Tropical Water Quality Hub

National Environmental Science Programme

Final Report

Optimising the management of riparian zones to improve the health of the Great Barrier Reef

Keryn I Paul, Rebecca Bartley and John S Larmour

CSIRO

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Keryn I Paul[1], Rebecca Bartley[1] and John S Larmour[1], Micah J Davies, Debbie Crawford[1], Shane Westley[2], Shannon van Nunen[2], Bart Dryden[3], and Cassandra S James[4]

[1] CSIRO Land and Water
[2]Fitzroy Basin Association Inc.
[3]Terrain Natural Resource Management
[4]Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University

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ACRONYMS

AG.............. Australian Government
AGB............. Above-ground biomass
BGB............. Below-ground biomass
BMP............. Best Management Practices
CRRP........... Community Rainforest Reafforestation Program
DoEE............ Department of the Environment and Energy
ERF.............. Emission Reduction Fund
GBR............. Great Barrier Reef
GIS............... Geographical Information Systems
NESP........... National Environmental Science Program
NRM............. Natural Resource Management
QG............... Queensland Government
TREAT.......... Trees for the Evelyn and Atherton Tablelands
TRARC......... Tropical Rapid Appraisal of Riparian Condition
TWQ............. Tropical Water Quality
WTTPS......... Wet Tropics Tree Planting Scheme
WQIP........... Water Quality Improvement Plan

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EXECUTIVE SUMMARY

The health of the Great Barrier Reef (GBR) is threatened by excessive delivery of sediments (and the pollutants they carry) to the marine environment. Remediation of riparian vegetation is considered an important mechanism for reducing stream bank erosion, improving water quality, and subsequently GBR health outcomes. But despite previous investments in such projects, there is a paucity of information on whether previous investments have been successful in delivering these benefits, and what mechanisms or incentives could be refined to better facilitate success. To help fill this knowledge gap, this study undertook three activities.

Methodology:

1. **Project-scale success.** Explore the success of previous investments through both field-based assessments of improved water quality (as indicated by a Condition Score), and face-to-face semi-formal social surveys of landholders.
2. **Catchment-scale success.** Review of requirements for widespread landholder participation and whether this implies merit in alternative incentive schemes.
3. **Expanding the metrics of success.** Quantify co-benefits through field-based assessments of biodiversity (as indicated by Plant Cover index and landscape-scale metrics of project size and connectivity) and carbon mitigation.

Key findings were:

1. **Sub-optimal rehabilitation.** Re-visiting previous investments demonstrated that improved water quality outcomes (as indicated by a Condition Score) increases with project age, at least where grazing extent was relatively short. However, results also indicated that remediation projects may not result in full rehabilitation to conditions of 'natural' intact remnant vegetation. This was because most project areas were relatively narrow in width, thereby leading to persistent poor plant cover, erosion and/or weeds.
2. **Importance of financial incentives.** Previous work has shown that the most important drivers for landholder engagement in GBR catchments were private benefits, and that the key barriers for landholder participation were financial. Consistent with this, our social survey findings indicated widespread uptake of riparian remediation works will require landholders aligning environmental and production goals, particularly in regions of relatively low productivity that offer less flexibility, e.g. destocking during drought.
3. **Overcoming normalising behaviour and perceived risks.** Overcoming normalising behaviour (i.e. ideas and actions that have come to be seen as 'normal' through social processes) was also important in ensuring widespread participation in riparian remediation. There was also a need for landholders to overcome perceptions that remediation projects are impractical (i.e. complex and expensive), and scepticism of reported links between water quality and their management practice.
4. **Prioritising resources to maximise impacts.** Findings from the social survey also revealed a vast range in management intensity, with some cases of very large investment of resources being places in a few small projects. Further work is required to verify whether, for a given level of resources, greater benefits to GBR health are attained through implementation of less resource intensive projects across larger area rather than undertaking fewer resource intensive projects across a limited area.
5. **Expansion of the definition of success.** Our results from field-based assessments contributed to enhancing the evidence-base for building confidence in emerging

schemes that effectively provide landholder stewardship payments for the provision of multiple environmental services. We found significant benefits to biodiversity were attained after only 10 years where grazing periods in the dry season were relatively short (< 2 months). However, these benefits were moderated by the often poor size and connectivity of these projects, particularly in the Wet Tropics NRM region. Rates of biosequestration of carbon in planted or regenerating trees and shrubs varied with site productivity, but importantly, were 2.61–6.56 (and 1.17–1.63) times higher than anticipated based on rain-fed stands of similar age, species mix and stand stocking densities growing under the same climatic conditions in the dry subtropics (and wet tropics or subtropics), presumably due to riparian stands accessing additional ground and surface water. Moreover, remnant trees that are common within many riparian remediation project areas provided an additional significant store of carbon. These results confirmed that riparian areas play a disproportionately large role in providing benefits to biodiversity and biosequestration due to their relatively fertile alluvial soils and increased moisture levels.

Recommendations were:

1. **Facilitate landholder groups to engage and build local knowledge.** There is a need for base funding to support landholder groups working together to utilise learnings from local demonstrations and knowledge to develop guidelines for recommended management practices, thereby contributing to overcoming normalising behaviour and ensuring guidelines for management are practical and provide benefits to agricultural production. Increased monitoring of the water quality impacts of practices at a paddock and catchment scale is also required to overcome remaining (albeit declining) scepticism of reported links between water quality and their management practice.
2. **Facilitate alternative incentive schemes.** Our results also support exploring the merits of implementing an incentive scheme that provides landholder payments that are directly linked to outcomes of improved water quality (e.g. indicated by Condition Score), biodiversity (e.g. indicated by Plant Cover Index) and carbon mitigation (e.g. indicated by ERF methodologies). With all environmental services considered, payments may be sufficient to overcome the financial barriers (e.g. opportunity costs of foregone agricultural production), thereby facilitating the scale of participation required to have real outcomes to the health of the GBR. Moreover, given landholder payment are outcome-based (as opposed to paying for fencing, etc. via grants), they incentivise not just the establishment of the project, but its on-going maintenance.
3. **Underpinning research to support riparian remediation.**
    - Ascertain a condition scoring method that provides an improved estimate of likely benefits to water quality from remediation of riparian vegetation.
    - Assess possible trade-offs between grazing extent and environmental benefits, and requirements to optimise environmental benefits by better understanding the possible trade-offs between project quality and the quantity of projects.
    - Explore whether remediation projects are more likely to approach optimal Condition Scores when they have increasing extents of remnant vegetation within the project area, are relatively wide, and/or are well connected.
    - Develop cost-effective methodologies for indicators of improvements in water quality and biodiversity, and refine ERF methodologies such that they account for the: (i) high carbon mitigation potential of riparian zones, and; (ii) carbon stocks protected in remnant vegetation within the project areas.

1.0 INTRODUCTION

1.1 Background

The health of the Great Barrier Reef (GBR) is threatened by excessive delivery of sediments (and the pollutants they carry) to the marine environment resulting from widespread removal of deep-rooted natural vegetation post-European settlement, particularly when this entailed removal of riparian vegetation from along streambanks (e.g. McCulloch et al. 2003). In recent years, health of the GBR has become increasingly vulnerable to the negative impacts of transported sediment and pollutants, frequent plagues of crown-of-thorn starfish (*Acanthaster planci*), and a changing climate resulting in increased episodes of coral bleaching and ocean acidification (Hairsine 2017).

Water Quality Improvement Plans (WQIP) for catchments draining to the GBR have been prepared by the Regional NRM Bodies and Councils and the Queensland Government (QG, 2016). These WQIPs outline a need for large-scale system repair, including remediation of riparian vegetation to improve water quality at catchment-scales, and hence, provide improved GBR health outcomes. This concern has meant that the Australian and Queensland governments have targeted about $2 billion of investment to improve water quality of run-off from the 35 major catchments of the GBR (QG, 2017a).

1.2 Riparian vegetation and water quality

Increased sediment flux to the GBR since European settlement of Australia arising from increased streambank erosion due to:

1. Widespread removal of native riparian vegetation from along streambanks, either through deliberate clearing for development, or through the combined effects of stock grazing and fire;
2. Removal of large, woody debris in many streams, and;
3. Increased flows resulting from extensive clearing of deep-rooted natural vegetation from non-riparian areas higher in the catchment (e.g. Price and Lovett 2002; Lawson et al. 2007; Godfrey and Pearson 2012).

Radionuclide tracing studies in Queensland indicated that streambank erosion contributes about 30% of the end of catchment sediment in the large dry tropical streams (Wilkinson et al., 2015), and closer to 40% in wet tropical streams that do not have such extensive gully erosion (Hateley et al., 2014). Similar results were found in subtropical catchments (Olley et al. 2013; Laceby et al. 2015), and in non-GBR tropical catchments in the Northern Territory and Queensland (Caitcheon et al. 2012).

Riparian vegetation remediation protects against streambank erosion by:

1. Decreasing sub-aerial erosion by protecting the soil surface from rain splash and scour by stream flow, and from disturbance by livestock, and also reducing the speed and erosive force of the water flowing along the bank;
2. Increasing the soil cohesive strength by root reinforcement, and by moderating soil pore water pressure through evapotranspiration and shading and protecting against mass failure, or slumping of the bank;

3. Roughening the channel at the reach scale and thereby slowing the velocity of flood flow down the valley to reduce scour at the toe of the bank and on the outside bends of rivers, and;
4. Slowing the velocity of in-channel flow through vegetated bars and benches, particularly when these riparian zones are vegetated with grass and dense shrubs with stems able to bend over and lie down in a peak flow (e.g. Price and Lovett 2002; Hubble et al. 2010; Wilkinson et al. 2016).

In addition to decreasing streambank erosion, riparian vegetation also contributes to improved water quality by decreasing surface runoff and filtering particulate matter and pollutants from water as it infiltrates. For example, promoting vigorous riparian vegetation limits nutrients and pesticide inflow via promoting infiltration and deposition into the soil due to the reduced velocity of runoff, while the often moist and high organic carbon status of soils under such vegetation provides reducing conditions (Price and Lovett 1999; Decamps et al., 2004; Dosskey et al., 2010). This generally results in less nitrogen running into steams due to increased nitrogen immobilization in microbial biomass, and enhanced rates of denitrification (Neilen et al. 2017). Previous studies, globally and in Queensland, have also shown that riparian vegetation decreases streambank erosion, and hence, inflow of sediment, nutrients and pesticides (Table 1).

Due to the tendency of livestock to concentrate around water, many riparian zones are heavily impacted by grazing where trampling and/or consumption of vegetation impedes regeneration and further exacerbates erosion (Trimble and Mendel 1995; George et al. 2011). These impacts are greatest in smaller streams with low banks and shallow depths given these provide easier access to livestock (Williamson et al., 1992). For example, grazing of riparian areas will supress natural regeneration due to trampling and/or consumption of tree seedlings (e.g. Jansen et al. 2007). There is evidence in Australia that high livestock grazing intensities can supress riparian vegetation (Table 2). Similar results have been obtained overseas (e.g. Schulz and Leininger 1990; Huber et al. 1995; Howell 2001; Scrimgeour and Kendall 2002; Clary and Kinney 2002; George et al 2011). As well as having an indirect effect on water quality via its impact on vegetation, livestock in riparian areas may also have a direct impact on water quality through fouling of the water, and increased soil erosion through both the physical disturbance of the soil and the formation of bare walking tracks and pads (Williamson et al. 1992).

Table 1: Summary of previous studies demonstrating decreased streambank erosion and improved water quality outcomes with improved condition of riparian vegetation.

What was assessed where	What was found	Source
Compared water quality in three land uses (agricultural *vs*. eucalypt plantations *vs*. native forests) along nine streams in the Gilgel Gibe catchment, southwestern Ethiopia.	Both species richness and diversity values of forest sites were significantly higher than agricultural sites. Similarly, stream water quality deterioration indicator gradient such as total suspended solid, water turbidity, and orthophosphate were significantly lower in forest than in agricultural sites.	Alemu et al., 2018
Four paired sites in, with each pair consisting of four woody riparian vegetation, and four grass-dominated vegetation. Each set of paired sites were located within 1.5 km of each other in the Lake Baroon catchment, subtropical Queensland.	Found less P was exported from wooded riparian zones, irrespective of the scale of rainfall. But for N leaching losses from riparian zones, this depended on both vegetative uptake and soil microbial processes, the relative importance of which was driven by hydrological conditions (i.e., rainfall).	Neilen et al., 2017
Uses a randomised block design was used to assess water quality changes resulting from converting plots previously used for corn production into short-rotation willows harvested for biofuel in riparian buffer zone, Connecticut, USA.	Significantly lower concentrations of total nitrogen (41%) and total phosphorus (53%) were observed in overland flow from willow plots than from corn plots. Shallow ground water concentrations at the edge of willow plots were also lower in total nitrogen (56%) and NOx (64%), but 35% higher in total phosphorus. Suspended solid concentration were also lower (71%) in overland flow associated with willow compared to corn.	Rosa et al., 2017
Compared the water quality at 21 sites in catchment areas with different land uses (pristine forest, native forest, exotic forest plantation, and agricultural land) in the Araucanía and Los Ríos Regions of Chile.	Water quality (nutrient concentration and suspended solids) was poor plantations and agricultural land, whereas water quality and other indicators of water health (e.g. macroinvertebrates etc.) was highest in the pristine and native forests.	Fierro et al., 2017
Used four paired sites (regrowth forests *cf*. degraded pasture) in the Baroon Pocket Dam catchment, Mary River, south-east Queensland to assess the impact of regrowth of riparian vegetation on condition score, channel width, slope complexity and soil nutrients.	The condition score average 34 in the regrowth sites and only 13 in the degraded paired sites. The regrowth sites had a higher cover of canopy, low ground cover and organic litter. Channel complexity was also significantly higher in the regrowth sites. Although there was less nutrients in soils under regrowth than in degraded pasture sites, this is not indicative of a poorer nutrient retention capacity given the study did not account for the possibility of increased assimilation of nutrients due to the relatively high biomass of the regrowth stands, nor likely higher soil C content and hence, higher rates of denitrification.	Laceby et al., 2017
Related water quality measurements to the extent of riparian vegetation within four streams in the Russell and Mulgrave catchments of the wet tropics, Qld.	NOx concentrations and loads were significantly lower in streams with greater riparian vegetation cover, width, age and condition score.	Connolly et al., 2015
Compared nitrate and phosphorus supply rates to the riparian zone in woody and non-woody buffers on agricultural land in four study sites in southern Québec, Canada.	Site level comparisons between agricultural buffer types suggest that 9-year-old poplar buffers have stored 4-10 times more biomass N and 3-7 times more biomass P than adjacent herbaceous buffers. As a result, soil NO_3 and	Fortier et al., 2015

	P supply rates during the summer were respectively 57% and 66% lower in 9-year old poplar buffers than in adjacent herbaceous buffers.	
Studying the Moreton Bay catchment, Queensland, sediment and nutrient loads were measured in 186 flow events across 22 sub-catchments with different proportions of remnant woodland.	The sediment yield per unit area from a catchment containing no remnant vegetation was predicted to be between 50 and 200 times that of a fully vegetated channel network; total phosphorus between 25 and 60 times; total nitrogen between 1.6 and 4.1 times.	Olley et al., 2015
Five streams in catchments with pastoral dairy farming as the dominant land use were monitored for periods of 7–16 years to detect changes in response to adoption of best management practices (BMPs).	Trend analysis showed a decrease in suspended sediment concentration for all streams, generally increasing water clarity, and lower *E. coli* concentrations in three of the streams. These are attributed to improved stream fencing (cattle exclusion) and greater use of irrigation for treated effluent disposal with less reliance on pond systems discharging to streams.	Wilcock et al., 2013
A paired-catchment design on four river reaches was used to compare restored riparian buffers (2-20 years old) with control sites upstream. Measured water quality. Lake Ellesmere catchment, New Zealand.	Riparian restoration had a positive effect on water quality in terms of increasing dissolved oxygen and decreasing turbidity.	Collins et al., 2013
Five paired sites (unvegetated vs. revegetated) assessments of channel erosion scores in East Gippsland and North East Victoria.	80-95% decrease in channel erosion score after 13-18 years.	Hardie et al., 2012
Compared streambank erosion (via pin plot assessment) in contrasting land uses (cropping *vs*. grazing *vs*. grass filters *vs*. forest buffers) along streams in eastern Iowa, USA.	Riparian forest buffers had the lowest streambank erosion rates and contributed the least soil and phosphorous to stream channels. The next best was grass filters followed by pasture where cattle were fenced out of the stream. Cropped fields had the highest streambank erosion rates and soil losses and very high phosphorus losses.	Zaimes, et al., 2008
Livestock exclusion, rock placement and natural regeneration (herbs, shrubs and trees) 3-4 m from the bank, Spring Creek catchment, Pennsylvania, USA	3-4 years after riparian treatments, vegetation increased from <50% to 100% in the formally grazed riparian areas, and suspended sediment in stream flows decreased by 47-87%.	Carline and Walsh, 2007
Compared 14 livestock exclosures and adjacent grazed areas, upper Columbia River basin	Greater bank stability and smaller width-to-depth ratio when livestock were removed.	Coles-Ritchie et al., 2007
Studied infiltration and update of nutrients from aritifical runoff in grass *vs*. grass-shrub riparian buffers, Northeastern Kansas, USA.	Found that including shrubs in the buffer decreased nutrient runoff, mainly due to an increase in infiltration. This impact on improved water quality was even greater than an increase in the width of the buffer.	Mankin et al., 2007
Erosion pin monitoring over three years in the Daintree catchment	Streambank erosion rates were 6.5 times (or 85%) lower with cf. without riparian vegetation	Bartley et al., 2008
Undertook 3-year monitoring of runoff and subsurface flow under 10 m wide buffers of 3-6 year old *E. globulus* plantations near Albany, Western Australia.	The *E. globulus* reduced total phosphorus, filterable reactive phosphorus, total nitrogen and suspended sediment loads from surface runoff by 10 and 40%.	McKergow et al., 2006a,b

