Natural resource management planning: can more cost effective outcomes be achieved.

Megan Star, John Rolfe, Terry Beutel, Kev McCosker, Robin Ellis, Tom Coughlin

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Abstract

The decline in health of the Great Barrier Reef and the pressure on allocating funds efficiently has resulted in the catchments adjacent to the reef revising their Water Quality Improvement Plans. The Fitzroy basin and coastal catchments is 152,000km^2 and geographically diverse, past work has identified the need to prioritise funds to achieve cost effective outcomes. For this paper we aim to present an alternative approach to effective prioritisation of sediment reductions. The approach integrates spatial information regarding the sediment source and process, levels of adoption, bare ground cover, and cost into a function to rank neighbourhood catchments. The results identify particular areas of the catchment and also demonstrate the complexity of the issue and the challenge the Fitzroy Basin Association faces when allocating funds. It does however demonstrate that there are effective opportunities in particular areas within the catchment, proving it to be a useful approach in understanding where in the catchment to focus efforts for different sediment reductions.

Introduction

Natural resource management in Australia has changed significantly with changes to government programs and funding arrangements. In the past these policies and programmes have been criticised at a national level for not delivering outcomes, not integrating biophysical data and not being cost effective (Pannell 2009). The declining health of the Great Barrier Reef from increased loads of sediments and nutrients which are attributed to agricultural land uses has resulted in a number of programs since 2009 to improve water quality (Waterhouse et al. 2011). Although there have been a number of state and federal level plans and targets developed, the natural resource management groups who implement the programmes and projects have had limited planning or ability to integrate data across various key characteristics that influence sediment load.

Funding arrangements from Federal and State programs such as the Australian Government's Reef Programme and industry Best Management Practices (BMP) programs via natural resource management groups has been directed to progress towards achieving the Reef Water Quality Protection Plan (Reef Plan) (2013) targets. Reef plan states a number of targets for sediment, nutrient and pesticide run-off reduction in the grazing, grains and sugar industries to halt the decline of the Great Barrier Reef (GBR). The targets include: 20% in sediments, 50% in nutrients and 40% in pesticides along with 90% of land managers using best management practices and a minimum 70% late dry season ground cover (Queensland Government 2013).

Fitzroy Basin has been ranked as "Very High" for sediment load reduction, and "High" for pesticide load reduction (Reef Plan 2013). The 2009 baseline load report estimated 2.9 million tonnes of sediment, 3,900 tonnes of phosphourus, and 1,300 tonnes of total nitrogen can be attributed to human activity as annual emissions to the Great Barrier Reef. Run-off reduction work focuses on the two dominant industries of grazing and grains to achieve the targets. An annual Reef Report Card assesses progress towards the targets, and highlights the slow progress as a result of a number of complexities such as climate, landholder adoption, geographical variation and poor targeting of on-ground projects. Given these results, there is increased pressure to improved current outcomes.

The National Water Quality Management Strategy (NWQMS), a Federal initiative, funded all catchments in the Great Barrier Reef to update the catchments water quality improvements to allow for a more strategic approach to allocate on-ground funds and achieve the targets. The key objective of the NWQMS is "to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development". This objective is linked to the pollutant reduction targets that have already been developed for the Fitzroy Basin under the Reef Water Quality Protection Plan (Reef Plan) (2013).

Although a number of aspects of the catchment are monitored and reported in the Reef Plan report card a key limitation has been for the Fitzroy Basin Association (FBA) to integrate and strategically implement the data to improve on-ground investments. This paper presents an approach to improve how funds can be allocated across a large and diverse catchment and to integrate data in a useful format to understand how improved outcomes can be achieved.

Background

The FBA area covers an area of 152,000 km^2. It encompasses the tributaries of the Mackenzie, Isaac and Connors, Dawson, Comet and Nogoa rivers and occupies one tenth of Queensland's land mass. All the tributaries enter into the Fitzroy River, which drains into the World Heritage–listed GBR. The adjacent catchments of the Boyne and Calliope rivers (which drain directly to the GBR) are commonly considered in conjunction with the Fitzroy Basin and administered by FBA (Figure. 1).

Land use in the Basin is dominated by grazing (80%) and broadacre grain cropping and irrigated cotton (8%). The climate in the Fitzroy Basin is sub-tropical and semi-arid, with highly variable summer rainfall, and drought being a recurring feature. The Basin has experienced extensive land use modifications, with the clearing of Brigalow (*Acacia harpophylla*) dominated woodland for grazing and cropping. By 1996, approximately 60% of all remnant vegetation had been cleared or substantially altered, impacting significantly on the amount of soil run-off (approximately doubling it) exported from native vegetation (Packett et al. 2009). These characteristics, combined with the impacts of cropping and grazing industries, have raised concerns about water quality and the present and future health of the GBR (Webster 2008).

