8 Mean 15 (25)	Caitcheon et al., 2012
Daly River	0.9 ± 0.2 to 3.4 ± 0.2	−25 ± 8 to 46 ± 10	Caitcheon et al., 2012

	Mean 2.1 (0.8)	Mean 3 (22)	
SE Queensland	-0.3 to 7.2 Mean 2.4 (1.8)	-12.5 to 83.5 Mean 26.8 (26.2)	Olley et al., 2012

3.2 *Sample Treatment and Measurement*

Upon deposition onto the soil surface fallout ^{137}Cs and $^{210}Pb_{ex}$ bind strongly to soil particles, mostly in the upper 10-15 cm of soil profiles. Since these radionuclides bind preferentially to fine-grained particles it is necessary to fractionate soils and sediment to minimise variations in concentrations due to differences in particle size distributions within samples (Walling, 2005; Wallbrink et al., 1999). In this study we only analysed the clay and fine silt fraction (<10μm) of soils and sediments to minimize particle size effects. We also corrected for variations in organic matter and interstitial water content by using "mineral" concentrations determined from loss-on-ignition measurements. Analysis of the samples for gamma radionuclides was undertaken at the CSIRO radionuclide laboratory. All samples were individually slurried with water and settled to the point where the fine fraction, less than 10μm, was decanted, dried and pressed into sealed perspex containers for radionuclide analysis following the procedures described in Leslie (2009).

3.3 Data analysis

To compare the two river sediment sampling methods we tested for a difference in the fallout radionuclide activity concentrations between samples collected using the integrated time integrated samplers and drape grab samples at each site using a "paired t test". First difference between the samples at each location and it uncertainty was calculated ($X_{Di} \pm x_{Di}$) where X_{Di} is the difference at site *i* and x_{Di} its uncertainty. Then the weight average difference in activity concentrations for the drape and integrated samples ($\overline{X_D}$) was calculated such that:

$$\overline{X_D} = \frac{\sum x_{Di} X_{Di}}{\sum x_{Di}} \qquad \text{(Equation 1)}$$

The associated weighted standard deviation was calculated as follows:

$$\overline{\sigma_D} = \sqrt{\frac{\sum x_{Di}\left(X_{Di} - \overline{X_D}\right)^2}{\frac{M-1}{M}\sum x_{Di}}} \qquad \text{(Equation 2)}$$

Where M is the number of none zero weights. The t test statistic was then calculated as:

$$T = \frac{\sqrt{n}\,\overline{X}_D}{\overline{\sigma_D}} \qquad \text{(Equation 3)}$$

The same approach was used to compare the hillslope lag deposits and hillslope sediment trap samples.

To determine the distributions of the fallout radionuclide activity concentrations in the surface-soil and channel end members we followed a similar procedure to Caitcheon et al., (2012) and Olley et al., (2012). The data related to the surface soil and channel samples were used to derive probability distributions (incorrectly referred to as probability density functions in Caitcheon et al., (2012)) describing their distributions. The probability distributions were created for each sample using the following:

$$P(a \le X \le b) = \frac{1}{n}\sum_{j=1}^{n}\int_{a}^{b}\frac{1}{\sqrt{2\pi\sigma_j^2}}\, e^{-\frac{(x_j-\mu_j)^2}{2\sigma_j^2}}\, dx \qquad \text{(Equation 4)}$$

Probabilities were summed using bin width (*b–a*) of 0.03 Bq kg^{-1} for ^{137}Cs and 1.0 Bq kg^{-1} for $^{210}Pb_{ex}$; *a* and *b* are the lower and upper limits of the individual bins; μ_j is the jth individual sample activity concentration and σ_j its uncertainty. The bins covered the full range of measured values. Total probability for each distribution summed to one. Unlike in the two previous studies which used this approach (Caitcheon et al., 2012; Olley et al., 2012) where the resultant summed probability plots were then fitted using standard probability functions (e.g. Lorentzian; Gaussian) we used the summed probability distributions as determined in our mixing model.

The modelled surface soil (hillslope lag *A* and hillslope sediment trap *B*) and channel distributions (*C*) were used in a three component mixing model such that:

$$A_{Cs}x + B_{Cs}y + C_{Cs}z = D_{Cs},$$

$$A_{Pb}x + B_{Pb}y + C_{Pb}z = D_{Pb},$$

$$x + y + z = 1 \qquad \text{(Equations 5)}$$

where D is the resultant distribution (D_{Cs} for ^{137}Cs and D_{Pb} for $^{210}Pb_{ex}$); x, y and z are modelled as truncated normal distributions such that they are greater than zero and less than 1. For each of the river samples the proportional contribution from each of the components was estimated by simultaneously minimising mixing model difference (MMD):

$$MMD = \left|\frac{D_{Cs}-M_{Cs}}{M_{Cs}}\right| + \left|\frac{D_{Pb}-M_{Pb}}{M_{Pb}}\right| \qquad \text{(Equation 6)}$$

where *M* is the probability distribution for each river sample determined as above from the measured value and its associated uncertainty. We also ran the mixing model using two components; channel/gully and hillslope sediment trap distributions, and channel/gully and hillslope lag distributions by setting either x and y to zero.