Assessed nine riparian buffer zone schemes in North Island, New Zealand that had been fenced and planted (age range from 2 to 24 years) and compared them with unbuffered control reaches upstream or nearby.	Generally, streams within buffer zones showed rapid improvements in visual water clarity and channel stability, but nutrient contamination responses were variable.	Parkyn et al., 2003
Undertook 10-year monitoring of stream nutrients and sediment pre- and post- cattle exclusion and revegetation of a riparian area in Albany, Western Australia	Fencing off and actively revegetating streams with eucalyptus species can reduce sediment yields by 90%, but in sandy soils with low phosphorus retention, although N exports decreased, P exports did not.	McKergow et al., 2001, 2003
Monitoring stream nutrients and sediment pre- and post- dairy cattle exclusion and revegetation of a riparian area in North Carolina, USA.	Weekly nutrient (Nitrate, nitrite, TN and TP) and sediment concentration decreased by 30-82% when the grazed riparian area had livestock excluded and riparian vegetation (hardwood and softwood trees) had been established for <3 years.	Line et al., 2000
Using nutrient budget modelling to estimate the retainment of nutrients (N and P) in riparian forests within the Chesapeaka Bay catchment, USA.	Where most of the excess precipitation moves across, in, or near the root zone of the riparian vegetation, 50%–90% of the total loading of nitrate was retained in shallow groundwater, sediment in surface runoff, and total N in both surface runoff and groundwater. Retention of phosphorus is generally much less. In regions with deeper soils and/or greater regional groundwater recharge the retention of nutrients was much less.	Lowrance et al., 1997
Measurement of sediment and nutrient loads before and after stock exclusions and revegetation treatments were applied across a 73 km^2 catchment, Lake Rotorua catchment, New Zealand.	After implementation, the load changed by -85% for sediment, -27% for particulate P, -26% for soluble P, -40% for the particulate N, and +26^ for the dissolved N.	Williamson et al., 1996
Monitoring stream sediment pre- and post- cattle exclusion of a wooded riparian area in Ohio, USA.	Despite similar rainfall, annual sediment concentration decreased by more than 50% in the 5 years of cattle exclusion from the wooded riparian area *cf*. to the proceeding 7 years of continuous cattle grazing.	Owens et al., 1996
Four flooded streams in southern British Columbia	Using pre- and post-aerial photography of 748 river bends, it was found that river bends with riparian vegetation were nearly five times less likely to undergo erosion during a flood event than non-vegetated bends.	Beeson and Doyle, 1995
Assessed vegetation growth and improved water quality 17 years after revegetation of the Whangamata Stream, which flows into Lake Taupo (Taupomoana), New Zealand.	Found by 6 years, rapid growth of vegetation had stabilised the banks and improved water quality. After 7-12 years, channel vegetation acted as a nutrient filter, further improving water quality. Development of a diverse bank flora improved wildlife habitat. After 13-17 years there was increased shading of the channel, better fish passage but decreasing nutrient filtration ability.	Howard-Williams and Pickmere, 1994
In an experimental area in southern Sweden, compared the surface runoff extent between grass and beech buffers that had a the same slope, and were separated by only 50 m.	Surface runoff extended a distance of at least 16 m on the grass strips, while all the water disappeared after only 4 m along the beech strip.	Vought et al., 1994, 1995

Monitored nutrients (N and P) from lysimeters located in cropped areas and adjacent riparian forests, on the Embarras River, Illinois, USA.	On an annual basis the forested areas were more effective at reducing nitrate cf. cropped areas, but were less efficient at retaining total and dissolved P.	Osborne and Kovacic, 1993
Five streams in the South Island, New Zealand that had both grazed and 'retired; reaches.	Grazing mainly impacted the channel form (namely erosion resulting from undercutting) of small streams (<2 m) under intensive grazing. But the dominate form of erosion of channel migration was not related to grazing.	Williamson et al., 1992
Tauwhara catchment, near Hamilton, New Zealand.	Sediment and nutrient concentration in run-off events were significantly lower in ungrazed cf. grazed riparian grasses.	Smith, 1989
150 m mixed woodland, Schleswig-Holstein, northern Germany.	Found that the mean nitrate concentration in subsurface water significantly decreased in the forest buffer when compared to the permanent pasture.	Knauer and Mander, 1989
Garonne Valley, Southern France.	Found that the mean nitrate concentration in subsurface water significantly decreased as a result of the forest riparian buffer.	Pinay and Decamps, 1988
50 m pine forest riparian buffers, North Carolina, USA	Found that the mean nitrate concentration in subsurface water significantly decreased as a result of the forest buffer.	Jacobs and Gilliam, 1985
Nutrient (N and P) monitoring in surface runoff in cropland *cf*. an adjacent riparian forest on the Rhode River, Maryland, USA	The ~50 m riparian buffer was effective at nutrient removal and limiting the diffuse-source of nutrient inflow. Mean annual concentrations of N and P in surface runoff were reduced by 83% and 81 respectively with the major proportion removed in the first 19 months of the forest.	Peterjohn and Correll, 1984
Monitoring of soil and ground water nutrients content flowing into and out of a forested riparian zone situated within an agricultural watershed in catchments of the Little River, Georgia, USA	Nutrient update and removal by soil and vegetation in the riparian forest prevented output from agricultural uplands from reaching the stream channel.	Lowrance et al., 1984

Table 2: Summary of some previous studies demonstrating that high livestock grazing intensities can supress riparian vegetation in Australia.

What was assessed where	What was found	Source
Monitored the cover and biomass production in low intensity grazing (only 01.3-0.6 DSE/ha/yr) and non-grazed plots in *E. camaldulensis* dominated woodlands, Barmah-Millewa forest area, NSW.	Total cover was slightly but significantly lower in grazed than in non-grazed plots (43.4% vs. 50.8%).	Lunt et al., 2007
A comparison grazed and non-grazed riparian habitats in two case study regions: Blackwood River south of Perth, and the Ord River in the Kimberley, WA.	Grazing had a strong influence on the size distribution of tree species, particularly in the Blackwood River. However, due to the occasional high volume floods that occur in the Ord River area, the vegetation is adapted to disturbances and therefore appeared to be less prone to cattle disturbance.	Pettit et al., 2001
Assessed riparian vegetation condition score (e.g. cover and structural complexity, etc.) at 146 sites of varying livestock grazing intensities on the Murray and Murrumbidgee Rivers, Murray-Darling Basin, NSW.	Riparian condition score was lower in paddocks with higher stocking rates of livestock, where there are no periods of rest from grazing and where there are no sources of alternative water provided.	Jansen and Robertson, 2001
Diversity, density and biomass measurement within grazed and non-grazed riparian areas of mainstream and tributaries of the Murrumbidgee River, NSW.	Seedlings and saplings of dominant Eucalyptus tree species were up to three orders of magnitude more abundant in areas with no stock access, and the biomass of groundcover plants was an order of magnitude greater in areas with no stock access.	Robertson and Rowling, 2000

1.3 Requirements for successful outcomes for the GBR

With the Australian and Queensland governments investing $2 billion to improve water quality and thus, GBR health (QG, 2017a), it is important to ascertain the key requirements for ensuring riparian remediation projects are successful in contributing to this goal. This will require four considerations, as outlined below.

Success may take years to realise. Although there is much evidence of the benefits of riparian vegetation on water quality (Table 1), such indications of successful remediation of riparian vegetation become increasingly evident over time (e.g. Sanger et al. 2008; Lennox et al. 2011; Feld et al. 2011), and therefore, may take many years to realise. Some have found little benefit to sediment yields within the first 3–10 years of remediation with woody vegetation (e.g. Marsh et al. 2004; Harrison et al. 2004; McKergow et al. 2006a,b; Hughes et al. 2012), particularly where there are morphological trajectories of stream widening and deepening resulting in legacy effects of previous clearing of vegetation on water quality (e.g. McBride et al. 2010; Dosskey et al. 2011; Kristensen et al. 2014).

Management practices will be an influencing factor. Management decision influence the type, structure, density and position of riparian vegetation, and these factors will in turn modify the structural and hydrological benefits that this vegetation provides (e.g. Croke et al. 2017). This is summarised in the review of Best Management Practices (BMPs) for improved water quality outcomes from riparian remediation projects (Appendix A). However, these generic BMPs represent ideal management given unlimited resources and the sole goal of improving water quality outcomes. There is a need to ascertain what management practices have actually been implemented in past riparian remediation investments, and whether they are indeed successful in generating vegetation that provides the structural and hydrological benefits required to contribute to improved water quality. Although current Australian Government grants for addressing streambank erosion require basic condition monitoring (i.e. assessment of vegetation cover and erosion associated with documentation of management and rainfall conditions, Table 5 of Wilkinson et al. 2016), this was not the case for previous investments made under earlier incentive schemes.

Necessity of widespread landholder uptake. Even if well managed, small isolated patches of new vegetation may have little overall effect on water quality at the catchment scale, and indeed if poorly placed, may only serve to shift the focus of erosive stream energy downstream (Wilkinson et al. 2016). Hence, as outline in the Reef 2050 plan (QG, 2017a), strategies designed by the Australian and Queensland governments to encourage widespread landholder participation in riparian remediation projects will be most successful when they promote the drivers for engagement by landholders, and address the barriers to participation in riparian remediation projects. There have been numerous social surveys undertaken of landholders within GBR catchments to ascertain their motivations and barriers for participation in riparian remediation projects (e.g. Vanclay & Lawrence 1995; Herr et al. 2004; Lockie and Rockloff 2005; Lankester et al. 2009; Januchowski-Hartley et al. 2012). To ensure this work is succinctly communicated to policy makers designing programs for incentivising riparian restoration projects, it is timely to review results from these surveys.

Incentive schemes. Previous and current government incentive schemes for riparian remediation projects in GBR catchments have been based on one-off grants for project establishment. But given such government grants have limited resources, to further increase incentives for landholders to improve long-term water quality outcomes for the GBR, NRM bodies and industry are trialling a new incentive scheme; Reef Credits (GreenCollar 2018). Reef Credits is a voluntary scheme to incentive landholders by paying for water quality improvements and other environmental benefits arising from improved land management. Hence, there is currently interest in incentivising widespread uptake of well managed riparian remediation projects by expanding the metrics of success to include not just benefits to water quality, but also other environmental benefits such as improved biodiversity and contributing to mitigation of climate change through the biosequestration of carbon. It is therefore also timely to improve the evidence-base for underpinning methodologies that provide standard quantification of biodiversity and biosequestration outcomes, thereby building confidence in emerging schemes that provide landholder stewardship payments, e.g. environmental market-based incentives that bundle or stack credits from multiple environmental services (Ribaudo 1998; Rolfe et al. 2006; Kapambwe and Keenan 2009; Woodward, 2011).

1.4 Objectives and scope

Despite decades of previous investments by government into riparian zone management in catchments draining to the GBR, there has been little investigation into whether these previous investments have been successful at both the project-scale (i.e. does a healthy stand of riparian vegetation result in improved water quality), and also in terms of incentivising participation by landholders at the scale required to achieve real outcomes to GBR health. There is also a paucity in data to quantify the co-benefits (i.e. biodiversity and biosequestration) that riparian remediation projects may provide, and whether these can be harnessed in alternative investment schemes. To address these issues, the objective of this study was to answer three key questions:

1. **Project-scale success: Learnings from previous investments**. Have previous investments in riparian remediation projects in the GBR been successful in improving water quality (as indicated by a condition score), and which management practices do landholders considered to be important in ensuring success?
2. **Catchment-scale success: Review of requirements for widespread landholder participation**. What are the key drivers and barriers for landholder participation in riparian remediation projects at the scale required to achieve GBR health outcomes, and does this imply a role for alternative incentive schemes?
3. **Expanding the metrics of success: Assessment of multiple benefits**. Can the definition of success be expanded to include not just improved water quality outcomes, but also biodiversity and biosequestration benefits, and how can these multiple benefits be utilised by policy makers in alternative incentive schemes?

Although inflow of sediment to the GBR may be decreased following system repair more broadly than remediation of only riparian areas (e.g. Wilkinson et al. 2016; Hairsine 2017), other NESP TWQ projects are addressing the effectiveness of remediation of gullies (Bartley et al. 2017) and wetlands (Waltham et. al. 2018). Hence, the work reported here explores the effectiveness of riparian (i.e. stream banks and immediately contiguous land) remediation projects only. Our focus is on how government resources available for revegetation and/or facilitation of natural regeneration of vegetation in riparian zones can be best focused to maximise outcomes for GBR health. We assume policy makers are already aware of the primary importance of protecting remaining remnant vegetation given it is much more cost-effective to protect these areas than to rehabilitate them later after poor management.

2.0 METHODOLOGY

2.1 Project-scale success: Learnings from previous investments

2.1.1 Field-based assessments

To gain some insight into whether previous investments in riparian remediation projects have been successful, field assessments were undertaken at 41 project areas of known age and management regime (Table 3, Appendix B and C). These included both revegetation and regeneration project types undertaken in areas of land used for either cropping (sugarcane or bananas), cattle grazing (of a range of intensities), or urban development. The ages of the projects ranged from 3–35 years. For six study sites with relatively low stocking density and/or small size, the entire project area was assessed. For all other study sites, 5–32 transects were used for assessment, depending on the size of the project area. All transects were 5 m width. But transect lengths varied (between 3–221 m) within and between sites based on the width of the riparian project area (Appendix C), with total transects lengths measured varying from 100 m in relatively small sites to up to 2,236 m in relatively large sites (Table 3).

Table 3: Key characteristics of the 41 study sites across which field assessments were undertaken in five key sub-regions (Cairns Coastal, Atherton Tablelands, Upper Fitzroy, Dawson, and Mary River) of GBR catchments. Grazing length was categorised as either none, light, moderate or high when the length of dry season grazing was 0 months, ≤2 months or accidental grazing only, 3–8 months, and ≥9 months, respectively.

Site No.	Type of project	Project age (years)	Grazing length	Number of transects (and total length, m)	Area measured (ha)
	Wet Tropics NRM region; Cairns Coastal sub-region				
1	Revegetation; Sugarcane/Urban	8	None	27 (727)	0.36
2	Revegetation; Sugarcane/Urban	8	None	5 (151)	0.08
3	Revegetation; Sugarcane/Urban	8	None	8 (195)	0.10
4	Revegetation; Sugarcane	25	None	11 (330)	0.17
5	Revegetation; Sugarcane	14	None	24 (262)	0.13
6	Revegetation; Sugarcane	3	None	all	0.33
7	Revegetation; Sugarcane	11	None	all	0.86
14	Revegetation; Sugarcane	3	None	10 (175)	0.09
19	Revegetation; Urban	35	None	7 (266)	0.13
	Wet Tropics NRM region; Atherton Tablelands sub-region				
8	Revegetation; Cattle grazing	23	None	18 (455)	0.23
9	Revegetation; Cattle grazing	19	None	16 (428)	0.21
10	Revegetation; Cattle grazing	13	None	12 (485)	0.24
11	Revegetation; Cattle grazing	13	None	8 (100)	0.05
12	Revegetation; Cattle grazing	19	None	all	0.08
13	Revegetation; Cattle grazing	6	None	13 (400)	0.20
15	Revegetation; Cattle grazing	17	None	12 (403)	0.20
16	Revegetation; Cattle grazing	24	None	8 (191)	0.10
17	Revegetation; Cattle grazing	14	None	10 (367)	0.18
18	Revegetation; Cattle grazing	26	None	9 (226)	0.11
	Fitzroy NRM region; Upper Fitzroy sub-region				
20	Regeneration; Cattle grazing	4	Light	20 (1804)	0.90
21	Regeneration; Cattle grazing	5	High	25 (817)	0.41
22	Regeneration; Cattle grazing	5	High	22 (2157)	1.08

23	Regeneration; Cattle grazing	5	Moderate	22 (1054)	0.53
24	Regeneration; Cattle grazing	5	Moderate	20 (1000)	0.50
Fitzroy NRM region; Dawson sub-region					
25	Regeneration; Cropping/Cattle grazing	8	Moderate	30 (1512)	0.76
26	Regeneration; Cattle grazing	5	Moderate	26 (1523)	0.76
27	Regeneration; Cropping/Cattle grazing	3	Light	20 (1373)	0.69
28	Regeneration; Cropping/Cattle grazing	3	Light	32 (1136)	0.57
29	Regeneration; Cattle grazing	4	Moderate	20 (2236)	1.12
Burnett Mary NRM region; Mary sub-region					
30	Revegetation; Cattle grazing	20	Light	13 (363)	0.18
31	Revegetation; Urban	14	None	20 (415)	0.21
32	Revegetation; Cattle grazing	5	Light	8 (249)	0.12
33	Revegetation; Cattle grazing	20	Light	7 (255)	0.13
34	Regeneration; Cattle grazing	32	None	12 (645)	0.30
35	Revegetation; Urban	27	None	6 (441)	0.22
36	Regeneration; Bananas	17	None	5 (309)	0.15
37	Regeneration; Cattle grazing	21	Light	6 (534)	0.27
38	Revegetation; Cattle grazing	14	Light	all	0.07
39	Revegetation; Cattle grazing	9	Light	all	0.06
40	Revegetation; Cattle grazing	8	Light	all	0.04
41	Regeneration; Cattle grazing	32	None	8 (262)	0.10

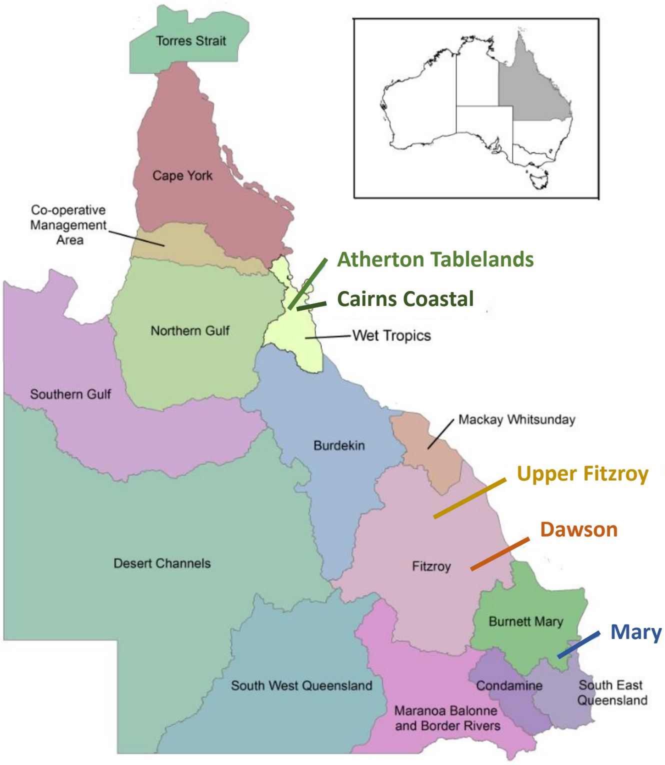

Figure 1: The five key sub-regions (Cairns Coastal, Atherton Tablelands, Upper Fitzroy, Dawson, and Mary River) across which study sites were assessed. The 'Cairns Coastal' and 'Atherton Tablelands' region encompasses sites in the Mulgrave-Russell River, Johnstone River and Barron River catchments.