Recent estimates of modelled post-development, long-term annual suspended sediment export from the Fitzroy Basin to the GBR lagoon range from three to four-and-a-half million tonnes per year (Packett et al*.* 2009; Waterhouse et al*.* 2011). The key source of sediment pollutant entering the GBR is an increase in bare ground from grazing lands in the catchments. Karfs et al. (2009) also recognised that increased ground cover, particularly at the end of the dry season, and improved land condition can prevent excessive amounts of sediments entering streams and rivers. With such heterogeneity between land types regarding soil characteristics, land productivity and slope, the sediment loads exported vary significantly throughout the catchment and its land types (Silburn 2011; Silburn et al*.* 2011b).

Figure 1. Fitzroy Basin

Currently FBA has three sub-regional groups (Dawson Catchment Coordinating Authority, Capricornia Catchments, and Central Highlands Regional Resource Use Planning), which operate with field staff to engage and work with landholders. The field staff have in the past worked in smaller geographical parcels defined as neighbourhood catchments. From these neighbourhood catchments (NC) field staff have alternated neighbourhood catchments, basing their activities for extension, field days and engagement for a period of time solely on the landholders in these NC. The boundaries of the NC are based on the smaller scale catchments and comprise a varying number of landholders. The Basin has a total of 192 neighbourhood catchments and was used as the scale for this prioritisation (Figure 2). The number of NC varies in each of the sub-catchments, with a maximum of 66 in the Dawson and a minimum of 28 in the Boyne.