4. Results

4.1 Reproducibility of sampling

The weighted differences in the ^{137}Cs activity concentrations between the drape and integrated samples are shown in Figure 2a. There is no systematic trend in the calculated differences with the weighted mean concentrations. The ^{137}Cs weight mean difference (solid line) and weighted standard deviation (dashed lines) are 0.5 Bq kg^{-1} and 1.2 Bq kg^{-1} respectively; consistent with zero at 1σ. Similarly there is no systematic trend in the calculated differences with the weighted mean concentrations for $^{210}Pb_{ex}$ (Figure 2b). The weight mean difference (solid line) and weighted standard deviation (dashed lines) are -3.5 Bq kg^{-1} and 28.4 Bq kg^{-1} respectively; again consistent with zero at 1σ. The t statistics for the difference in concentrations for the ^{137}Cs and $^{210}Pb_{ex}$ where 2.0 and 0.6 respectively with 21 degrees of freedom, from this we can conclude that there is no detectable difference in the activity concentrations for both ^{137}Cs and $^{210}Pb_{ex}$ between the river sampling methods at the p=0.95.

There is also no systematic in the ^{137}Cs concentration in the hillslope samples collected either as lag deposits or using the hillslope sediment traps (Figure 3a). Though there is greater spread in the data; the ^{137}Cs weight mean difference and weighted standard deviation are -0.6 Bq kg^{-1} and 8.7 Bq kg^{-1} respectively; again consistent with zero at 1σ (T=0.34). In contrast there is a marked difference between $^{210}Pb_{ex}$ activity concentrations on the samples collected as lag deposits compared to the hillslope sediment trap samples (Figure 3b); with concentrations being significantly higher on the sediment trap samples (T=6.52).

Concentration of $^{210}Pb_{ex}$ are correlated (Figure 4; r^2=0.79) with Loss-on-ignition (LOI) in these samples. ^{210}Pb is known to have a higher affinity for organic matter than ^{137}Cs (reference) and we consider that the difference between the two groups of samples is primarily due to a higher proportion of organic matter (measure by LOI) in the sediment trap samples.

4.2 ^{137}Cs concentrations in the river sediment samples

Activity concentrations of ^{137}Cs and $^{210}Pb_{ex}$ in river samples tend to be lower than those on the hillslope surface lag deposits or hillslope sediment traps samples (Figure 5). The activity concentrations of ^{137}Cs and $^{210}Pb_{ex}$ are only weakly correlated in the hillslope sediment trap (r^2=0.22) and the hillslope lag deposits (r^2=0.19) samples. The lack of a strong correlation between ^{210}Pb and ^{137}Cs in the source samples means that they can be used independently or in combination to estimate the relative contribution of the sources to the river sediments; we have used both the ^{137}Cs and $^{210}Pb_{ex}$ data to estimate the relative contribution of surface-soil to the sediment samples collected from along the rivers draining into Princess Charlotte Bay.

4.3 Probability distributions and the mixing model

The ^{137}Cs and $^{210}Pb_{ex}$ concentration data from samples collected from rivers are shown in Figure 6 (a and b) together with their respective end member probability distribution plots. Because of the significant difference in the hillslope lag and hillslope sediment traps sample $^{210}Pb_{ex}$ concentrations we did not combine these data sets to characterize the concentration probability distributions from surface soils. Instead we treated these as distinct end members and the mixing model was run in three ways. First using all three end members distributions (channel/gully, hillslope lag, and hillslope runoff trap) and then with the contribution from either the hillslope lag or hillslope sediment trap distributions set to zero. Figure 7 show a comparison between the results from each of the two component mixing models and the three component mix model. In each case the two component mixing models either provide a comparable or lower estimate of the surface soil contribution. Consequently, to ensure a rigorous test of the hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay we have used the three component model, which gives the higher surface soil contributions.

4.4 Relative surface soil contributions

The average relative surface soil contributions from samples collected from each of the river sampling sites are shown as pie charts in Figure 8. The contribution of surface soils to the sediments samples collected from both the top of the Laura and Normanby Rivers are all low <10%. Both the upper catchments in these river systems contain extensive gully networks (see Figure 1). The contribution of surface derived sediments estimated at the two sites on the Laura River upstream of the junction with the Normanby River increase from the average upstream value of less than 8 ± 2% to 19 ± 2% at the site upstream of the Normanby junction. Concentrations on the Normanby River just downstream of its junction with the Laura consistent with this value, with an average of 17 ± 2% contribution from surface derived material. Concentrations of surface derived material on the Normanby then decrease downstream to be 0 ± 2% at the lowest site sampled (on the Bizant River a distributary of the Normanby River). Jack River is the only tributary on the Laura-Normanby which shows any significant contribution of surface derived material (65 ± 5%).