Although it was beyond the scope of this study to measure the influence of the riparian remediation project on water quality *per se*, the Tropical Rapid Appraisal of Riparian Condition (TRARC, Dixon et al. 2006) assessment was used as a simple surrogate of this. TRARC provides 24 scores from transect-based visual assessment that are grouped into indices of condition of the riparian zone. These are grouped into four indices- each contributing a maximum value of 25 (Fig. 2). These four indices then sum to derive the overall condition score (maximum value of 100). Other ‘disturbance’ factors, such as measure of average riparian buffer width when compared to average stream width (i.e. Tree Clearing), were also assessed to derive the TRARC Pressure Score (also a maximum value of 100).

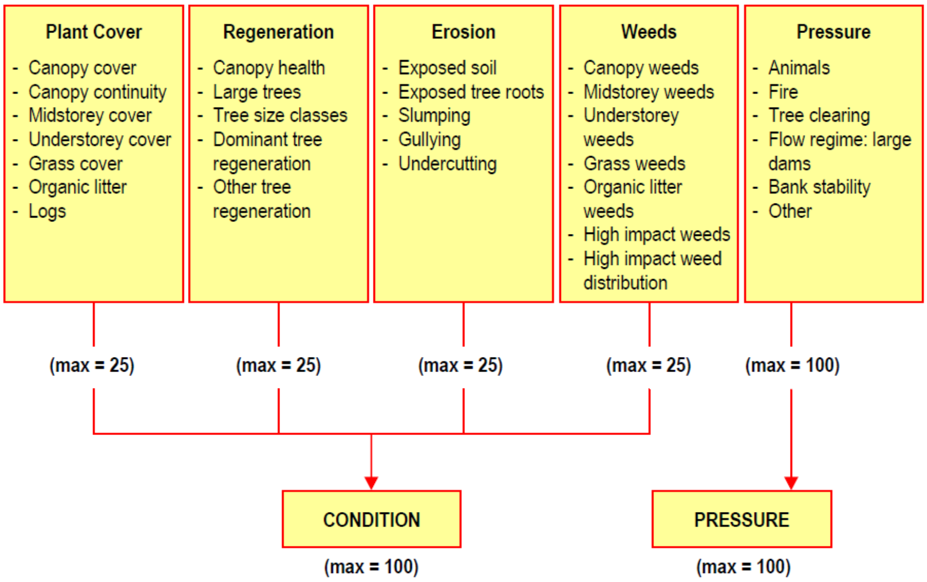

Figure 2: TRARC, whereby visually assessed Indicators are grouped into five categories (sub-indices) that can be combined to give an overall Condition Score and Pressure Score for the study area.

These visual assessment scores were obtained for the lower, mid and upper reaches of each transect measured at the Fitzroy study sites, with the weighted average values of indies and scores being derived in accordance with the relative contribution of each of these sections to the total width of the project. This was done for the study sites assessed in the Upper Fitzroy and Dawson sub-regions. But given their generally smaller size and more uniform characteristics, visual assessment scores for the study sites in the Cairns Coastal, Atherton Tablelands and Mary sub-regions were noted as a subjective weighted average for the project area.

We explored whether there was any indication that the trends for increased Condition Score with project age differed between revegetation and regeneration projects, and particularly, the grazing intensity of the study sites. We also explored which indices of the Condition Score tended to contribute to this increase in both revegetation and regeneration project types.

It should be noted that the TRARC Condition Score is designed to indicate the condition with respect to intact and undisturbed vegetation. It therefore will provide an indication of the extent to which a riparian remediation project has approached full rehabilitation. Clearly full rehabilitation may not be necessary to maximise the impact of riparian remediation on improved water quality outcomes, e.g. some weeds can be beneficial in reducing stream bank erosion. However, it was beyond the scope of this study to develop a refined condition score that reflects these impacts more directly.

2.1.2 Social surveys

Face-to-face semi-formal social surveys (largely open questions, with some prompt options provided for some of these) were conducted by regional representatives from Regional NRM Bodies and Councils and/or Landcare Groups. These were undertaken for 42 landholders that between them manage 52 riparian remediation projects covering various bioregions:

- Nine revegetation projects on land used for sugarcane or urban developing within the Cairns Coastal sub-region, Wet Tropics NRM region (Table 3);
- Ten revegetation projects on land used for cattle grazing in the Atherton Tablelands sub-region, Wet Tropics NRM region (Table 3);
- Five regeneration projects on land used for cattle grazing in the Upper Fitzroy sub-region, Fitzroy NRM region (Table 3);
- Five regeneration projects on land used for cattle grazing and/or cropping in the Dawson sub-region, Fitzroy NRM region (Table 3), and;
- An additional 23 study sites from a related project (FBA 2017), with these all being located on land used for cattle grazing in the Fitzroy NRM region.

The face-to-face interviews were used to explore the extent to which landholders agree with and implement some of the key practices outlined in generic BMPs summarised in Appendix A, and whether management practices vary by region. Landholders were also asked why they had undertaken their riparian remediation projects. Table 4 outlines some of the prompts provided to landholders.

Table 4: Prompts given to landholders when asked how they managed their riparian areas, what they consider are the key drivers of success of riparian remediation projects, and why their project was undertaken.

Region	Prompts used
	Management practices used
Wet Tropics	- Only plant species known to be competitive and have high survival rates? - Protecting tube stocks used, e.g. tree guards? - Mulching at establishment used? - Weed mats at establishment used? - Totally closed off to grazing? - Fencing the riparian zone, and fence maintenance? - Off-stream watering point installed (such as a trough)? - Grazing used as a management tool to reduce fuel load. If so, continuous or rotational? - Grazing used as a management tool to reduce weeds. If so, continuous or rotational? - Fire used to manage weeds and competition from grasses. If so, how often? - Mowing weeds/grass. If so, how often? - Herbicide. If so, how often? - Pest control used? If so, how are these pests/feral animals controlled? - Other?
Fitzroy	- Totally closed off to grazing? - If grazed, what time of year and for how long? - Grazing used as a management tool to reduce fuel load? - Wet season spelling used? - Fire used to manage riparian areas?
	Key drivers of what landholders perceived to be successful projects
All	- Well placed in area where risk of erosion or flood damage is minimised - Good mix of species a key driver of success? - Regular control of weeds a key driver of success? - Regular control of feral animals a key driver of success? - Managing grazing

	- Managing fire - Other
Goals: Why the project was undertaken	
Wet Tropics	- Improved health of the waterway - Landscape rehabilitation, e.g. repair or prevent erosion within a creek/river bank - Part of overall improved environmental outcomes for my property, e.g. whole farm planning - Biodiversity benefits - Mitigation of climate change via sequestering carbon - Employment/funding opportunities - Improved aesthetics and/or land values - Provision of stock shelter - Other
Fitzroy	- Prevent the risk of erosion in a creek/river bank - Repair erosion within a creek/river bank - Stop cattle from watering and potentially causing erosion - Protect existing remnant vegetation for biodiversity - Manage frontage country for improved ground cover - Improve water quality within the stream/river – less sediment runoff - Other
Open question	
All	- What advice would you give other land managers doing this kind of project, and is there anything that region partners or others could do to better support projects in future?

2.2 Catchment-scale success: Review of requirements for widespread landholder participation

2.2.1 Drivers and barriers for landholder participation

We reviewed the numerous previous surveys of Australian landholders to improve our understanding of what key factors determine the uptake of riparian remediation projects; either revegetation and maintaining existing remnant vegetation, or spelling riparian pasture or fencing off waterways for livestock exclusion. This review mostly focused on surveys of landholders with riparian areas in GBR catchments. The results were summarised in terms of key drivers for engagement/uptake, and barriers to uptake of riparian remediation projects or best management practices of riparian zones.

Although the social survey undertaken in this study (Section 2.1.2) was largely utilised to inform project-based success, useful insights into requirements for catchment-scale success were also obtained given the interviews provided the opportunity for landholders to provide suggestions on how the support for riparian remediation projects could be improved. These suggestions were documented in relation to the key drivers and barriers for landholder participation.

2.2.2 Alternative incentive schemes

Consideration of the drivers and barriers for landholder participation raises the related question of what incentive schemes are likely to be the most successful. Therefore, we also reviewed alternatives incentive schemes. The focus was on Australian case studies of the Emission Reduction Fund, and opportunities presented from emerging markets that bundle or stack credits from multiple environmental benefits.

2.3 Expanding the metrics of success: Assessment of multiple benefits

An assessment of both biodiversity benefits and biomass carbon were made at each of the 41 study sites listed in Table 3 (Section 2.1.1).

2.3.1 Biodiversity benefit

For each of the 41 study sites, assessments were made of the two key requirements for biodiversity benefits (LWA 2003; Clark et al. 2015):

1. Condition of the project, including factors such as tree health, understorey diversity, structural diversity, number of tree hollows and weediness. The TRARC Plant Cover Index (Fig. 7, Section 2.2.3) was applied, with the more comprehensive *monitoring* of biodiversity (e.g. Kanowski and Catterall 2007) being beyond the scope of this project.
2. Landscape metrics, including size and connectivity of the project area. Geographical Information Systems (GIS) analysis tools (QG, 2018) were used to quantify the average width of the riparian project areas studied, the longitudinal length riparian project corridor, as well as categorise the connectivity within a 10 km radius of the project area. This categorisation of the 10 km radius area around the project site included:
    1. Fragmented, narrow and evidence of grazing pressure;
    2. Narrow intact vegetation on bank slopes;
    3. Wide (5–10 m) vegetation on adjacent banks, or;
    4. Very wide (>10 m) vegetation on adjacent banks.

Although there have been numerous more complex approaches to measure landscape connectivity (e.g. Tischendorf and Fahrig 2000; Smith 2015; Stirnemann et al. 2015), the pragmatic approach used here for the landscape-scale assessment for biodiversity benefits was consistent with operational TRARC approach of visual assessments for scoring indices for condition at the project-scale.

We explored whether there was any indication that the trends for increased Plant Cover Index with project age differed between revegetation and regeneration projects, and particularly, the grazing intensity of the study sites. We also explored whether the size and the typical connectivity of the project areas differed between the Wet Tropics, Fitzroy and Burnett Mary NRM regions.

2.3.2 Carbon storage and typical rates of sequestration of carbon

At each of the field assessment sites, stem diameters were measured for all trees and shrubs within each of the randomly placed transects, or for six study sites, the entire project area (Table 3). Similar transect-based (5 m wide by 13–69 m long, depending on the width of the riparian buffer zone) measurements of stem diameter were made in previous studies of 63 older (> 20 years) riparian areas in two separate studies (James, C., pers com. 2017). The first of these studies entailed assessment of riparian sites located throughout the South-East Queensland and Burnett Mary NRM regions, with three replicate transects being assessed for each of the 44 riparian sites (James et al. 2016). The second study was of 19 riparian sites located within the Burdekin NRM region, with no transects replication being undertaken.

For all 104 sites where stem diameter measurements were made (41 from this study plus 63 from previous studies), estimates of biomass carbon were made based on the assumption that about 50% of both above-ground biomass (AGB) and below-ground biomass (BGB) is comprised of carbon (Gifford et al. 1999, 2000). To estimate AGB and BGB, we utilised allometric equations that predict biomass based on stem diameter. Such equations have been developed for the main plant functional types in Australia (Paul et al. 2016, 2018b), with these being deemed appropriate to apply to trees or shrubs from the Wet Tropics, Fitzroy and Burnett Mary NRM regions given these equations were derived based on 124 (129), 472 (36) and 737 (57) individual trees or shrubs sampled for ABG (and BGB) from these regions of Queensland, respectively. The total allometry-predicted biomass of all trees and shrubs within each transect was summed, and expressed on a per area basis. This was done separately for remnant and younger regenerated or planted trees or shrubs. These results were then used to estimate the average (± standard error) biomass, and biomass carbon stocks, within all woody vegetation in each riparian remediation project. However, rates of sequestration of biomass in carbon were calculated by considering only the regenerating or planted trees and shrubs within each site given any carbon stocks in pre-existing remnant vegetation was assumed to represents the baseline carbon stock that existed prior to the project commencing. Although additional accumulation of biomass carbon in remnant trees is possible post-project establishment, measurement of this was beyond the scope of the project as longer term monitoring would be required.

In the revegetation stands assessed in the Wet Tropics or Burnett Mary NRM regions, remnant trees could generally be visually distinguished from the younger planted trees. However, there was some uncertainty in this categorisation. Moreover, for stands where there was natural regeneration in the eucalypt woodland regions studies in the Fitzroy NRM region, remnant trees were often numerous and could not be visually distinguished from the younger regenerating trees. However, diameter frequency distributions, assessed on site-by-plant functional type basis, revealed skewing towards the smaller size classes. Hence for regeneration stands, the conservative assumption was made that all individuals greater than the 85^{th} percentile diameter size were remnant individuals, while those smaller than this were assumed to be regeneration attributable to the project. We also explored the impact of assuming this cut off was the less conservative 95^{th} percentile. Similarly, in revegetation stands, we also explore the impact of categorising remnant trees by size class (using both the 85^{th} and 95^{th} percentile) rather than relying on the subjective visual assessment for signs of senesces due to old age.

Taking into account the uncertainty in estimates of biomass carbon, we explored whether there was evidence of increases in biomass carbon with increasing age of the remediation projects, and whether this differs between revegetation and natural regeneration project types. Estimates were also provided for typical rates of sequestration of carbon in these various project types. Given the management regime tended to be related to the bioclimatic region (e.g. revegetation projects are common in the Wet Tropics NRM region while natural regeneration projects are common in the Fitzroy NRM region), this confounded our dataset. It was therefore not statistically viable to assess the impact on biomass carbon of factors such as the bioclimatic region, or whether or not the stand was grazed.

3.0 RESULTS AND DISCUSSION

3.1 Project-scale success: Learnings from previous investments

3.1.1 Is there evidence of success of previous investments?

Across all the ecoregions studied, there was an indication that the Condition Score (Fig. 2) of riparian remediation projects improves over time (Fig. 3a). Given there was no relationship between Weed Index, Erosion Index and Plant Cover Index with age of project, the improvement in Condition Score appeared to be mainly attributable to an improvement in the Regeneration Index. For projects where there is no grazing, or where grazing periods are relatively short, there was some indication that the Regeneration Index, and hence, the Condition Score, increases with the age of the project (Fig. 3b). However, there was a paucity of data to verify that the Regeneration Index remains supressed over the longer-term when regeneration projects have moderate-to-long grazing periods.

Although the Condition Score assessments do indicate that, in general, current management practices of a range of riparian remediation projects result in an increase in condition (and thus presumably water quality) over time, these Scores appear to plateau at 55–65 rather than continue on a trajectory to an optimal Score of 100. Hence, assuming a 'natural' intact remnant riparian zone has a Condition Scores of 100, even after 35 years of revegetation, the riparian Condition Score has only partially rehabilitated, mainly due to limited sub-index scores for Plant Cover, Erosion and Weeds. This is substantiated by the relatively high Pressure Scores of the project sites measured (data not shown), with these averaging 26–30 for all three ecoregions studied. The main contributor to this pressure was the fact that most project areas had riparian buffer zones that were relatively narrow (i.e. high Tree Clearing score), presumably because landholders were seeking to minimise the areas for revegetation or regeneration in order to maintain agricultural production. Indeed, as discussed further in Section 3.2, although landholders of riparian areas may adopt practices that contribute to improvements in water quality, their key goals tend to be financial.