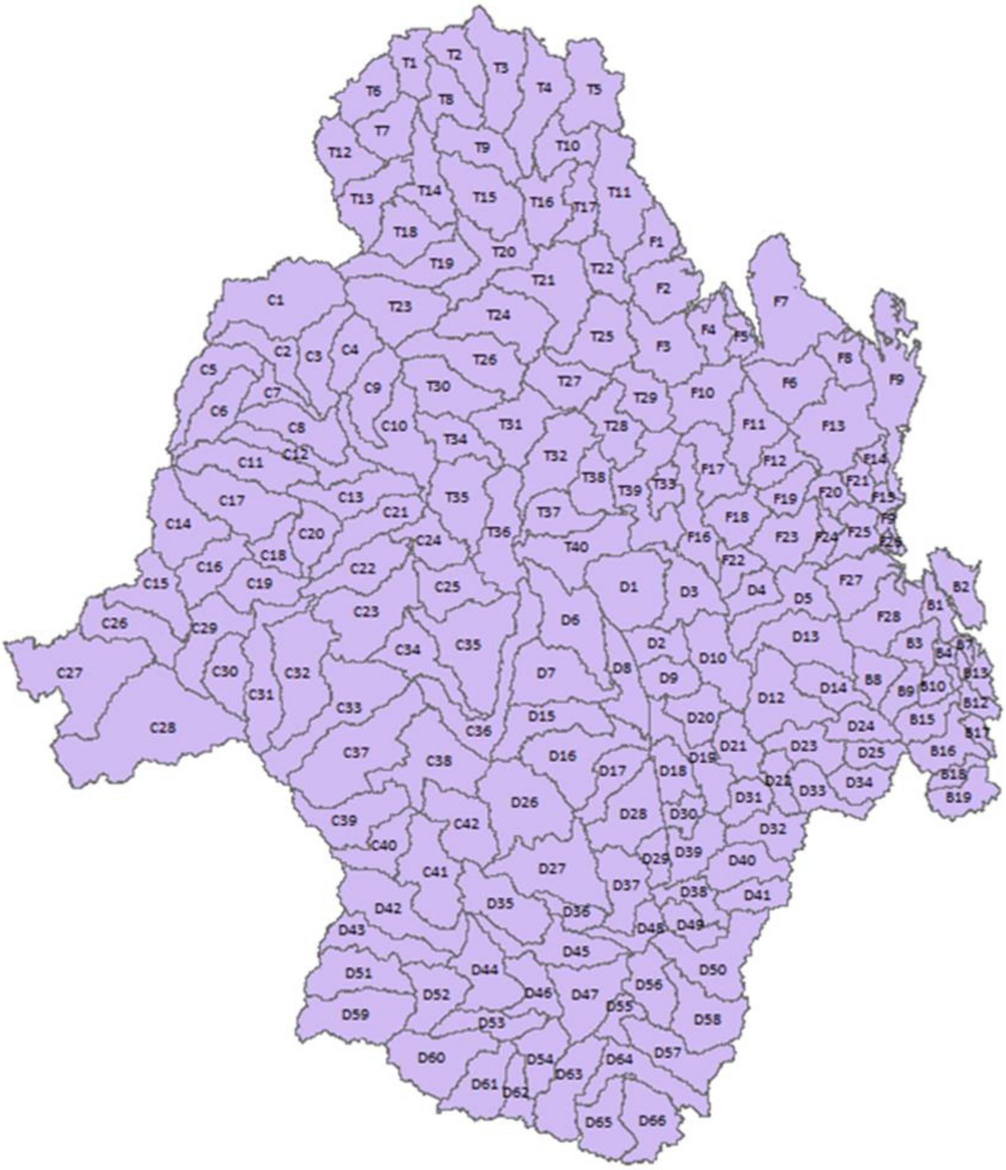

Figure 2: Neighbourhood catchments within the Fitzroy Basin Association area

In 2002 with the development of NHT2, regional bodies were required to develop a ‘strategy and investment plan’. This involved identifying assets; ranking and prioritising assets after accounting for risk; establishing and prioritising goals, objectives and targets for realistic achievement through the investment planning process; and consulting the public (Farrelly and Conacher 2007).These tasks are complex and require expertise in gathering and using science and information, local and practical knowledge, and an understanding of public values. These skills and knowledge are reported to be lacking (Seymour *et al.* 2008), but are critically needed to make prioritisation decisions. The spatial and temporal impact of a decision can vary dramatically from an individual field to a whole region and from a year to a whole century, based on the complexity and geography of the NRM issue.

These information gaps can pose be a constraint on the quality of decision making by a regional body (Seymour *et al.* 2008). A survey completed by 18 regional bodies identified that there was limited use of economic and social information. Integration of information was also lacking, and evaluation and tracking of outputs and activities was minimal. This reflects the lack of clear reporting guidelines to government funders and provides an opportunity for a framework to be developed (Seymour *et al.* 2008).

A key challenge for NRM groups in developing their strategy and investment plans was the critical gaps in the resource condition information base. This resulted in large numbers of NRM groups proposing investment in data collection. All plans set long-term resource condition targets and short-term management actions; however, the links between the asset resource base and the subsequent short-term management strategy was depicted with various levels of clarity. The complexity of the plans highlight the importance of sharing resource information between governments, scientists and NRM groups (McAlpine *et al.* 2007).

Integrated resource management has been the approach for many NRM programs to be implemented as it provides an integration of community involvement, technical knowledge and organisational structure. This collaboration approach provides a more adaptive and flexible approach to address uncertainty, complexity and interconnectedness associated with NRM then previous programs. However, there is little information and few resources dedicated to the evaluation of the approach, as a result of the complexity associated with difficult trade-off decisions made in integrated resource management. The difficulty arises because NRM programs provide intangible services with broad social functions, which makes it impossible to measure or calculate the marginal economic benefits associated with the program (Bellamy *et al.* 1999).

Methods

The approach was designed to allow FBA to allocate investments spatially, understand the cost-effectiveness of future investments, to plan and monitor progress towards the Reef Plan targets of a 20% reduction in sediments and particulate nutrients. A critical aspect was for field and management staff to understand the process and the data.

The Fitzroy Basin is affected by either gully, hillslope or streambank erosion, a prioritisation of neighbourhood catchments within the Basin needs to be undertaken to determine the relative importance of areas based on different decision variables. Given that sediment is the key pollutant for reductions, the focus has been predominately on sediment with particulate nutrient highly correlated. It was assumed that where sediment reductions occurred inherently particulate nutrient reductions also occurred.

The method involved integrating spatial layers regarding where in the catchment sediment was being exported from. Following this the variables for capacity to change in regards to the adoption of management practices, improved ground cover, time and delivery to the Great Barrier Reef and cost for reductions were integrated into a function.

$$Targeted\ Neighbourhood\ catchments = \ loads\ \frac{(N.Cover \times N.Mgt\ \times N.Del)}{N.Costs}$$

Where:

Where the loads refer to the tonnes per hectare for the NC, *N. Cover* refers to the residual ground cover data that was normalised and then multiplied by *N.Mgt,* which is the level of adoption for B management practice for grains and grazing normalised, which was mulitplied by the delivery ratio of what is delivered to the reef *N.Del*. This was then divided by *N.Costs*.
This section will explain each of those variables.