Of the other rivers draining into the bay only the samples from Saltwater Creek show any significant contribution from surface derived sediment (37 ± 5%; at the upper sampling site).

The mean estimate of contribution of surface derived sediment for all of the river samples (n=70) is 16 ± 2%. For samples collected along the Normanby – Laura River system (n = 27) this is 13 ± 3%; and for the Stewart River 11 ± 1%. Our results are consistent with channel and gully erosion being the dominant source of sediment and the hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay is rejected.

5. Discussion

The Laura-Normanby River has been identified using catchment scale modelling as the third largest contributor of sediment to the GBRWHA (e.g. Prosser et al., 2001, Brodie et al., 2003). These studies also identified surface soil erosion as the dominant erosion process. This was largely based on the assumptions that the open woodland vegetation that dominates the savannah landscape in these catchment, coupled with the intense tropical rainfall and seasonal burning regimes, would result in high hillslope sediment yields and that gully erosion in these tropical landscapes was limited because the channel networks were at their fullest extent. However, as more field based research is conducted on tropical systems the relative contributions of subsurface gully and channel erosion appear to dominate (this study; Wasson et al., 2002; Wasson et al., 2010; Hughes et al., 2009; Bartley et al., 2007; Brooks et al., 2008; 2009; Caitcheon et al., 2012; Olley et al., 2012).

What was perhaps neglected in the original assumptions, was that for the same reasons high sediment production rates were predicted on savannah hillslopes, long term slope evolution has led to a situation where many of the steeper slopes are sediment starved, and either mantled by a stone lag or stripped to bedrock, and hence contributing very little sediment supply under contemporary conditions. Much of the stored sediment that can potentially be remobilised in these landscapes is found in colluvial toe slope deposits or in the extensive alluvial deposits (see Figure 1). Hence, the processes, stream bank and channel erosion, that rework these sediments are likely to be the critical controls on contemporary sediment yields.

Caitcheon et al., (2012) summarized the few published estimates of surface soil contributions to Australian tropical rivers using $^{210}Pb_{ex}$ and ^{137}Cs (Table 2). These results indicate that surface soils are a minor component of the sediment being transported in large river systems in tropical Australia. Our results add to this body of evidence and show that erosion mitigation activities should focus on sub-soil sources, and the associated process leading to the acceleration of sub-surface erosion processes, primarily gully and river bank erosion. This does not suggest that hillslope cover factor management should not remain a high prioirity, given its role in modifying surface water runoff – a key driver of gully erosion.

Table 2: Tropical Australian studies that have used radionuclide tracers to estimate relative surface soil contributions to the lower catchment (after Caitcheon et al., 2012)			
Catchment	Mean Surface Soil Contribution %	Tracer	Reference
Daly	11	^{137}Cs	Wasson et al., (2010)
Ord	10	^{137}Cs	Wasson et al., (2002)
Upper Fitzroy	20	^{137}Cs and $^{210}Pb_{ex}$	Hughes et al., (2009)
Herbert	50	^{137}Cs	Bartley et al., (2004)*
Herbert	20	^{239}Pu	Tims et al., (2010)*
Burdekin	17	^{137}Cs, $^{210}Pb_{ex, C}$	Wilkinson et al., (2012)
Mitchell	3	^{137}Cs	Caitcheon et al., (2012)
Daly	1	^{137}Cs	Caitcheon et al., (2012)
Cloncurry	0	^{137}Cs	Caitcheon et al., (2012)
Laura–Normanby	13 ±3	^{137}Cs and $^{210}Pb_{ex}$	This study
Stewart	11 ±1	^{137}Cs and $^{210}Pb_{ex}$	This study

*Note these two studies were carried out pre and post cyclone Larry

6. Conclusion

Activity concentrations of ^{137}Cs and $^{210}Pb_{ex}$ on river sediment samples collected from the Stewart and Laura–Normanby River systems are consistent with channel and gully erosion being the dominant source of sediment at all of the sites sampled and they show that most (85% plus) of the sediment being transported along the main stem of the rivers draining into Princess Charlotte Bay originates from sub-soil erosion of gullies and stream banks. The hypothesis that surface soil erosion dominates the supply of sediment in the river systems draining into Princess Charlotte Bay is not supported by these findings. This result, together with the evidence from similar studies on tropical Australian rivers indicates the primary source of sediment to tropical rivers is gully and channel-bank erosion. This study reinforces the importance of testing model predictions before they are used to target investment in remedial action.

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