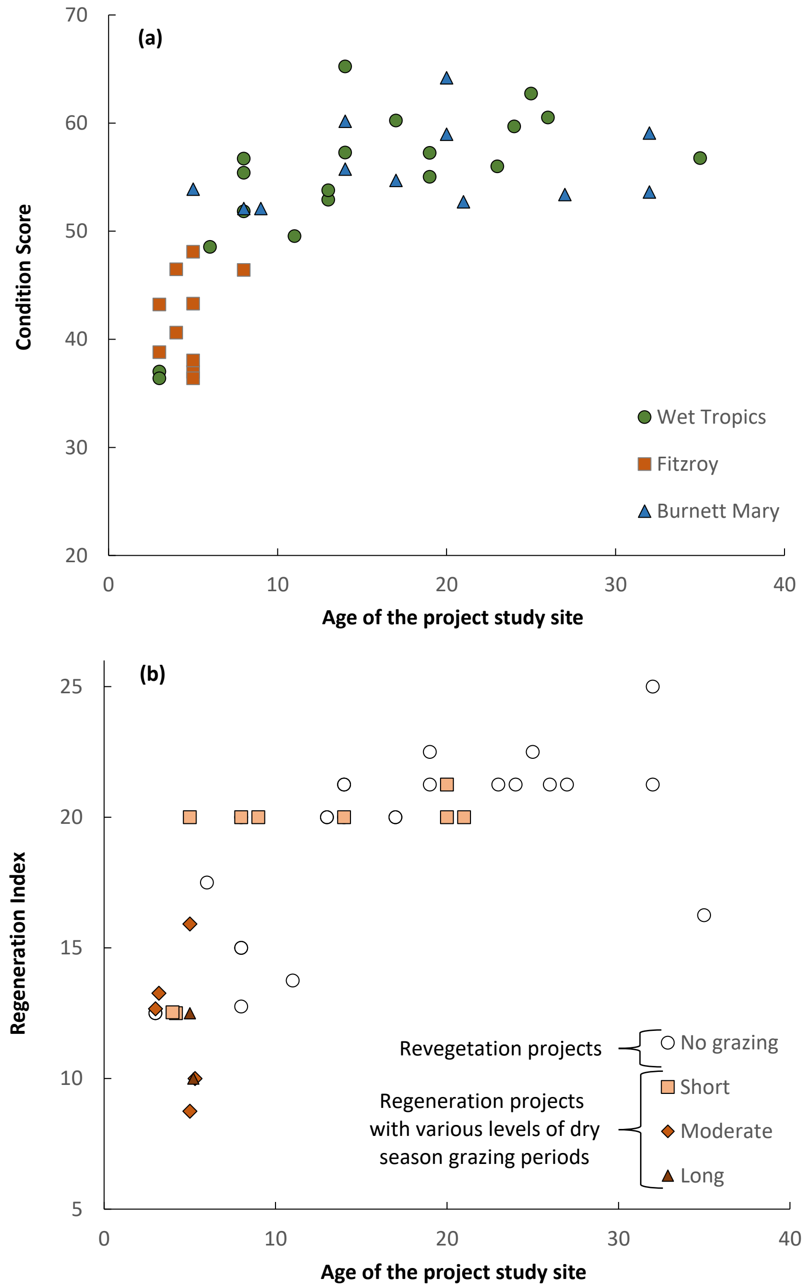

Figure 3: The influence of age of the riparian remediation project on the TRARC (Fig. 2): (a) Condition Score, and; (b) Regeneration Index. Grazing length was categorised as either none, light, moderate or high when the length of dry season grazing was 0 months, ≤2 months or accidental grazing only, 3–8 months, and ≥9 months, respectively.

Nonetheless, attaining a Condition Score of 100, or full rehabilitation (Section 2.1.1), may not be necessary to maximise the impact of riparian remediation on improved water quality outcomes, e.g. some weeds can be beneficial in reducing stream bank erosion. Further work is required to develop a refined condition score that reflects these impacts more directly.

3.1.2 What practices are currently used and considered important?

Revegetation in sugarcane and urban areas of the Cairns Coastal sub-region, Wet Tropics NRM region

All non-pastoralist landholders interviewed in the Cairns Coastal sub-region agreed that weed control was a key driver of what they considered to be a successful project. For weed control, all used herbicide (generally initially 1-2 monthly for the first 1-3 years), and some also used mulching (44%) and mowing (33%). Most (80%) interviewees agreed that having a good mix of species was another key driver of success, and only planted species known to be competitive and have high survival rates. Many interviewees also commented that there was a requirement for watering (67%) and re-planting (e.g. post flood or cyclone damage) until canopy cover/establishment (44%). Very few (<22%) of those interviewed nominated placement of project areas and management of feral animals or fire to be key drivers of success. Although spot cultivation was generally used (e.g. auger attachment operated from a small excavator or dingo digger), very few (<10%) undertook broad-scale cultivation (e.g. tine ripping) prior to planting.

We found a key motivator for almost all (89%) interviewees in this sub-regions was to improve aesthetics and land values. But landscape rehabilitation and improvements in water quality were also important to many (78%). Biodiversity benefits was a driver to undertake revegetation projects for 67% of those interviewed, while sequestration of carbon to mitigate climate change was a driver for only 22%. Obtaining employment benefits or funding, and improving whole farm planning were a key driver for only 22% of those interviewed in this region.

Revegetation in grazed lands in the Atherton Tablelands sub-region, Wet Tropics NRM region

In this sub-region, all landholders interviewed with grazed cattle for either fattening or dairy production agreed that complete exclusion of livestock and weed control were the key drivers of what they considered to be a successful project. Management practices were generally similar to those used by landholders in the Cairns Coastal sub-region, with all landholders interviewed in the Atherton Tablelands also regularly using herbicide (generally initially every 3 months for the first 3 years), and some also using mulching (40%) and mowing (10%) for weed control. Most (67-70%) interviewees also agreed that having a good mix of species and undertaking in-fill planting to replace losses (e.g. after heavy frosts) were other key drivers of success. Very few (<30%) of those interviewed nominated placement of project areas to be key drivers of success, although there were suggestions that project sites need to be selected to ensure they are accessible for weed control. Only 10% mentioned a need for watering at establishment, and none undertook fire management, control of feral animals or broad-scale cultivation (e.g. tine ripping) prior to planting.

Of all the landholder groups we surveyed, those in the Atherton Tablelands sub-region appeared to have the strongest culture of conservation. All landholders from this region agreed that as part of their whole farm planning, riparian remediation projects were undertaken for biodiversity benefits, landscape rehabilitation and improvements in water quality. The focus of the conservation goal was around the provision of wildlife corridors and habitat connectivity. Most (90%) also cited improvements in aesthetics and land value, and the provision of stock shelter, as being important motivators. Another important motivator in this sub-region was employment, with many of the projects we studied being undertaken with assistance from the Wet Tropics Tree Planting scheme that was set up to provide employment to displaced timber workers after the Wet Tropics World Heritage listing.

Natural regeneration in grazed lands in the Fitzroy NRM region

Pastoralist in the Fitzroy NRM region that had fenced off riparian areas for natural regeneration largely agreed (82%) that grazing management was the key driver of success of their projects, with most (79%) confirming grazing was used to control the fuel load. Only 6% of those interviewed had the area totally closed off to grazing. Of those that regularly grazed, none grazed in the wet season months. The number of months that livestock were typically on-site each year were <2, 3-5 or 6-9 for 48%, 33% and 19% of the sites, respectively. Only 18% of interviewees commented that rotational grazing (based on feed or moisture) was used, yet 52% nominated wet season spelling as a management practice they use. Having projects well placed in areas where risk of erosion or flood damage of the project was minimised was nominated another key factor to success by most (70%) pastoralists interviewed as most (88%) of the sites flooded; 52% of which flooded at the relatively high frequency of every 1-2 years. A good mix of species regenerating, and regular control of weeds, were also both nominated by only some (39%) interviewees as being key drivers of success. Fire management was considered a key driver of success by only 15% of those interviewed, with only 9% indicating that fire was used to manage riparian areas. Very few interviewees (12%) nominated regular control of feral animals as being a key driver of success.

The fact that 79% of pastoralist we surveyed in the Fitzroy NRM region used grazing as a management tool to reduce fuel load was consistent with the fact that most (76%) of these pastoralists cited that they were motivated to undertake their riparian remediation project as it provided an opportunity to manage this riparian areas for improved ground cover. Many (61-70%) also mentioned other factors motivating them included stopping cattle from potentially causing streambank erosion, repairing streambank erosion and improving water quality. But only about half of the pastoralist surveyed said they were motivated by protecting existing remnant vegetation for biodiversity.

3.2 Catchment-scale success: Review of requirements for landholder participation widespread

3.2.1 Review: Drivers and barriers for engagement/adoption of BMPs

Previous surveys of landholders in GBR catchments (Table 5) have consistently indicated that the most important drivers for landholder engagement were private benefits, particularly a sense of stewardship and improved landscape aesthetics and property value. Consistent with survey results from other regions of Australia (Qureshi and Harrison 2001; Goodale et al. 2015), broader social benefits obtained from riparian remediation projects (e.g. biodiversity, reduction in greenhouse gas emissions, and recreational values of the catchment) were not generally ranked highly as drivers for engagement by most riparian landholders.

Table 5: Surveys of drivers for engagement/adoption for active revegetation management (e.g. revegetation or maintaining remnant riparian vegetation), for spelling riparian pasture, or fencing off waterways, for livestock exclusion.

What was done	Results found	Source
	Revegetation or maintaining remnant vegetation	
Interviewed 13 landholders from Scheu Creek in the Johnstone River catchment in the Wet Tropics NRM region.	When asked to rank their priorities, economic was by far the greatest (0.63). Well behind this was environmental (0.19) and social (0.17) values. More specifically, the weighted objectives by farmers was, by far, highest (0.35) for minimising loss of crop	1,2

	land. Other factors that were important were a reduction in off-site damage costs (0.15), water-treatment costs (0.13), and the protection of human health (0.13). Other factors (water quality, land stability, habitat, fishing values, recreation values) had much lower value, each with weighted objectives of <0.04.	
Interviewed project participants of the Community Rainforest Reforestation Program (CRRP) which commenced in 1993, and of which 65% entailed revegetation of riparian areas in the Wet Tropics NRM region.	Of participants interviewed, 25% ranked timber production as the primary motivation, and another 20% ranked this as a moderately important factor. Other important motivations were creek bank stabilisation (the primary reason for 20% of respondents). In contrast, <10% ranked as important either land 'rehabilitation and conservation', aesthetics, provision of shade and shelter, and creation of windbreaks.	3,4
Interviewed 14 representative landholders in the Wet Tropics NRM region.	When landholders were asked what motivates them to seek out information and resources to improve operations, most stated a desire to be 'on top of their game', and having a sense of satisfaction in being capable managers.	5
Interviewed 21 landholders (including horticulture, sugar cane production, and cattle grazing) in the Mackay-Whitsunday NRM region.	Of participants interviewed, 62-86% cited biodiversity and improved landscape aesthetics; 48-57% for sense of stewardship and improved landscape aesthetics; 24-52% for reduction of invasive species. In contrast, <10% of respondents indicated other factors (improved production, better access to water for stock, tourism, fishing and fish passage) as being important. Very few respondents indicated improved water quality as a priority in general for public benefit (<5%), or on their own properties for private benefits (<38%).	6
Interviewed 123 landholders with properties that bound the Barron and the South Johnstone Rivers (55% for sugarcane farmers; 10% cattle graziers, and 15% fruit and vegetable farmers) in the Wet Tropics NRM region.	Found that landholders who had traditional practices handed down had relatively weak intentions and showed significant norming behaviour. But appreciation of environmental benefits and functions of streamside forest did have an effect on management practices. They also identified older landholders often had a lack of understanding and acceptance of scientific information on the importance of the riparian zone to the health of the GBR, and had little trust in efficacy of recommended practices for riparian management. They also had a negative view to further regulations to riparian vegetation management.	7
Revegetation or maintaining remnant vegetation		
A two-hour focus group with landholders from the Fitzroy Basin.	When asked to discuss the reasons why fencing to control livestock access to riparian lands were important in their properties, most stated the avoidance of stock losses over a flood season and improved productivity through better pasture management. Public benefits for better riparian management were less important than those private benefits.	8
Interviews with beef producers from 18 family-operated properties in the Burdekin rangelands.	Largely based on the perceived production benefits, e.g. fence and wet season spelling could increase quantity and quality of riparian pastures, easier cattle mustering, off-stream watering points guarantees water supply to cattle, increased chance of lease renewal. But also motivated by desire to practice 'good' stewardship and attachment to the land. However, only management/monitoring of pasture and weeds (not fencing and grazing management per se) was associated with the benefits to improved water quality and ecological condition of riparian areas.	9
Interviewed21 landholders (including horticulture, sugar cane production, and cattle grazing) from the Mackay-Whitsunday NRM region.	Of participants interviewed, 33% cited a sense of stewardship and improved landscape aesthetics, while only 19% cited biodiversity and improved landscape aesthetics. In contrast, other factors (improved production, better access to water for stock, tourism, fishing and fish passage) each had <10% of respondents indicating this was important. None of the land	10

	holders selected 'Improved water quality for public benefit' as a priority. Even on their own properties, <5% selected 'Improved water quality for private benefit' as a priority.	
Interview of 45-55 cattle produces surveyed in the Burdekin NRM region.	Landholders do not focus on ecosystem conservation - specifically native vegetation and revegetation, but they engage in activities related to cattle grazing and pasture management. Higher adoption rates were associated with higher education levels, and with greater financial capacity.	11

[1,2]Qureshi and Harrison (2001, 2003); [3,4]Harrison et al. (2003, 2004); [5]Emtage and Shrestha (2010); [6]Januchowski-Hartley et al. (2012); [7]Flick et al. (2013); [8]Rolfe et al. (2004); [9]Lankester et al. (2009); [10]Januchowski-Hartley et al. (2012); [11]Herr et al. (2013)

These results suggest that landholder knowledge of riparian conservation issues and congruent attitudes are necessary but not sufficient to ensure participation in riparian remediation projects at levels likely to achieve improvements at the landscape scale (Curtis et al. 2003; Rolfe and Gregg 2015). A survey of landholders with riparian zones in the Wet Tropics (Flick et al. 2013) and the Fitzroy and Burdekin catchments (Rolfe and Gregg 2015) showed that participation in riparian remediation projects was not related to information barriers, or the awareness of human impact on local streamside vegetation. Indeed across Australia, most landholders already have a strong stewardship ethic, and differences in attitudes have generally not been linked to increased adoption of BMPs (Curtis and de Lacy 1996; Curtis and Robertson 2003). The review of the literature indicated that there are four main barrier to adoption of BMPs, with these being discussed in order of importance below.

Financial constraints

Limited financial benefits, and a lack of financial security (whether it is perceived or actual), have been identified by as key reasons why landholders do not adopt riparian remediation projects; both in GBR catchments (Vanclay & Lawrence 1995; Herr et al. 2004; Lockie and Rockloff 2005; Lankester et al. 2009; Januchowski-Hartley et al. 2012) and elsewhere in Australia (Rhodes et al. 2002; Curtis and Robertson 2003; Ede 2011; Buckley et al. 2012; Greiner 2015; Conner et al. 2016; Zhong et al. 2016). Many agricultural industries are financing high debts and often small profits, which makes changes in individual management difficult, especially if change is perceived to be risky (Lawrence et al. 2004).

When interviewing cattle pastoralists in the GBR catchments (Fitzroy and Burdekin), Rolfe and Gregg (2015) found that, by far, the most statistically significant factor explaining the limited adoption of riparian remediation projects was financial constraints. A majority of landholders agreed that initial capital costs were too high for adopting rotational grazing practices, and to a lesser extent, pasture spelling activities, in their riparian areas. The constraints are likely to be related to the additional capital costs involved in providing additional fencing and waters for these practices. Similarly, Herr et al. (2013) found that a majority of cattle pastoralists surveyed in the Burdekin were concerned with financial constraints. The top four financial constraints were: excessive initial capital costs (90% agreed); low returns on investment (84%); loss of productivity capacity or property and income (79%), and; high ongoing effort or costs (72%).

Financial constraints are also important to landholders with cropping enterprises within GBR catchments. Most sugarcane growers preferred least costly narrow riparian buffers (Qureshi and Harrison 2001). This is because in cropping areas, landholders see wide buffers as having high opportunity costs (i.e. taking up valuable production land), and they need the space at the end of the cropping field to turn the tractor around (Flick et al. 2013). Consistent with this, when interviewing 14 landholders in the Wet Tropics, Emtage and Shrestha (2010) found that many sugarcane growers have grave concerns for the future financial viability of their industry and their own enterprises. They found a consistent argument made by sugarcane growers was that in order to adopt BMPs their overall industry must be sustainable and financially viable.

As outlined in Section 3.2.2, these results provide support to incentive schemes based on financial benefits.

Peer recognition and norming behaviour

Normalising behaviour is define as ideas and actions that have come to be seen as 'normal' through social processes. Maintaining traditional management practices through normalising behaviour is another important barrier to adoption of riparian remediation projects, with social cohesion (e.g. neighbourhood friendships) positively predicting willingness to implement riparian buffers (Armstron and Stedman 2015). Surveying 54 landholders across the Fitzroy and Burdekin catchments, Rolfe and Gregg (2015) found that adoption of riparian remediation projects was inversely related to the extent to which landholders with mostly traditional management approaches appeared to be content to maintain their operations. Consistent with this, in a survey of 121 land holders with properties that bound the Barron and the South Johnstone Rivers (55% for sugarcane farmers; 10% cattle graziers, and 15% fruit and vegetable farmers), Flick et al. (2013) found that landholders who had traditional practices handed down had significant norming behaviour, with relatively weak intentions for participation in conservation activities.