Sediment loads

The sediment loads are derived from the Source Catchment Model which is currently used across the Reef catchments to assess all pollutant reductions from the Fitzroy Basin and to analyse progress towards the Reef Plan targets. The Source Catchments Model identifies where the current levels of the sediments and nutrients are coming from, the erosion process and industry. The limited empirical data across the catchment results in the model is the best available spatial data to date.

Source Catchments runs at a daily time-step, allowing the user to explore the interactions of climate and management at a range of time-steps, only the average annual catchment loads were required for reporting purposes over a 27-year period (1986-2013). Models were validated against the six years of loads monitoring data collected at a total of 31 individual sites (12 end-of-systems and 19 sub-catchment sites) (Turner et al. 2013) and any additional data sets available to validate modelled load estimates (Fentie et al. 2013; Dougall & Carroll 2013).

There are a number of levels at which Source Modelling can be chosen as decision variables for the purpose of prioritising neighbourhood catchments. This has been the unit selected as the most relevant management unit for field staff and the relevant sub-regional organisations. The Source Catchments model accounts for a number of biophysical parameters across the catchment, such as slope, soil type, soil erosivity, vegetation, pasture species and bare ground. The model allows the process to identify the sediment loads (in unit of tonnes) from the different erosion process of hillslope, streambank and gully and accounts for sediments and nutrients across the different land uses; however, the prioritisation process in this study will only focus on grazing and cropping land uses.

Residual ground cover

Ground cover is the non-woody vegetation (forbs, grasses and herbs), litter, cryptogrammic crusts and rock in contact with the soil surface (Muir et al. 2011). The quantity of ground cover present can have significant influence on pasture productivity, infiltration and run-off, and ground cover maintenance is an effective action for minimising the impacts of wind and water erosion (Beutel et al. 2014; Tindal et al. 2014) and increasing productivity in grazing systems (Karfs et al. 2009; McIvor 2001; Star et al. 2013). In the GBR catchments, ground cover targets have been implemented by Regional NRM groups and as part of the Reef Water Quality Protection Plan (Department of the Premier and Cabinet 2013) in an effort to maintain ground cover, particularly in dry periods, to minimise erosion and increase grazing land productivity.

Capacity to leverage ground cover data sets is built on approximately 15 years of research that, in its current iteration, produces seasonal (four/year) estimates of ground cover in 30m pixel resolution for about 95% of Queensland (Tindal et al. 2014). In this study a derivative of available ground cover data set was used. Four main alternatives were considered; ΔGC, D condition probability, mean cover and cover residual.

ΔGC (Bastin et al. 2012) is the best validated of the ground cover derivatives considered here. ΔGC measures ground cover deficit at times of extreme drought by comparing cover at any point with higher percentiles of cover within a moving window placed around each pixel. It is useful for separating grazing and rainfall effects on cover. In the context of the study, it had two main draw backs; the last available image dates to the 2004 drought and this image is based on an older cover algorithm that is masked over approximately 40% of the Fitzroy where woody cover is too high to permit its use.

Land condition probability mapping was developed by Beutel et al. (2013) in the Burdekin and Fitzroy NRM regions. These data include four layers, one each for the probability that any point is in A, B, C or D grazing land condition (Beutel et al. 2013). The underlying model included mean ground cover (2009–2011) imagery, ΔGC2004 imagery and long-term average rainfall, and was trained on about 1600 roadside land condition observations taken in 2010 and 2011. The D condition layer was considered in this work. The main drawbacks of this product were that it included the same extensive woody mask as the ΔGC, and the fact that the current version is unvalidated beyond the modelled sites.

Mean cover images have been available in various iterations for a long time. These images simply average pixel values at any point across a series of dates. The choice of dates is flexible (we chose spring imagery 2008–2014 inclusive), and the imagery is simple to create, so could incorporate the newer “cover under trees” imagery with minimal woody cover masking. The main drawback of this imagery is that it only reflects average rainfall to some extent and hence it is more likely to confound management and climatic impacts on cover.

The residual cover image was derived from the mean cover image, and had the same minimal woody cover mask. The residual calculated in any pixel indicates the difference between measured and expected cover, but is standardised across the cover gradient. Expected values are based on a sampling envelope around any pixel, similar to the ΔGC that should facilitate discrimination of management and rainfall impacts on cover, but in this study the product was based on more recent imagery (2008–2014) than the current ΔGC. The product has not been field validated, and is used here in the absence of a suitably updated ΔGC product.

Residual cover was summarised at neighbourhood catchment-scale by estimation of the 10th percentile of residual cover in each neighbourhood catchment. We did this to discriminate catchments by their lower cover values since these are most relevant to sediment loss. These resulting neighbourhood catchment rankings provided the next iteration of the optimisation with low residual cover catchments in priority Source Catchments considered highest priority, and those with low residual cover identified as of limited interest given marginal scope to improve cover levels.

Management practice effectiveness

Ensuring that on-ground investments are effectively spent requires a range of management practices to support the relevant infrastructure in achieving an outcome. To understand the level of management that currently exists to support improvement across the erosion processes and industries the Paddock to Reef (P2R) Water Quality Risk frameworks have been utilised.

For each industry (grazing and cropping) there is a suite of specific management systems defined under the water quality risk framework relevant to hillslope management, gully management or streambank management in grazing systems and soil, nutrient and herbicide management in cropping systems (Shaw et al. 2013). The framework was used to describe and categorise management practices according to recognised water quality improvements at a paddock scale. P2R Water Quality Risk frameworks seek to align management practice to a range of likely risk states (Tables 1 and 2). For ease of referral these are referred to as A, B, C or D in this document (Tables 3 and 4).

Table 1. P2R classification of management practices in the grazing industry.

Water Quality Risk	Low	Moderate	Moderate-High	High
Resource condition objective	Practices highly likely to maintain land in good (A) condition and/or improve land in lesser condition	Practices are likely to maintain land in good or fair condition (A/B) and/or improve land in lesser condition	Practices are likely to degrade some land to poor (C) condition or very poor (D) condition	Practices are highly likely to degrade land to poor (C) or very poor (D) condition
Previous 'ABCD' nomenclature	A	B	C	D

Table 2. P2R classification of management practices in the grains industry.

Water Quality Risk	**Low**	**Moderate**	**Moderate-High**	**High**
Previous 'ABCD' nomenclature	A	B	C/D	

A representative sample of grazing properties were surveyed on a one-on-one basis and the managers were asked a series of questions aligned to the practices articulated in the P2R Water Quality Risk framework for grazing in rangelands. The practices are weighted according to their estimated influence on off-site water quality. Responses to questions were used in developing water quality risk scores for each enterprise, and ultimately assigning water quality risk ratings from high risk to low risk outcomes and practices that support erosion processes are included, these are then categorised accordingly. The same outputs for grain growers are derived from assessments conducted through the Grains BMP program. Aggregation of the water quality risk ratings for enterprises at the river basin (e.g. Dawson) level provides estimated distributions of property management, or adoption benchmarks (e.g. Table 3 contains benchmarks for grazing management at the Fitzroy Basin scale).

The justification to focus on landholders that already implement B level management practices is that effective use of financial grants (incentives) and extension should ideally occur in a setting conducive to adoption. Similarly, relatively high management effectiveness in response to previous extension is taken as an indicator that new extension work (possibly with a renewed emphasis on practices more explicitly targeted for sediment reductions) may have a higher probability of adoption by these landholders compared to landholders that have previously not engaged with support staff.

Table 3. Percentage of grazier classification of management practice across the different erosion process in the Fitzroy

Erosion process	**% graziers with adopted management practices**			
	A	B	C	D
Hillslope	**4%**	**14%**	**59%**	**23%**
Streambank	**20%**	**16%**	**15%**	**48%**
Gully	**6%**	**15%**	**55%**	**24%**

Table 4. Percentage of grains management practices effectiveness on cropping land.

	% growers with adopted management practices			
Water Quality Parameter	A	B	C	D
Run-off & Soil loss	**14%**	**27%**	**58%**	**1%**
Herbicide Management	**3%**	**65%**	**29%**	**3%**
Nutrient Management	**1%**	**53%**	**39%**	**7%**

For each scenario, the average management practice effectiveness for grazing on B condition land for the three soil erosion processes is 15% (see Table 2). This ratio was multiplied by the grazing area in each neighbourhood catchment to obtain average management practice effectiveness for grazing. For cropping, the same was done using average management practice effectiveness ratio for run-off and soil loss of 27% (see Table 4). The total average management practice effectiveness for grazing and cropping was then obtained by adding up the effectiveness value for each land use type for each neighbourhood catchment.