Prevailing property management norms are most influential within neighbourhoods where there are strong social ties among residents. Given landholders in GBR catchments are motivated through examples from others (Rolfe et al. 2004), promoting a supportive normative climate for riparian BMPs is paramount (Fielding et al. 2005). Hence, community group involvement in local demonstrations of the merits of BMPs is important (Curtis and de Lacy 1998). Indeed, landholders in GBR catchments highly value local demonstrations and trials, obtaining advice from locally based, experienced people involved in agricultural research and development (but not the government), thereby waylaying their concerns about how others see their riparian management (Lankester et al. 2009; Emtage and Shrestha 2010; JRCMA 2013; Flick et al. 2013).

To overcome the normalising behaviour barrier, improved engagement of community groups of landholders is recommended. Some ideas for community engagement that were provided by landholders we surveyed (Section 3.1.2) included facilitating regional-based cooperative groups that will not only keep costs (e.g. for fencing) down through economies of scale, but help landholders learn from each other. Others suggested providing base funding to support experienced Landcare Groups with proven ability in both engagement and education to overcome local issues. Given the production-focused culture of many landholder groups in GBR catchments, to overcome the normalising behaviour barrier, in some regions local demonstrations may be important to demonstrate riparian remediation projects contributing to:

1. Agricultural production benefits via providing numerous off-stream water points that have better quality drinking water for livestock, improved pasture growth via nutrient return from livestock that are more evenly distributed, improved efficiency of mustering,

less loss of livestock (e.g. falling down steep banks, getting stuck in muddy river banks, etc.), livestock sheltering from harsh weather and graze understorey grasses and shrubs (e.g. Ede 2011), increased buffering of crops and pastures from wind, and providing habitat for beneficial animals, e.g. pollinating insects and predators of pests (e.g. Johnson 2001; LWA 2003; ARRC 2017);

2. Whole-farm production benefits such as supplying wood products (e.g. timber, poles, posts, broombush, firewood, charcoal, etc.) or non-wood products (e.g. seeds, essential oils, honey, pharmaceuticals, etc.), and;
3. Increased land values and hence, security for financial loans, with anecdotal evidence from real estate agents suggests that well managed riparian frontage can add up to 10% to the market value of a rural property (ARRC 2017).

In contrast to many regions where there are normalising behaviours barriers, in other regions, there is potential for utilising community goodwill to volunteer labour for riparian remediation works in these areas. For example, our survey results obtained from the Atherton Tablelands and urban areas (Section 3.1.2) indicated that the community appreciates additional benefits from riparian remediation projects through increased income from recreation and ecotourism, e.g. bird watching habitat, canoeing, walking trails and other activities compatible with rivers and their adjacent lands (ARRC 2017).

Risk and uncertainty

Numerous studies (Herr et al. 2005; Greiner et al. 2009; Greiner and Gregg 2011; Januchowski-Hartley et al. 2012) have identified perceptions of risk (e.g. impractical programs) and government mistrust (sovereign risk) as key barriers to adoption of riparian remediation projects the GBR catchments. Similar results have been obtained in other regions of Australia (e.g. Parminter et al. 1998; Curtis and Robertson 2003; Ede 2011; Curtis and Race 2012). For example, when assessing which impediments to conservation practices had a medium-high ranking, Herr et al. (2013) found that 58-69% of cattle produces surveyed in the Burdekin nominated factors such as uncertainty about tenure, future of the industry and the property, and variability of climate (e.g. droughts). Windle et al. (2005) reported that many pastoralists with freehold leases in central Queensland are suspicious of government initiatives around riparian buffers (i.e. erosion of their private property rights), with 30% of graziers surveyed specifically stating they are not interested in dealing with the government. Nonetheless, with some cattle pastoralists in the Burdekin adopting riparian BMPs in the belief that it will increase their chance of lease renewal (Lankester et al. 2009).

Discontinuity between the source and the impact of poor water quality is also a barrier to adoption of BMPs as landholders are increasingly aware that they are being asked to undertake work where there is considerable off-site or community benefits (Curtis et al. 2002). There is often a denial of individual responsibility in addressing the problem (Dutcher et al. 2004; Lankester et al. 2009; Flick et al. 2013). For example, when surveying 14 landholders in the Wet Tropics, Emtage and Shrestha (2010) found that most landholders were sceptical about reported links between the degradation of water quality and their practices, with most not perceiving that the GBR is under the level of threat that governments have portrayed. There were therefore some landholders in the Wet Tropics that are aggrieved that rural landholders seem to be specifically targeted as the cause of all environmental degradation while other sectors, notably mining and urban areas, are not receiving the same attention (Emtage and

Shrestha 2010). Nonetheless, in contrast to these previous studies, we found that water quality issues ranked as an important driver by those interviewed. This is probably attributable to the increased awareness (e.g. media coverage) in recent years of the declining health of the GBR. Increased monitoring of the water quality impacts of practices at a paddock and catchment scale will nonetheless give further credibility to the use of these practices by producers (Qureshi and Harrison 2001; Lankester et al. 2009; Flick et al. 2013).

Many other surveys of landholders in GBR catchments have demonstrated that perceptions of risk extend to include a lack of assurance that complex riparian remediation projects will be successful given BMPs guidelines are often inadequately generic. In their survey of landholders across the Fitzroy and Burdekin catchments, Rolfe and Gregg (2015) found that riparian BMPs being too complex, difficult to trial, and not fitting in with current practices, were ranked as some of the main limitations to adoption of riparian BMPs. This may be why most (75-92%) of landholders surveyed by Herr et al. (2013) cited lack of information and local leadership as being a medium-high ranking factor impeding adoption of conservation practices, with many (58%) also citing a poor link between property management and environmental outcomes as an impediment. Consistent with results obtained in Section 3.1, tailoring of BMPs based on local issues will also assist in waylaying the perceived risk by many landholders in GBR catchments that riparian remediation projects will be successful. For example, ideas that were mentioned during our survey of landholders in the Wet Tropics (Section 3.1.2) included ensuring sugarcane production was minimally impacted by selecting smaller growing tree species in sugarcane regions to ensure that the woody vegetation does not encroach on sugarcane harvesting, and/or use of tree hedging before cane harvesting.

Access to resources: time and skills

Having sufficient time or being physically able to undertake remediation work are also critical barriers to adoption of riparian remediation projects (Curtis and Robertson 2003; Ede 2011). In their survey of landholders across the Fitzroy and Burdekin catchments, Rolfe and Gregg (2015) found that one of the main limitations to adoption was a lack of capability to do the work. Similarly, in their survey of cattle producers in the Burdekin, Herr et al. (2013) found that 86-88% of landholders ranked a lack of time or skills on the property as medium-high in terms of being an impediment to adoption of conservation practices.

Revegetation projects in the Wet Tropics have also been criticised in their requirement for high inputs by landholders (Harrison et al. 2004). Indeed there is evidence in the Wet Tropics that participants in conservation programs were those that were less burdened with property-related workloads when compared to non-participants (Moon et al. 2012). Rather than undertake expensive management-intensive revegetation with multiple species across a limited area, the same resources may deliver more benefit to GBR health through wider implementation of much less expensive management practices. This may include manipulation of regeneration or regrowth (Kanowski and Catterall 2007; Sanger et al. 2008), or planting only pioneer and fast-growing and low maintenance species, or in grazing areas, planting species resistant to cattle (e.g. bunya and hoop pine), or if there was sufficient seed stock in the ground, simply facilitate natural regeneration (JRCMA 2013; Elaine Ridd, Johnstone Ecological Society). In such approaches, a selective herbicide can be used to control invasive grasses, and they may still potentially lead to biodiversity outcomes in the longer term as a result of distribution of seeds via bird and floods. Additional resources may be sourced to plant additional species only for highly degraded sites of high priority, or where the project objectives also include providing biodiversity conservation corridors, and/or carbon sequestration. Further work is required to verify cost-benefit analysis of different management options.

In terms of overcoming the time and skill barriers, in addition to increasing the base funding of Landcare Groups, other suggestions provided by the landholders we interviewed included:

- Ensuring Government funding for riparian remediation projects are allocated to individual properties based on their merit rather than solely relying on priority areas where landholders may not necessarily have the capability required;
- Taking advantage of the large number of people that are willing to volunteer assistance, particularly in urban and public areas when community groups are given the opportunity to have a sense of ownership of a remediation project, and;

3.2.2 Alternative incentive schemes

Undertaking riparian remediation projects is often expensive and varies across properties For example, in grazing areas, general estimates of riparian remediation range from about $900 to $16,000 per kilometre for a combination of fencing and associated offsite watering points (Rolfe et al. 2006; Star et al. 2013; Bartley et al. 2015). In cropping areas (e.g. sugarcane), costs have been estimated to be even higher at about $25,000 per kilometre for a 10 m wide buffer (Lovett and Price 2001), or about $5,300 per hectare (Eono and Harrison 2001). There are limited resources for government-based grants to provide assistance in implementing these expensive riparian remediation projects, particularly considering some resources may need to be reserved for strategic purchasing of properties in priority areas (Jansen and Robertson 2001; Curtis et al. 2002), and also possible realignment of the cadastral boundaries (e.g. to account for river meandering) within riparian zones. Moreover, past grant-based investments have assisted in establishing riparian remediation projects, but many landholders indicated costs associated with site maintenance (e.g. weed control and fence maintenance) were significant and potentially a disincentive to undertake works (Ede 2011).

Given financial barriers are limiting landholder participation in riparian remediation projects (Section 3.2.1), landholders are most likely to be engaged in market-based instruments that give them clear financial incentives to supply mitigation actions (Rolfe et al. 2006); not just implementing remediation works, but also valuing them sufficiently to undertake maintenance activities to ensure long-term successful outcomes. Clearly, unless landholders have particularly strong conservation cultures there is also a requirement to ensure these financial incentives are higher than the opportunity costs of foregone agricultural production within the riparian zones being remediated. Indeed Herr et al. (2013) found 72% of cattle produces surveyed in the Burdekin thought that obtaining credits for delivery conservation services would be moderately-to-highly effective in incentivising adoption of conservation practices. In their survey in the Burdekin catchment, Lankester and Greiner (2007) also found that a conservation credit system was a ranked relatively highly by landholders in terms of being considered an effective incentive. However, administration costs need to be managed in relation to the benefit in order to make a crediting system more favourable than other incentives that are perceived to be simpler by landholders, e.g. income tax incentives, cost-sharing, rate/lease or debt reduction for conservation, etc. (Lankester and Greiner, 2007; Maraseni and Dargusch, 2008; Januchowski-Hartley et al. 2012; Cacho et al., 2013; Kragt et al., 2014; Torabu and Bekessy 2015). Financial incentives will also need to be relatively high to overcome the disincentives to participate in conservation programs requiring permanent commitments (Comerford 2014). Nonetheless, trials overseas have shown that crediting systems can be successful. For example in the United States, Water Quality Trading schemes are developing (e.g. Zhong et al. 2016; Motallebi et al. 2016), as are voluntary carbon markets such as Clear Water Carbon (Wilkerson & Gunn 2013).

Bundling and stacking credits from different ecosystem services are concepts gaining global attention as mechanisms to better incentivise landholders (Deal et al., 2012; Robertson et al., 2014; Van der Biest et al., 2014), e.g. GBR Credits (GreenCollar, 2018). Further studies are required to estimate the likely cost-to-benefit ratio of a market-based mechanisms in Reef catchments. But whether via a market-based mechanisms or via other schemes resulting in landholder payment for provision of environmental services (e.g. direct action via Emissions Reduction Fund), there is potential to utilise the co-benefits that riparian remediation projects provide to overcome financial barriers to participation. Per unit area, riparian zones tend to have relatively high plant and animal diversity, and high structural diversity. Hence, despite occupying only a relatively small percentage of land area, riparian areas play a disproportionately large role in providing biodiversity benefits (Bennett et al. 2014; Nimmo et al. 2016; Yeatman et al. 2016; Law et al. 2017; Selwood et al. 2017). Similarly, riparian areas play a disproportionately large role in carbon storage within biomass. When compared to the surrounding land, riparian land often has taller and denser vegetation because of the fertile alluvial soils and increased moisture levels within the riparian zone (ARRC 2017). Indeed studying environmental planting revegetation projects in temperate regions of Australia, Paul et al. (2018a) found that above-ground biomass of 35 stands established in riparian, gully or floodplain zones averaged 1.54 times higher than expected based on empirical models of above-ground biomass calibrated to equivalent types of environmental plantings (i.e. site productivity, stand density, species mix and configuration) established in non-riparian areas (N=605 stands).

In Australia, the largest 'market' (at $2.55 billion) for payment of ecosystem services is the reverse action scheme for project-based provision of quantifiable a reduction in greenhouse gas emissions; the Australian Governments Emission Reduction Fund (ERF). Under the ERF, landholders of land that has potential to be forest or woodland, but which had <5% cover of woody vegetation at the start of the project, may receive carbon payments when they either:

1. Undertake revegetation of mixed species as per the environmental plantings (EP) Methodology (AG, 2018a), or;
2. Facilitate natural regeneration as per the Human Induced Regeneration (HIR) Methodology (AG, 2018b).

Both of these ERF Methods utilise the FullCAM model (Richards and Brack, 2004) to quantify carbon sequestered due to growth of the vegetation and the accumulation of debris following regeneration or revegetation. However, despite the ERF being a relatively well developed market, in isolation, credits for carbon are insufficient to cover the costs of riparian revegetation (e.g. Matzek et al. 2014). Therefore, policy-settings for facilitation of widespread uptake of riparian remediation projects will require the stacking/bundling of carbon credits from ERF (or other voluntary carbon markets) together with credits from improved water quality and biodiversity. This would also result in greater efficiencies.

Further work is required to explore the merit in building off the ERF direct action scheme, and/or incorporating components of the ERF into a market-based scheme, to facilitate the payment for all quantifiable and verifiable environmental services provided by riparian remediation projects; improved water quality, biodiversity and carbon mitigation. Consideration needs to be given to the fact that many landholders in GBR dislike ‘government handouts’ and bureaucracy (Emtage and Shrestha 2010), and in particular, government regulation (Qureshi and Harrison 2001; Herr et al. 2013). However in one preliminary study that entailed interviewing 14 policymakers and academics active in the field of carbon and biodiversity in Australia, Torabu and Bekessy (2015) found widespread support for bundling and stacking schemes due to the efficiencies it provides, e.g. easing transaction costs for landholders, and reduced monitoring costs for regulators.

3.3 Expanding the metrics of success: Assessment of multiple benefits

3.3.1 Biodiversity benefits

There an indication that biodiversity benefits at the project-scale, as indicated by the TRARC Plant Cover Index, do improve over time in response to the implementation of most types of riparian remediation projects (Fig. 4). The only exception was for regeneration projects where there was moderate-long periods of grazing during the dry season. However, given the paucity of data for such project types, further work is required to ascertain whether the moderate-long periods of dry season grazing limit the improvements in biodiversity benefits. Indeed if biodiversity benefits are a goal for riparian remediation projects, it will be essential to understand how grazing management influences the Plant Cover Index in the different bioregions.

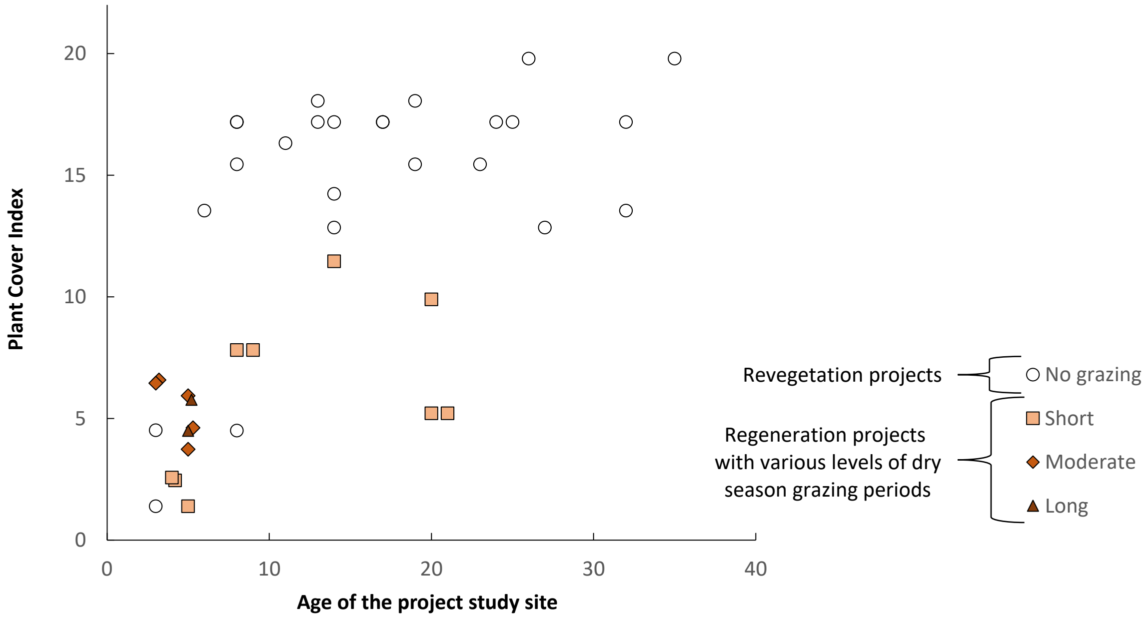

Figure 4: Relationship between the field-based assessment of Plant Cover Index and age of riparian remediation projects, including revegetation projects as well as regeneration projects with varying extents of grazing. Grazing length was categorised as either none, light, moderate or high when the length of dry season grazing was 0 months, ≤2 months or accidental grazing only, 3–8 months, and ≥9 months, respectively.