Costs

A combination of incentive and opportunity cost were estimated for each of the neighbourhood catchments. Opportunity costs, *O*, per hectare for each neighbourhood catchment in the case for grazing areas were added separately to each neighbourhood catchment. The opportunity cost for grazing land use in each neighbourhood catchment, O_{NC}, was derived based on the following function:

$$O_{NC} = I + GM \times \Delta \, production$$

where GM is for gross margin (income less costs) for cattle production in the Fitzroy Basin, this was based on a 5,000 ha finishing enterprise which has been estimated at $218 per adult equivalent adjusted for the Eastern Young Cattle Index as of June 2015 to $240 (Star et al., 2011). Δ Production is the marginal difference in grazing productivity adult equivalents per hectare in each neighbourhood catchment based on the combination of land types and average land condition across the NC. It was assumed that opportunity cost would only apply for a period of 10 years, which reflects the time period to adjust a self-replacing herd. The marginal change in production was informed by the bio-economic outcomes and estimated to be 27% on average across the catchment (Star et al., 2013b).

For cropping land, contour banks were the main erosion control considered, as other capital infrastructure has a broader combination of outcomes and may have associated private benefits. Contour banks have a minor impediment to crop production; however, over time do deteriorate. The timeframe was kept at 10 years for changes with the opportunity cost estimated to be 20%. The gross margin was averaged and weighted based on the combinations of crops and the ratio planted over a 10-year timeframe, this was based on the P2R modelling.

Table 5. Justification of cost components

Cost component	Description	Reference
Level of incentive	Initial incentive or capital costs for implementation management actions, e.g., fencing (de-stocking), revegetation, reshaping earthworks.	Wilkinson et al. (2015), Yitbarek et al. (2012), (Shellberg and Brooks, 2013; Wilkinson, 2014), Moraveck & Hall (2014).
Opportunity costs	Costs associated with forgone grazing profits by converting productive land into conservation areas to reduce the effects of erosion processes.	Adams et al. (2010), (MacLeod et al., 2004; McIvor and Monypenny, 1995) (Ash et al., 2011; Star et al., 2013a)

Most of the reviewed studies have not applied the cost components directly but mention the activities that link to soil management expenses, for example a need for regular monitoring and maintenance of rehabilitated sites.

The incentive costs, *I*, were obtained using the simplest soil management practice. For grazing land use that is the fencing of the affected area, basic soil amendments, and revegetation of the area using perennial grasses. $5,000 was selected as the nominal figure for grazing and $2,000 for cropping as the incentive amount based on a review of the past on-ground investments under Reef Rescue. It was assumed that these management practices would likely be appropriate for most sites regardless of soil erosion type, (e.g., gully, hillslope or streambank erosion), erosion severity and site-specific characteristics. However, this assumption may lead to an understatement of actual management costs compared to site-specific best management practices and should be considered when interpreting the results of this study.

Delivery ratio

The delivery ratio aims to capture the time element and the ability of changes at a paddock scale to have an impact at the Reef. Given there are a number of geographical figures, slope, water storages and processes across the catchment. It is estimated that large water storage such a Fairbairn dam capture up to 60% of sediments (Lewis et al. 2013). Across the Fitzroy there are a number of water storages in the form of dams or weirs across the catchments such as; Fairbairn, Callide, Neville Hewitt, Theresa Dam, Eden Bann, Burton George, Gyranda, Kroomit and Tartrus.

Achieving on-ground work in particular parts of the catchment will achieve reductions on the Reef in a shorter timeframe. Given that the Reef Plan targets are to be achieved by 2020 areas that will realise the benefits on the reef in a shorter time frame will be more effective to work in. Source modelling has accounts for what leaves the paddock and then what is delivered to the reef, this ratio was used to as a parameter.

Results

The results highlight the complexity of targeting resources, with two neighbourhood catchments T33 and F15 gaining a score of 149.89 and 138.20 respectively. T33 has a considerable high pollutant load of 475.66 tonnes per hectare with the mean across all catchments being 139.01 tonnes per hectare. For the other parameters T33 had a cover score of 0.45, a normalised management score of 0.61, a normalised cost score of 0.39 and a export delivery ratio of 0.45. F15 is 52.91 points ahead of the third highest ranked catchment B2 which has a score of 85.29, this is attributed to the difference in sediment load. F12 ranked 20th and almost has double the load of T33 at 949.72 tonnes per hectare however had a very low management effectiveness and higher costs and average cover (Table 6).

Table 6. Result of highest priority neighbourhood catchments for sediment reductions from grazing

Neighbourhood catchment	Sediment loads (t/ha)	N. ground cover	N. Best management practice	N. cost	Export delivery ratio	Grazing priority
T33	475.66	0.45	0.61	0.39	0.45	149.98
F15	375.38	0.81	0.09	0.20	1.00	138.20
B2	199.27	1.00	0.11	0.25	1.00	85.29
F5	242.39	0.69	0.21	0.46	1.00	76.05
F25	3278.22	0.69	0.02	0.62	0.95	68.96
F1	435.54	0.70	0.07	0.35	0.99	61.91
F17	918.65	0.64	0.10	0.45	0.48	60.63
B13	334.98	0.76	0.07	0.32	0.94	52.16
T29	374.87	0.56	0.33	0.56	0.39	48.07
B9	269.80	0.50	0.16	0.44	0.90	43.02
F3	319.32	0.51	0.11	0.43	0.94	41.26
F20	854.58	0.57	0.06	0.53	0.79	40.72
B8	334.05	0.51	0.08	0.28	0.86	40.32
F4	313.32	0.58	0.10	0.46	0.98	37.71
T22	50.05	0.50	0.82	0.18	0.31	35.14
F11	517.28	0.51	0.09	0.36	0.55	34.76
B1	328.97	0.76	0.05	0.36	1.00	32.10
F6	234.68	0.64	0.09	0.42	0.95	30.44
F12	949.72	0.53	0.04	0.59	0.76	23.01

The results indicate that although there are a small number of catchments that are clearly higher priority this is outweighed by the number neighbourhood catchments that are within a small of range of each other. Figure 3 highlights that across the 192 neighbourhood catchments the small number of catchments with a distinctly high score and the large amount that have marginal differences between them.

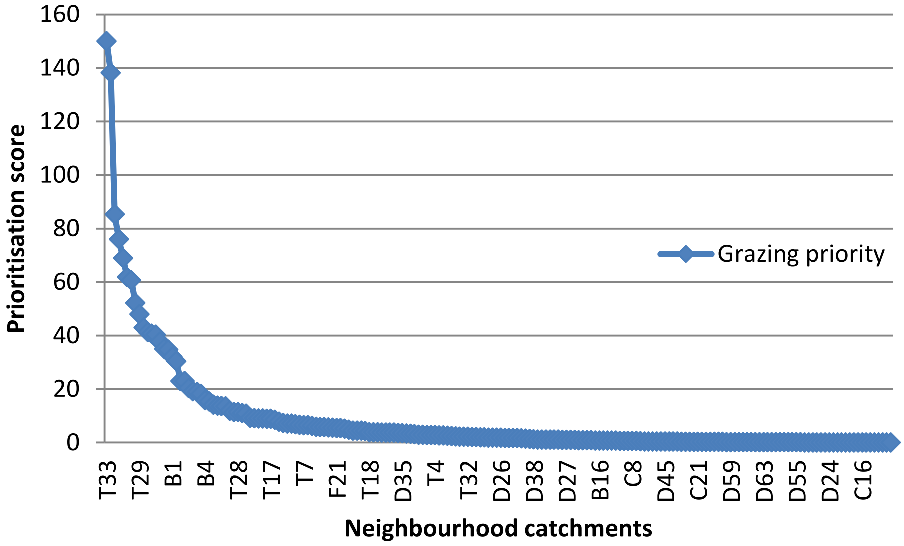

Figure 3 The range of scores for the top 20 neighbourhood catchments demonstrating the small number to easily target.

There are a smaller amount of NC which have grain farmers in them and therefore the total number is reduced. The larger grain growing regions are in the Central highlands or a the Callide valley this is reflected in the results with NC C22, C34, C23 and C10 located in the Central highlands and in close proximity to the Comet river. T20 is still a part of the Central highlands however is in close proximity to the Mackenzie river catchment which is a part of the Three Rivers sub-region.

The loads from cropping per hectare (21.1 tonnes per hectare) are significantly lower across the NC than grazing (475 tonnes per hectare) as weirs and storages that water and sediments are captured in along the system. Another key aspect is that the majority of sediment load is a result from hillslope or streambank with gullying not being as prevalent due to the farming system requiring flat and even paddocks.

Table 7. Result of highest priority neighbourhood catchments for sediment reductions from grains.