At the landscape-scale, typical widths of the project areas, and longitudinal lengths of the project corridors, were both higher in regeneration projects within the Fitzroy NRM region than in the revegetation projects within the Wet Tropics or Burnett Mary NRM regions (Fig. 5). Within a 10 km radius of regeneration projects, there was often (70% of study sites) surrounding vegetation of >5 m width (Fig. 6). In contrast, most (61% of study sites) revegetation projects had either fragmented vegetation, or just a narrow strip of vegetation along the banks, within a 10 km radius. Small widths of revegetation projects in the Wet Tropics was probably attributable to: (i) relatively high opportunity costs in foregoing agricultural production in these relatively productive lands, and; (ii) costs of revegetation projects limiting the size of projects under limited resources.

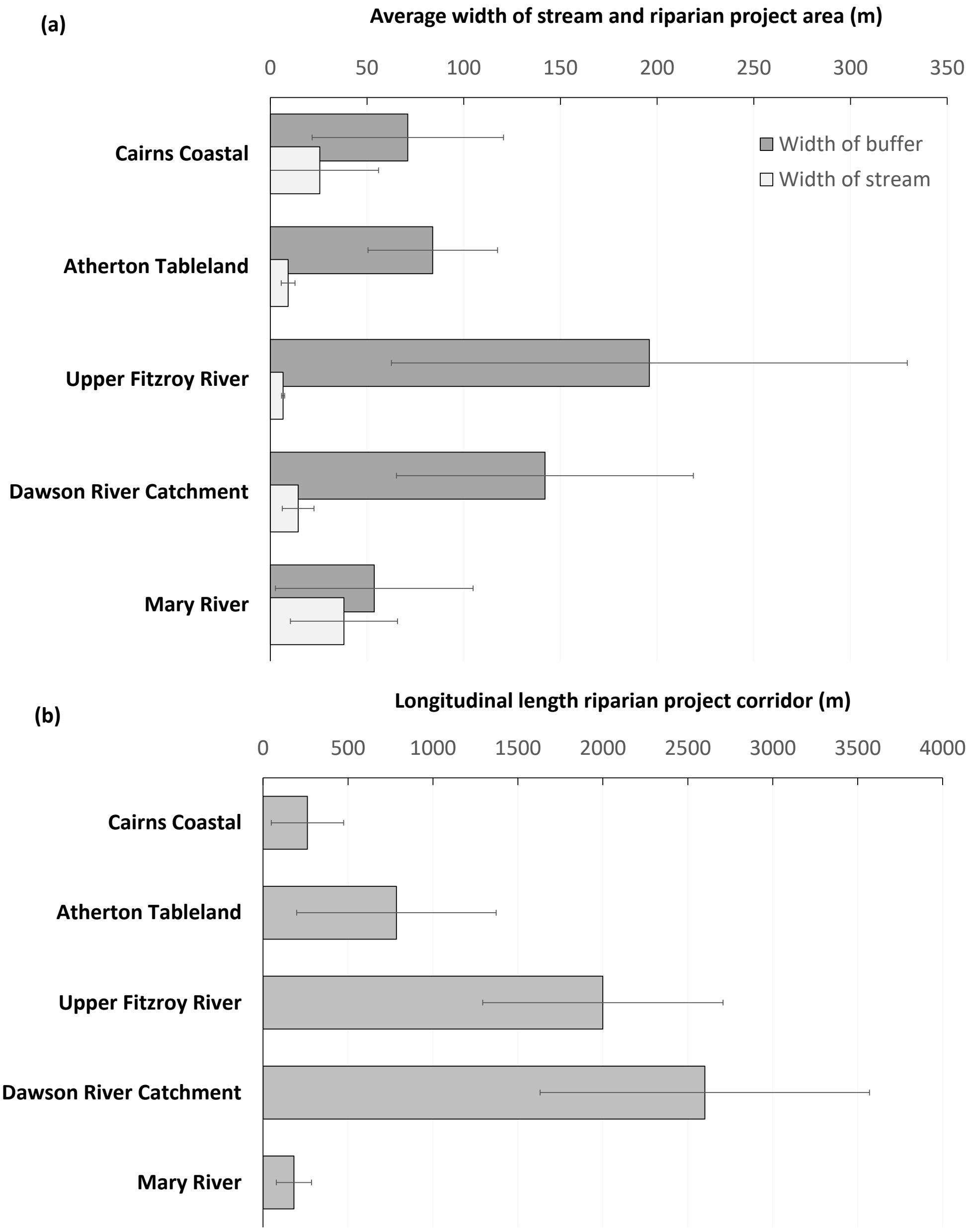

Figure 5: Landscape-scale metrics of: (a) width of width of riparian project area, and; (b) longitudinal length of the riparian project corridor, for project sites studied across the five case study regions.

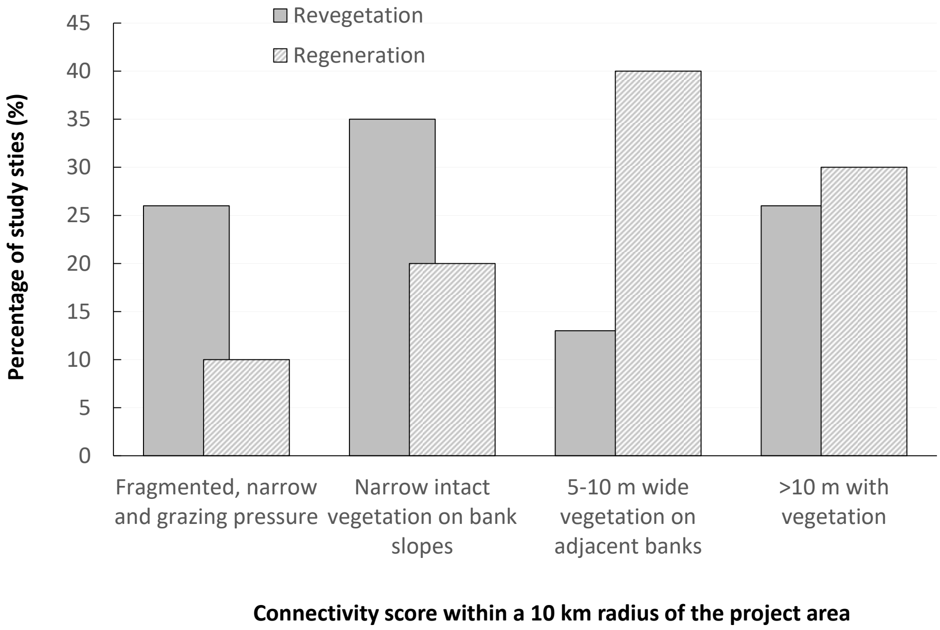

Figure 6: Landscape-scale metric of woody vegetation connectivity (based on four categories of connectivity) within a 10 kilometre radius of revegetation or regeneration riparian remediation projects.

To ensure biodiversity benefits, projects areas need to be wide enough (at least >10 m) to allow habitat and movement of smaller animals, and to prevent edge effects, including altered microclimate, invasion by weeds, and altered interactions among species (Saunders et al. 1991; Lovett and Price 1999). However, the functional width of the riparian zone (in terms of providing pathways for movement of most biota) at any given site being influenced by the proximity of other patches of vegetation, particularly remnant vegetation (Timm et al., 2004; Johnson et al., 2007; Hansen et al. 2010). For example, although birds may regularly travel 1000 metres or more, less mobile species like mammals and tree-dwelling marsupials will require <500 m between patches of vegetation (Lovett and Price 1999; LWA 2003; Jansen, 2005). Hence, our results suggest that although the biodiversity benefits *within* the project area are relatively high in revegetation projects in the Wet Tropics and Burnett Mary NRM regions, this benefit may be negated by the typically relatively poor size and connectivity of these projects. Conversely, although the within project area biodiversity benefits are relatively poor in regeneration projects in the Fitzroy NRM region, they nonetheless typically have a relatively good size and connectivity.

There are some regeneration project areas within the cattle grazing properties of the Fitzroy NRM region where the width of the project is relatively large to ensure fences are flood-proof and/or to ensure a viable paddock size, e.g. see aerial photos showing project boundaries in Sites 20, 22 and 29 (Appendix C). Questions remain as to the extent to which the grasses-dominant areas near the outer boundaries of these projects will attain natural regeneration of woody vegetation under moderate-high grazing intensities, and hence, whether the *entire* areas within the project boundaries can be categorised as riparian remediation per se. It is possible the main biodiversity benefit for fencing off these area is to better manage grazing to increase the level of protection of the *existing* remnant vegetation along the stream banks rather than fostering significant natural regeneration of new woody vegetation. Indeed, the highest priority for managing riparian vegetation should be to protect areas in good condition.

It is much more cost-effective to protect these areas than to rehabilitate them later after poor management (Lovett and Price 1999).

The results obtained indicate that more research is required to inform management regimes (particularly grazing) required to ensure that riparian remediation projects facilitate the restoration of the conditions that support the relatively high diversity of plants and animals in these areas when compared to the surrounding hillslopes, e.g. wide range of habitats and food types, less extreme microclimate and provision of refuge for native plants and animals in times of stress, such as drought or fire, and become reservoirs from which species can move out and recolonise adjacent areas when better times return (e.g. Capon, et al. 2013). This is important given many native plants are found only, or primarily, in riparian areas, and these areas are also essential to many animals for all or part of their lifecycle.

Although our study focused only on terrestrial biodiversity benefits, these benefits extend to include benefits to the aquatic ecosystem condition. This is because vegetation on riparian land regulates in-stream primary production through shading (reduced light and water temperature); supplies energy and nutrients (in the form of litter, fruits, terrestrial arthropods and other organic matter) essential to aquatic organisms; and provides essential aquatic habitat by way of large pieces of wood that fall into the stream and through root-protection of undercut banks (Seddell et al., 1990; Osborne and Kovacic 1993; Crook and Robertson, 1999). The reduction in light and temperature levels due to riparian vegetation also helps controls the growth of nuisance plants and algae, even when nutrient levels in the stream water have increased (Lynch et al., 1984; Lovett and Price 1999).

3.3.2 Carbon storage and typical rates of sequestration of carbon

When excluding baseline remnant trees, as expected, there was a general trend of increased biomass accumulation with increasing age of the riparian remediation project (Fig. 7). This trend was evident even given uncertainty in accounting for baseline carbon stocks (e.g. assuming remnant trees are those that were visually assessed, or the largest individuals in accordance with the 95th or 85th percentile of stem diameters measured for a given plant functional type) and the age of the project (e.g. project initiation data may not reflect the average age of the stand as there may be some re-planting post disturbances, or regeneration commenced only post favourable conditions). But even for projects of similar age, there was significant variation in biomass both within- and between-bioclimatic regions. Further investigation to build the replication within this dataset is anticipated to confirm that this variability can be accounted for by dynamics of factors such stand density and composition, e.g. influenced by planting densities, grazing intensity, control of weeds, and also the frequency and extent of disturbances from floods, cyclones and fire.

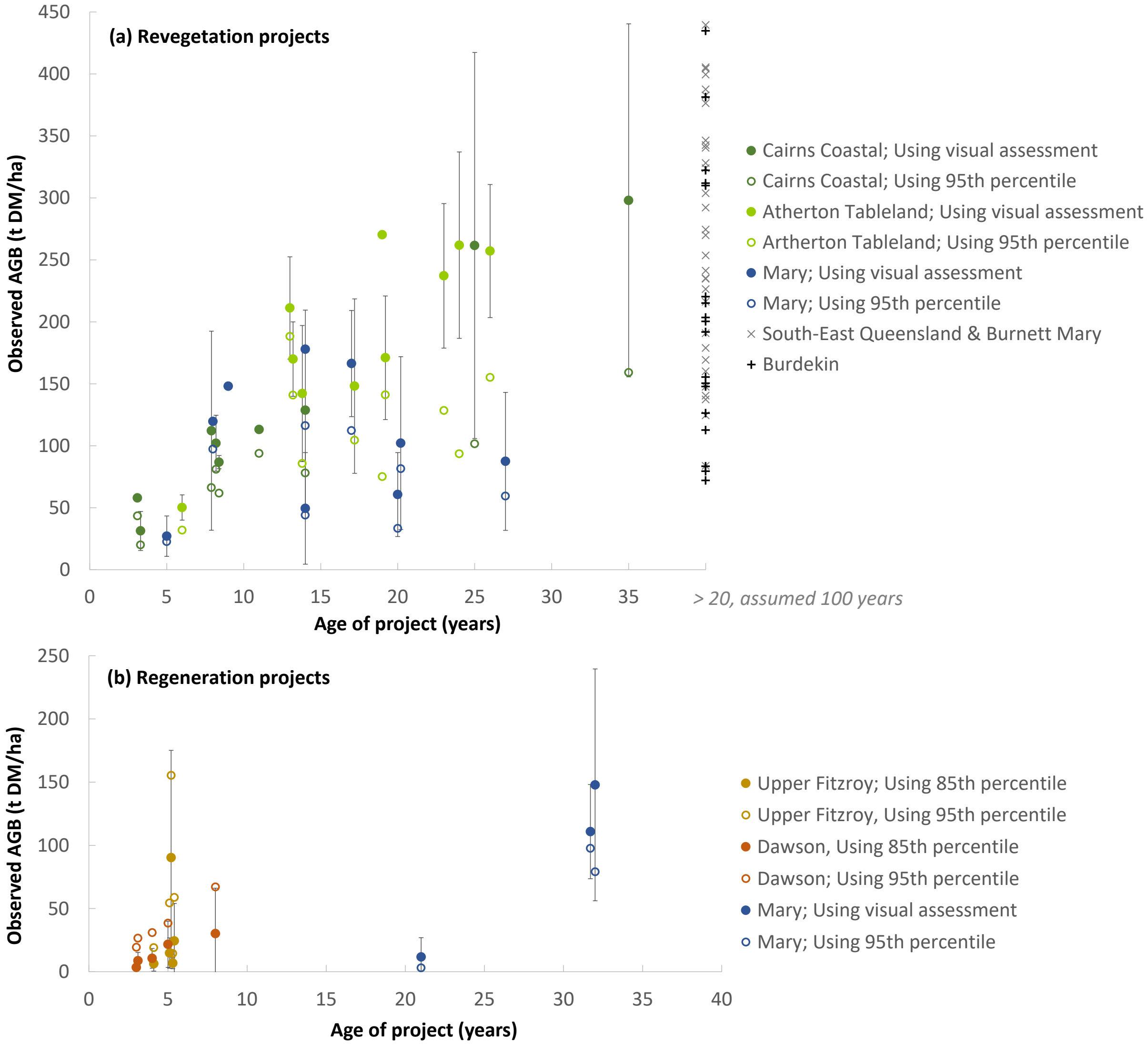

Figure 7: Relationship between above-ground biomass of woody vegetation (AGB) and the age of the riparian: (a) revegetation project, and (b) regeneration project. Solid and open symbols represent field-based AGB estimates obtained using alternative assumptions regarding baseline remnant trees. Error bars in AGB indicate the standard deviation in field-based average AGB estimates.

Field-based assessments of biomass indicated that, for a given project age category, more biomass accumulates in planted woody vegetation when compared to that accumulating in the regenerating woody vegetation (Fig. 8a,b). Hence, in young rapidly growing stands, rates of sequestration of biomass carbon average 8.9 ± 2.6 t C/ha/yr in revegetation stands, but only 2.8 ± 2.9 t C/ha/yr in regeneration stands (Fig. 8c). Similarly, in more mature stands, rates of sequestration of biomass carbon average 5.3 ± 2.2 t C/ha/yr in revegetation stands, but only 2.0 ± 1.2 t C/ha/yr in regeneration stands (Fig. 8c). The slower rates of sequestration of carbon in regeneration projects when compared to revegetation projects are probably attributable to the lower site productivities in relatively dry (mean annual rainfall < 750 mm yr^{-1}) bioregion of the Fitzroy NRM region when compared to that in the Wet Tropics bioregions (mean annual rainfall > 1,500 mm yr^{-1}). Additionally, at some sites where grazing lengths were moderate-high, grazing may have also contributed to relatively slow rates of regeneration.

When considering all woody vegetation on-site (i.e. existing remnant trees as well), and therefore the total storage of biomass carbon, there was less difference between revegetation and regeneration projects. In younger projects, natural regeneration stands often have a significant baseline carbon stock from remnant vegetation whereas many plantings are often established in areas that have little or no remnant vegetation. Hence, in younger stands, carbon stocks averaged 58.6 ± 28.9 t C/ha in revegetation stands, and higher at 81.5 ± 38.3 t C/ha in regeneration stands (Fig. 8f). But in mature projects, the higher rates of biomass accumulation in revegetation stands tended to negate the benefit from the initial baseline carbon stocks. Hence, in older stands, carbon stocks averaged 144.9 ± 65.8 t C/ha in revegetation stands, and only 91.9 ± 59.3 t C/ha in regeneration stands (Fig. 8f).

Consistent with the findings of Paul et al. (2018a) for riparian revegetation projects in temperate regions of Australia, results obtained from the 104 riparian sites studies here showed that biomass yield models calibrated for revegetation and regeneration of mixed native species in Australia (e.g. FullCAM, Richards and Brack 2004) substantially under-estimate carbon sequestration in riparian remediation projects, particularly those in the Fitzroy and Burdekin NRM regions (Fig. 9). These results suggest that the potential for biomass accumulation, and hence sequestration of carbon, was 2.61–6.56 times higher in riparian stands accessing additional ground and surface water when compared to that anticipated from rain-fed stands of the similar age, species mix and stand stocking densities growing under the same climatic conditions in the relatively dry (measurement sites having average annual rainfall was <750 mm yr^{-1}) NRM regions of Fitzroy and Burdekin. But even in the Wet Tropics, Burnett Mary and South-East Queensland NRM regions where measurement sites had an average annual rainfall of >1,500 mm yr^{-1}, the potential for biomass accumulation and sequestration of carbon was still 1.17–1.63 times higher in riparian stands accessing additional ground and surface water when compared to that anticipated from rain-fed stands of the similar age, species mix and stand stocking densities growing under the same climatic conditions.

Our results in GBR catchments (Figs. 8 & 9) were therefore consistent with previous studies of riparian vegetation in other parts of Australia (Burger et al. 2010; Dean et al., 2012; Ryan et al. 2015; Maraseni and Mitchell 2016; Paul et al. 2018a) and overseas (Scott et al., 2004; Matzek et al. 2014; Fortier et al. 2015) in that they suggest a relatively high potential for biomass carbon storage and sequestration in riparian zones. When compared to ecosystems in the surrounding hill slopes, riparian ecosystems have a higher productivity of biomass due to more mesic conditions, more reliable access to surface and ground water, and elevated nutrient levels derived from sediments and organic matter deposited by successive flood events close to the river (e.g. Lovett and Price 2007; Smith et al. 2017).

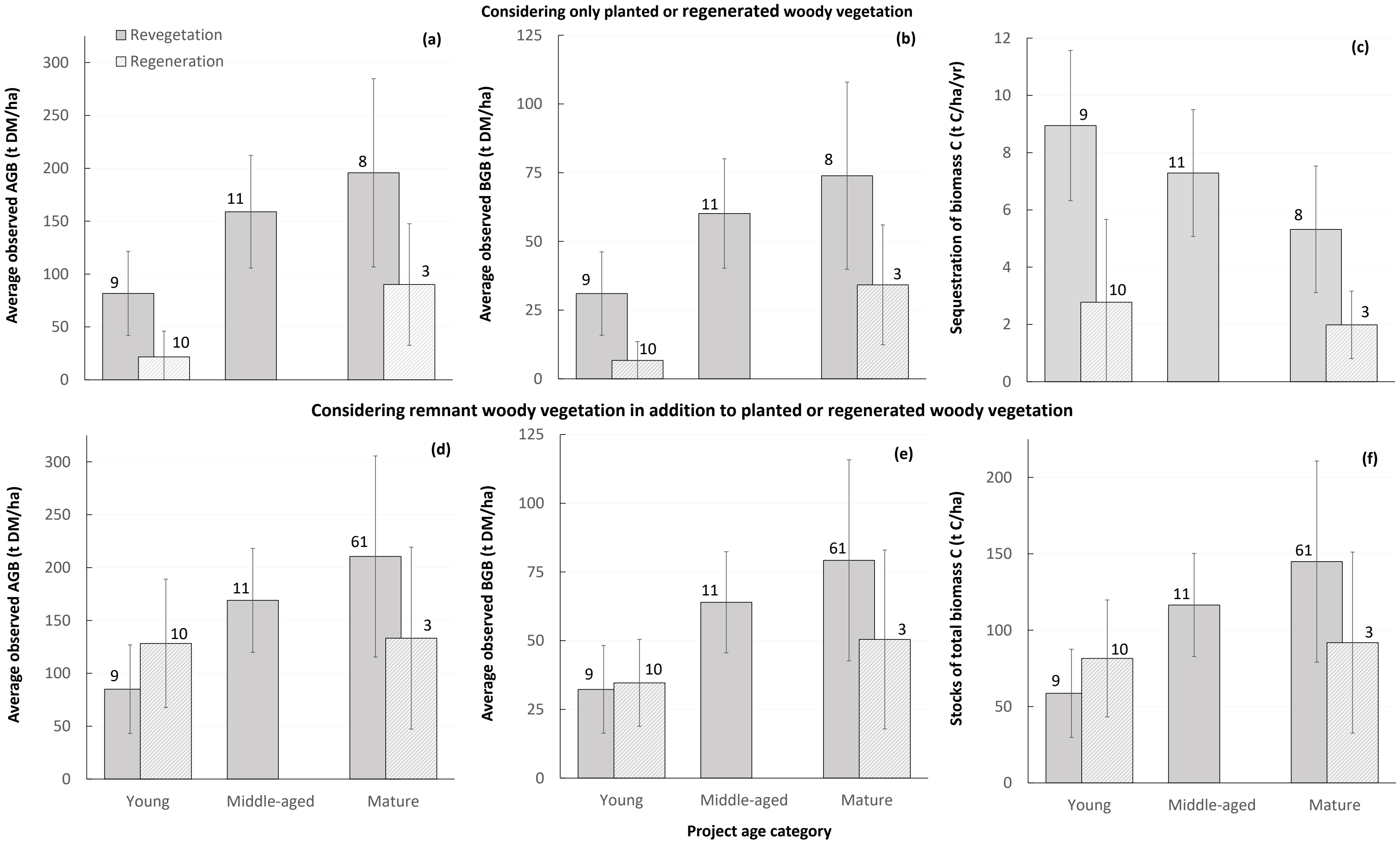

Figure 8: Field-based measurements of above-ground biomass stocks (AGB, a, d), below-ground biomass stocks (BGB, b,c), and estimates of rates of sequestration of biomass carbon (in both AGB and BGB, c, f) based on the type of project (revegetation or regeneration) and its age class (young, ≤10 years; middle-aged, 11-19 years, or; older, ≥20 years). The upper three panels (Fig. 8a,b,c) are results obtained for regenerating or planted trees and shrubs only, while the lower three panels (Fig. 8d,e,f) are the results include these younger trees and shrubs in addition to the remnant trees and shrubs that were on-site prior to the project establishing.

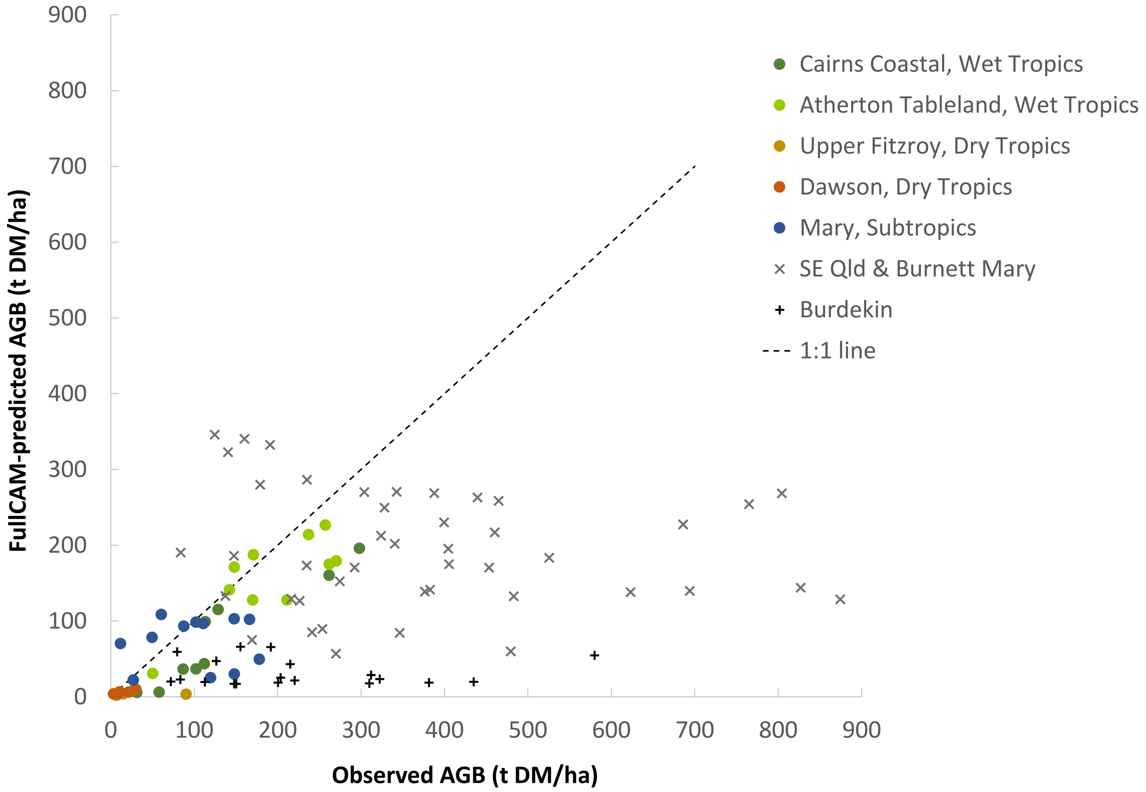

Figure 9: Relationship between stand-level above-ground biomass (AGB) predicted using the forest growth model FullCAM, and the AGB which was observed based on field-assessments of biomass (N=104) undertaken in the seven different GBR catchment regions studied. For the FullCAM-predicted AGB in SE Qld & Burnett Mary and the Burdekin (where stand age was only known as >20 years, source James, C pers. com. 2017), the conservative estimate of stand age of 100 years was made.

Widespread uptake of riparian remediation projects will not only improve GBR health via improved water quality, but because they provide a disproportionate contribution to carbon abatement, they also contribute to mitigation of climate change, thereby contributing to decreasing the frequency and intensity of high water temperature-induced GBR bleaching events (Hughes et al. 2017; Hairsine 2017). The generic BMPs outlined in Appendix A were developed on the basis of maximising the improvements in water quality. Improved water quality, biodiversity and climate change mitigation will all be delivered through establishing wide and well connected projects that facilitate a diversity of species and structural characteristics. However, if maximising the contribution to mitigation of climate change is the primary goal, in some landscapes, there may be potential to carefully manage the outer zones of riparian areas with sustainable harvest cycles (e.g. Hatten et al. 2018) that ensures the carbon re-sequestered during each cycle of growth is stored in wood products (e.g. timber products, e.g. Chittapur and Patil 2017), or used to offset greenhouse gas emissions from fossil fuel use (e.g. bioenergy or biofuels, etc., e.g. Rosa et al. 2017). This reiterates the need for groups of landholders to work together to agree to common goals as this will influence the tailoring of BMP in their region (Section 3.1.3).

4.0 GENERAL DISCUSSION: SUMMARY

Have previous investments been successful?

Although there was some indication that the Regeneration Index, and hence, the Condition Score, increases with the age of projects (Section 3.1.1), further work is required to verify whether:

- Increases in Condition Score observed for projects managed with relatively short grazing periods is also achieved for projects managed with relatively long grazing periods, and if so, in which regions.
- Condition Scores for remediation projects continue on a trajectory of plateauing at 55–65, hence indicating remediation projects do not achieve the optimal Score of 100 expected for full rehabilitation.
- A refined condition score may better reflect the impact of riparian remediation projects on water quality outcomes, e.g. accounting for the fact that some weeds may be beneficial even though they may limit the attainment to full rehabilitation of the vegetation.

This information is required to refine BMPs (Appendix A) with regard to grazing management and prioritising remediation projects. The apparent failure of riparian remediation projects to completely rehabilitate to optimal Conditions Scores was probably attributable to project areas being relatively narrow (i.e. Appendix C; high Tree Clearing index, and hence Pressure Score), thereby leading to the persisting evidence of either poor plant cover, erosion and/or weeds. Many landholders were seeking to minimise the areas for revegetation or regeneration in order to maintain agricultural production and minimise costs. Implications of these findings are that there may be merit in increasing the incentives for projects that protect and connect to existing remnant vegetation, e.g. premium incentives for improved landscape connectivity.

Which management practices are important?

Results from the social survey (Section 3.1.2) indicated that this varied with land use, region and landholder goals. When considered in light of the results from the review (Section 3.2.1), as outlined below, guidelines for management practices that ensure success at both the project- and catchment-scale need to be developed in accordance with an understanding of the key drivers and barriers to landholder participation.

Key drivers and barriers for landholder participation?

Overcoming financial barriers to uptake. Experience in Australia suggests landholder knowledge of riparian conservation issues and congruent attitudes are necessary but not sufficient to ensure adoption of riparian remediation works at levels likely to achieve improvements at the landscape scale. Review results demonstrated that the most important drivers for landholder engagement in GBR catchments were private benefits, and that key barrier for landholder participation was financial barriers (Section 3.2.1). Consistent with this, our social survey findings indicated widespread uptake of riparian remediation works will require landholders aligning environmental and production goals. Indeed our social survey results found that in pastoral regions of the Fitzroy NRM region, the goal was predominately grazing management, with very few landholders (only 6%) completely excluding cattle grazing whereas all landholders surveyed in the Wet Tropics completely excluded cattle grazing

(Section 3.1.2). Poorer site productivities in the drier regions offers less flexibility to destock if feed is unavailable (e.g. TERAIN WQIP 2015). This may explain why our survey results indicate BMPs developed solely for improved water quality outcomes (Appendix A) are not being adopted in these regions, e.g. most (96%) are not excluding livestock for >3 years following fencing to enable native perennial vegetation to develop a high biomass, while almost a half (52%) were not using only short periods (<2 months) of grazing in the dry season. The implications are:

- For BMPs to be widely adopted in some regions, they will require tailoring to minimise the impacts of agricultural production. These tailored BMPs may also be refined based on learnings from local demonstration sites. For example in the Fitzroy NRM region, these may demonstrate possible trade-offs between Condition Score of the project area and the extent of grazing.
- There may be merit in considering environmental markets as alternative incentive schemes. If the market price is sufficient to overcome the financial barriers to participation, payments for delivery of improved Condition Score (and hence water quality outcomes) may not only ensure widespread participation, but also improve efficiency given payment is based on outcomes, not fencing, etc.

Overcoming normalising behaviour and perceived risks. The review (Section 3.2.1) showed that having peer recognition (overcoming normalising behaviour) was important in ensuring widespread participation in riparian remediation. There was also a need for landholders to overcome perceptions that remediation projects are complex and expensive and thereby impractical, and also remaining scepticism about reported links between the degradation of water quality and their practice. These findings reiterate the need for:

- Tailoring of generic BMPs (Appendix A) by landholder groups (e.g. Landcare groups) to ensure they are:
    - Based on learnings from local demonstrations and knowledge, thereby contributing to overcoming normalising behaviour and ensuring peer acceptance.
    - Practical for the specific sub-catchments and land uses. For example, our survey results (Section 3.1.2) indicated that in the Wet Tropics weed control was considered paramount to the success of the projects, whereas this was not the case in the Fitzroy NRM region.
- Increased monitoring of the water quality impacts of practices at a paddock and catchment scale to overcome remaining scepticism about reported links between the degradation of water quality and landholder practice. This scepticism remains a barrier to participation, although our recent survey results (Section 3.1.2) suggests the message of landholder responsibility is gaining traction.

Prioritising resources to maximise impacts. The review (Section 3.2.1) showed that limited time and skills were a barrier to widespread participation. In contrast, the survey results (Section 3.1.2) from the Wet Tropics regions indicated that previous projects have been very resource intensive given they usually entailed site preparation, revegetation with tube stock, following by in-fill planting and weed control during the first few years. Such resources were put into these projects given the goal was often providing wildlife corridors and habitat connectivity. However, for a given level of resources, outcomes to GBR health may be greater with wide-spread uptake of less intensively managed projects rather than having a limited number of isolated but intensively managed projects. Implications of these findings are:

- Further work is required to verify whether, for a given level of resources, greater benefits to GBR health are attained through implementation of less expensive management practices across larger area rather than undertake expensive management-intensive revegetation with multiple species across a limited area. Cost-effective projects that may be assessed include:
  - In cropping areas with little viable seed bank, planting only pioneer and fast-growing and low maintenance species;
  - In grazing areas with little viable seed bank, planting species resistant to cattle (e.g. bunya and hoop pine), or;
  - In areas with sufficient seed stock in the ground, simply facilitate natural regeneration.
- There are clear opportunities to build on the good will (e.g. volunteer labour) of the community in many urban areas and some sub-regions that have a strong conservation culture, particularly if their key goal of providing wildlife corridors and habitat connectivity can be aligned with the broader community goal of improving outcomes for the GBR, e.g. via utilising environmental markets that bundle or stack credits from multiple environmental services.

Is there a role for alternative incentive schemes?

As outlined in Section 3.2.2, costs for riparian projects may be up to $16,000 and $25,000 per kilometre in grazing and cropping enterprises, respectively. Given this, and given government programs have only limited resource, existing government grant-based schemes are unlikely to facilitate uptake at the scales required to achieve real outcomes for the GBR. Moreover, such grant schemes generally do not resource on-going costs associated with site maintenance. Rather, alternative incentive schemes that provide landholder payments for the different ecosystem services are most likely provide clear finical incentives to supply widespread mitigation action; not just implementing remediation works, but also valuing them sufficiently to undertake maintenance activities to ensure long-term successful outcomes are concepts gaining global attention as mechanisms to better incentivise landholders. Implications of these findings are:

- Policy-settings for facilitation of widespread uptake of riparian remediation projects may require the stacking/bundling of carbon credits from ERF (or other voluntary carbon markets) together with credits from improved water quality and biodiversity.

Can the definition of success be expanded?