The results for cropping NC_ID	Sediment loads (t/ha)	N. Best management practice	N. Cost	Export delivery ratio	Combined Score (Grains)
C22	21.1	1.00	0.02	0.21	0.208
C34	19.2	1.00	0.02	0.19	0.190
C23	20.1	0.81	0.01	0.19	0.152
C10	12.7	0.66	0.02	0.20	0.131
T20	25.8	0.41	0.02	0.29	0.119
D16	105.2	0.29	0.01	0.35	0.104
T28	65.8	0.27	0.00	0.39	0.103
C4	12.0	0.45	0.02	0.16	0.074
D39	77.6	0.23	0.01	0.29	0.067
C3	10.3	0.38	0.02	0.17	0.065
D19	85.7	0.17	0.01	0.37	0.062
C13	6.5	0.37	0.02	0.16	0.058
C21	23.5	0.23	0.02	0.24	0.056
C9	17.0	0.24	0.02	0.19	0.046
D12	71.0	0.16	0.02	0.27	0.044
D18	24.8	0.12	0.02	0.36	0.042
C1	11.1	0.25	0.02	0.16	0.041
C12	8.6	0.22	0.02	0.17	0.038
D17	74.2	0.10	0.01	0.35	0.036
D30	99.8	0.11	0.01	0.32	0.034
C20	1.0	0.49	0.09	0.07	0.033

Discussion

The aim of this report was to the prioritise neighborhood catchments to achieve the Reef Plan sediment target. The method relies of a function which integrates a number of parameters to allocate scores to each of the neighborhood catchments. The result identified a relatively small number of NC that have a higher score relative to other NC. It also highlights the complexity of targeting and the difficulty for FBA to have effective outcomes once engagement in these key NC has occurred. It does however provide insights for FBA in the mix of mechansims, the outcomes achieved from cropping and grazing and the importance of ensure that further degradation does not occur in NC. Potential areas of engagement with mining industry which have not previously occurred, and improvements in the approach which would provide further understanding.

Past criticisms of NRM programs has been the inability to account for considering the outcome, lack of integration of biophysical data and poor targeting. However the results of this study demonstrate that the small number of NC that scored considerably higher than the remaining NC indicate that achieving outcomes through targeting is complex and may not always have a larger enough cumulative impact to achieve the desired end point which in this instance was to achieve the Reef Plan targets.

Currently mechanisms are being used assuming mutual exclusivity in NC which are very similar relative to each the erosion process is commonly attributed to gully or streambank. Although cover is a key driver of these processes a more systems approach to remediation will be required such as extension to improve the ground cover, incentives to allow for remediation work to the gully and potentially on-going extension to ensure that the infrastructure is monitored and maintained.

Similarly, temporal impacts are critical as to the private and public trade-offs (Star et al. 2015) therefore a mixture of mechanisms is required to achieve sediment reductions. Results of previous LiDAR studies have identified that larger gullies may be driven by episodic or event-based localised rainfall events and possibly exacerbated by low ground cover. This highlights that maintaining good ground cover at the end of a drought or the break of a dry season is important to avoid large sediment loss and erosion features which would require improved extension alone (Tindal et al. 2014).

Similarly, although mining only occupies 1% of the catchment, mining companies have grazing lease agreements in place for 4% of the catchment. Given that cattle enterprises are not their primary business there is the potential scope for engagement of mining companies to achieve mutually beneficial outcomes. Given the large areas involved, there is potential for low risk engagement with mining companies to facilitate low cost, large impact sediment reductions. Mining companies may be receptive to improved environmental management without reliance upon incentives, and income from livestock is not the critical business operating on that land.

Cropping areas have the potential to achieve sediment reductions with low cost and high adoption rates of supporting management practices. The dominant cropping soils also have very high fractions of particle size below 4 µm, which are increasingly understood to be extremely important in terms of the damage done to reefs (Lewis et al. 2015). In a number of the NC selected there is the opportunity to work with growers to achieve sediment reductions and achieve corresponding cumulative benefits through herbicide reductions and the applied DIN reductions. Advantages of investing in change in the grains industry is that the actual impacts of the change are realised virtually immediately, and the changes are relatively easy to verify. This may be in contrast to interventions in the grazing industry where benefits are likely to be realised over long time periods.

The approach has a number of caveats such as temporal, scope and threshold effects. The temporal period of each of the parameters and the duration of data supplied varied. Similarly, each of the parameters has complexity and confidence intervals that are compounded over a function. The approach similarly does not consider future climate impacts and does not consider parameters that may prevent further degradation across the catchment. Furthermore no threshold effects were accounted for in regards to effectiveness of extension in changing management practice or percentile cover.

The study does however provide a useful contribution to natural resource management planning and the ability to achieve outcomes through spatial consideration of data and targeting. It provides an approach which is understood by the field officers and team members of FBA and can be improved and updated as more information is available.

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