Bundling and stacking credits from different ecosystem services are concepts gaining attention as mechanisms to better incentivise landholders, e.g. Reef Credits. Such market-based mechanisms are well suited to incentivise riparian remediation projects as in addition to providing benefits to water quality (Table 1), riparian areas play a disproportionately large role in providing benefits to biodiversity and biosequestration. This is because, due to fertile alluvial soils and increased moisture levels, per unit area, riparian zones tend to have relatively high biomass, high plant and animal diversity, and high structural diversity. Results from Section 3.3 contribute to enhancing the evidence-base for building confidence in such emerging markets. Key findings and implications were:

- **Biodiversity.** Significant benefits to biodiversity, as indicated via the TRARC Plant Cover Index, were attained after only 10 years where grazing periods in the dry season were relatively short (< 2 months). Although the biodiversity benefits *within* the project area are particularly high in revegetation projects, this benefit may be negated by the typically relatively poor size and connectivity of these projects, with most (61% of study sites) revegetation projects having either fragmented vegetation, or just a narrow strip of vegetation along the banks, within a 10 km radius. But further work is required to:

- Verify whether moderate-long periods of dry season grazing moderate improvements in biodiversity benefits.
- Improve our understanding of the quantity *vs*. quality trade-off, particularly where facilitating wildlife corridors are a key goal.

- **Biosequestration.** Rates of sequestration of carbon in above- and below-ground woody biomass averaged about 5–9 t C/ha/yr in revegetation projects in the highly productive (mean annual rainfall >1,500 mm yr^{-1}) regions of the wet tropics and subtropics, and 2–3 t C/ha/yr in regeneration stands that were predominately located in the less productive (mean annual rainfall < 750 mm yr^{-1}) regions of the dry subtropics. Consistent with previous studies, these rates were 2.61–6.56 (and 1.17–1.63) times higher than anticipated based on rain-fed stands of similar age, species mix and stand stocking densities growing under the same climatic conditions in the dry subtropics (and wet tropics or subtropics), presumably due to riparian stands accessing additional ground and surface water. But further work is required to:
    - Refine the model-based ERF Methodologies for biosequestration from revegetation or regeneration to include riparian remediation projects. Given their relatively high rates of biosequestration, specific growth model calibrations will be required for riparian vegetation.
    - Assess whether some of the variability in rates biosequestration may be accounted for by factors such as planting densities, species mix, climate, extent of flood, cyclone or frost damage, etc.
    - Verify whether moderate-high lengths of dry season grazing moderate rates biosequestration in the longer-term
- **Protecting carbon stored in remnant vegetation.** Many of the previous riparian investments we assessed contained remnant trees. This was particularly common in fenced-off riparian remediation project areas in the Fitzroy NRM region. Because of this, storage of carbon in biomass was relatively high in these projects, averaging about 82–92 t C/ha. Implications of this finding are:
    - The ERF Methodologies for biosequestration from revegetation or regeneration may require modification to allow for baseline assessments of carbon stocks in existing remnant vegetation. Expanding these methodology such that they also account for carbon stocks in existing remnant vegetation may facilitate a market based incentive scheme that provides a premium payments for protecting areas that already store significant quantities of carbon.

5.0 RECOMMENDATIONS

Facilitate landholder groups to engage and build local knowledge

Facilitate landholder groups (e.g. by Landcare groups, or other groups that have demonstrated success) to work together to tailor generic BMPs (Appendix A) for their specific sub-catchments, land uses, and collective goals. Policy and base funding setting are required to ensure that these regionally-tailored BMPs can be refined over time based on findings from local demonstration sites. So long as this initiative is not perceived as being too complex and government-controlled, this approach will facilitate widespread uptake by overcoming barriers of normalising behaviour and perceived risks of project failure. Local demonstrations will be particularly useful to fill remaining knowledge gaps on possible trade-offs between:

- Condition Score of the project area and the extent of grazing, particularly in the Fitzroy NRM region where, to ensure widespread uptake, environmental goals need to align with their primary goal of maintaining or increasing agricultural production.
- Quantity and quality of the project, particularly where increasing the quantity of projects at the expense of decreasing their quality may possibly impact on their primary goal of generating wildlife corridors and habitat connectivity.

Facilitate alternative incentive schemes

Explore the merit (e.g. cost-benefit analysis) of phasing out grant-based funding of riparian remediation works and replacing this with alternative incentive schemes (e.g. markets that bundle or stack credits from environmental services and overcome opportunity costs of foregone agricultural production) given:

- Landholders are more likely to be engaged in market-based instruments that give them positive incentives in not just implementing remediation projects, but also to undertake maintenance that ensures successful outcomes in the longer-term, e.g. some pastoralists in the Fitzroy NRM region have used one-off grants to fence-off riparian zones for improved herd management, but continue to intensively grazed throughout the dry season as there is no financial incentive to value regeneration of the woody vegetation.
- This may improve efficiencies in achieving benefits to GBR health as landholder payments are directly linked to the delivery of the environmental service outcomes required. Also, policy settings can be utilised to adjust the value of water quality, biodiversity and carbon mitigation services within the inventive schemes framework, thereby attracting the types of project that are of most benefits to the outcomes required, e.g. for regions where wildlife corridors are paramount, placing a premium on biodiversity credits in this region will promote well connected revegetation projects with multiple species.
- Accounting for multiple environmental benefits is well suited to incentivise riparian remediation projects as in addition to providing benefits to water quality (Table 1), riparian areas play a disproportionately large role in providing benefits to biodiversity and carbon mitigation. This is because, due to fertile alluvial soils and increased moisture levels, per unit area, riparian zones tend to have relatively high biomass, high plant and animal diversity, and high structural diversity.
- Alternative schemes may also facilitate the capability to increase the incentives for projects that protect and connect to existing remnant vegetation, e.g. premium

incentives for improved landscape connectivity and/or presence of existing remnant trees that would be protected by the project. This is important given:

- There was some indication that previous investments are failing to completely rehabilitate to optimal Conditions Scores, presumably due to project areas being relatively narrow and isolated, thereby leading to the persistence of poor plant cover, erosion and/or weeds.
- There was evidence of significant carbon storage potential in remnant trees, and yet under existing schemes, these are not valued.

Underpinning research to support riparian remediation

- Assess possible trade-offs between grazing extent and environmental benefits, and between the requirements to optimise environmental benefits by better understanding the possible trade-offs between project quality and the quantity of projects. Ideally this work would be done in collaboration with landholder groups seeking local-based evidence to inform their regions BMPs for riparian remediation projects.
- Explore whether remediation projects are more likely to approach optimal Condition Scores (in addition to improved biodiversity benefits) when they are have increasing extents of initial existing remnant vegetation within the project area, are relatively wide, and/or are well connected with other vegetation patches within the landscape.
- Develop standard cost-effective methodologies for monitoring indicators of water quality improvement (i.e. an improved Condition Score) and biodiversity improvements (i.e. Plant Cover Index and landscape metrics of connectively), as well as refine methodology used in the ERF for revegetation and regeneration projects such that they account for the much higher rates of biosequestration found in many riparian zones.

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APPENDIX A: GENERIC BEST MANAGEMENT PRACTICES

A review was conducted of documentation of BMPs of riparian vegetation in Australia, with a particular focus on catchments influencing GBR health (Table 6). Recommendations outlined by these documents were then summarised to provide generic BMPs for riparian vegetation, with a focus on GBR catchments in the dry and wet tropics.

Table 6: Documents outlining recommended BMPs that were reviewed and summarised.

Reference	ID
ARRC (2017)	1
Wilkinson et al. (2016)	2
BCCA (2014)	3
Bartley et al. (2015)	4
Gould and Spink (2013)	5
JRCMA (2013)	6
George et al. (2011)	7
Hansen et al. (2010)	8
Cassowary Coast Regional Council (2010)	9
CaneGrowers (2009	10
Doust et al. (2008)	11
Lovett and Price (2007)	12
QG (2006)	13
Price et al. (2004)	14
DPIPWE (2003)	15
LWA (2003)	16
Lovett and Edgar (2003)	17
Ainsworth, N. (2002)	18
Price and Lovett (2002)	19
Bennett et al. (2002)	20
Lovett and Price (2002)	21
Lovett and Price (2001)	22
Prosser and Karssies (2001)	23
Greening Australia (2000)	24
Rutherford et al. (2000)	25
Lovett and Price (1999)	26
Karssies and Prosser (1999)	27
Abernethy and Rutherfurd (1999)	28
Meney (1999)	29

The review of BMPs resulted in a summary of key recommendations for riparian vegetation remediation projects in GBR catchments (Table 7). This summary of BMPs focuses on activities undertaken in riparian project areas only, and doesn't seek to duplicate BMPs graziers, or sugarcane or banana growers in the GBR catchments (e.g. QG, 2017b).

Table 7: Synthesis of *generic* BMPs for riparian remediation projects based on the literature reviewed (Table 4). Note recommendation to facilitate landholder groups to work together to tailor these generic BMPs for their specific sub-catchments, land uses, and collective goals.

Reference	BMP
Priority areas & site selection	• Refer to the priorities for streambank erosion control defined in regional Water Quality Improvement Plans (QG, 2016)*. • To avoid the project area being washed away, an understanding the stream power, bank material and channel confinement is required to anticipate the points of natural erosion and deposition, and possibly undertake: (i) 'river training' in accordance with the natural meandering morphology of the river, and (ii) enhanced vegetation extent upstream to

	regulate runoff and stream power, e.g. ideally, commence projects at the headwaters and progress downstream. • The most cost-effective option is to avoid the damage in the first place by protecting any existing in-tact remnant vegetation by controlling stock access, weeds and feral animals. Priority should be given to smaller first and second order streams where fencing off is likely to be most effective. If there is erosion in these areas, evaluate the impact of land use upstream and downstream as reducing runoff may be warranted, e.g. remediation of gully erosion higher in the catchment. • Priorities 'connecting' in-tact riparian zones (i.e. > 1 km in length), rather than establishing a patchwork of isolated riparian zones. Consider habitat connectively.
Network & planning	• Identify feasible and measurable objectives, e.g. if the key goal is to improve water quality, expensive habitat provision may not be required. • Draw on the experiences of others, e.g. reviewing relevant publications, talking to individuals and groups that have done similar works, and seeking the advice of riparian ecologists and botanists. • Ensure that early on in the planning, all of the interests in the stream have been identified to encourage people to share goals and ensure the avoidance of the project being scuttled by a powerful interest group. Also check for legislative or administrative constraints.
Where remnant vegetation is not-intact, encourage vegetation based on the type of erosion	• **Sub-aerial erosion:** Caused by loosened soil on the bank being carried away by water flowing past, e.g. rilling. Common in smaller streams, and results trampling by stock, impact of wind and rain, trees falling onto the streambank, large woody debris 'damming' of the water, etc. In these instances it is important to encourage vegetation to grow on the bank face to protect the bank from erosion due to most sub-aerial processes. • **Fluvial scour erosion:** Caused when the water flowing against a bank causes it to be washed away. Often affects the middle reaches of streams rather than smaller streams. Encourage vegetation (particularly macrophytes that will grow close to the toe) to grow on the affected bank face in order to reduce the flow velocity close to the bank, and thereby directly reduce scouring. The fibrous root systems of vegetation also directly strengthens bank material, making it harder to remove front the bank face. • **Mass failure:** Occurs when blocks of bank come loose and collapse, and can occur together with scouring. Tends to affect the middle reaches of streams rather than smaller streams. The most important role of vegetation in mass failure is for the fibrous roots to cross the failure plane (i.e. the fracture line where the slump block breaks away from the bank) and thereby providing reinforcement of this plane. The failure plane will either be steeper than the bank face, or will parallel the face. Vegetation should be particularly encouraged to grow at the bank toe, but also at the top of the bank. Added weight of trees on the bank will often reduce mass failure, especially if it is planted low on the bank face. Shallow-rooted species on the bank face are also useful for controlling shallow slips. • **Incised streams:** Where the streambed is deepening and the banks fail because they are over-steep and/or undercut. This type of erosion is often caused by de-snagging. In these instances, prior to commencing any riparian restoration the streambed first requires stabilising, e.g. with rocks or woody debris^, stabilised rock riffle or vegetation in the upper channel or gully floor. Then, fence off from grazing and allow the streambed and banks to be colonised by shrubs and grass that *cf*. trees, are more effective at reducing water velocity and don't deflect water into erodible banks. In headwater areas, trees can provide woody debris in the channel that increases the hydraulic resistance of the channel and banks. • **Channel widening:** Where both streambanks are eroding because the catchment has been cleared and the stream cannot cope with the extra runoff water, or because the banks have been over-cleared and are consequently eroding. In these instances, first stabilise the toe of the eroding banks, e.g. using rocks or other structures to help maintain the toe region. Establish vigorous vegetation fast far down the bank as possible, giving particular attention to the toe of the bank. Channel vegetation should be shrubs, grass and aquatic plants that *cf*. trees, are more effective at reducing water velocity and don't deflect water into erodible banks. Ensure channel capacity during peak flow is not hindered by vegetation chocking the channel or sediment bars. • **Erosion of the bank on the outside of a meander bend:** Most common in larger streams. It may be necessary to use mechanical protection (e.g. rock placed along the toe) to help

	stabilised the bank first, and where angle >45°, battering them back to less steep angle may be required. Establishing trees on the banks is effective when there is an approximate match between the height of the bank and the rooting depth of those trees. Vigorous vegetation should be encouraged even if they topple to the toe of the bank given toppled vegetated blocks may continue to grow and stabilise the toe of the bank.
Type of project	• **Natural regeneration:** When there are intact riparian areas (and seed sources) upstream, and management activities are undertaken to allow for natural regeneration, e.g. weed management and control of grazing animals. Also consider placing debris or silt traps at bank toe to facilitate sediment and seed deposition to encourage tree/shrub regeneration. • **Revegetation:** When native vegetation cannot be expected to recover naturally, e.g. areas disturbed by earthworks, highly degraded soils, or in areas where there are few riparian areas (seed sources) upstream and/or where existing woody vegetation cover is < 25% foliage projected cover on riparian/ floodplain surface. Revegetation may also be preferred over natural regeneration in areas where: (i) specific tree species are required for multiple riparian zone benefit (e.g. wildlife habitat corridor), or: (ii) erosion is relatively rapid and active revegetation is likely to have benefits sooner than natural vegetation regeneration.
Width	• The minimum allowance for the width is 5 m from the bank crest. But as the bank becomes steeper and higher, the zone of influence of the erosion processes extends deeper into the bank. Hence, in addition to the basic allowance, the width of riparian strips should also include a height allowance not less than the height of the bank measured vertically from the bank toe to the bank crest. • Alternative guides relate to the land use and stream order: In cropped areas, 25 m for streams, and 50 m for rivers. In grazed areas, 50 m for stream orders 1-2 (or creaks or channels up to 5 m wide), 100 m for stream order 3-4 (or streams 5-30 m wide) and 200 m for stream order 5-6 (or rivers more than 30 m wide). Wider zones of riparian vegetation may be needed to stabilise streambanks on outer bends that are more susceptible to erosion. • For smaller streams, wider buffers may be required to provide wildlife habitat and support the long-term survival of most birds and animals. If this is not practical, consider having sections of wide strips, particularly when these form suitable corridors with remaining vegetation. • For sugarcane and banana cropping areas, an additional 3-6 m grass buffer strip between the cropped area and the riparian vegetation will provide additional assistance in trapping nutrients and sediments.
Livestock management	• Following fencing, livestock should be excluded for > 3 years to enable native perennial vegetation to develop a high biomass. After this time, and only in non-dispersive and non-slaking soils, short periods of dry season grazing (when the bulk of the vegetation is dormant and the soil moisture is low) may occur within the fenced area to manage fire risk or vegetation composition where appropriate. • To reduce the risk of damage to fences during floods, fences should be located well away (preferably 30-50 m) from the main flow. Positioning the fence further from the stream will also allow for straighter fences, thereby reducing costs. It will also benefit erosion protection and wildlife by increasing the area being revegetated. • If some livestock access to the stream is required, keep the stock to a small restricted area that is: (i) fenced off from the riparian corridor, e.g. with two parallel fences about 2-20 m apart, (ii) relatively flat, with a maximum slope of 1:6, to reduce erosion and to make it easier for stock to get to the stream edge, (iii) located on the inside of a bend, where water movement is slower and the banks are less prone to erosion, (iv) has had the surface hardened (e.g. with gravel) at the access point, (v) not well sheltered in order to discourage stock to camp or loafing around the watering point, (vi) is angled in a downstream direction so that stock enter the stream in the direction of water flow, (vii) allows the stream to flow past the access point during peak flows, rather than into it, which can cause further erosion • If fencing is not cost-effective, livestock grazing of riparian vegetation may be reduced via: (i) herding though the use of off-stream watering points and supplement (e.g. sat licks) placement, and; (ii) adjusting both the stocking rates and the frequency of use to suit the sensitive nature of the land, e.g. carefully manage livestock to maintain complete ground cover, and avoid grazing riparian land in the growing and flowering season and when

	germination is occurring. This will be particularly important in the upper parts of the catchment.
Types of fences	• **Specialised solar-powered electric fencing for waterways**: Cheap and easier to construct, and repair if damaged in a flood event. Where the fence crosses the stream, steel cables are used to suspend chains or hinged panels which are electrified, and which can be removed in times of high flow. Electric fences can also be made portable, so that they can be removed altogether in times of flooding. • **Drop fencing**: These fences are attached in such a way that they can be manually disconnected from the permanent upright posts and laid over to allow the water to flow over the fence without damaging it. The fence is then quickly and easily stood up again after the flood waters have receded. In many cases, gates may not be necessary as stock and vehicles can also cross the laid down fence. • **Hanging fences**: These may be suspended from heavy duty cable, and have hanging panels that can swing upwards when the water level is high. These may be useful for smaller, narrower streams and prevent stock from accessing the protected area by walking up the stream • **Electronic virtual fencing**: Have transmitters that emit a signal to the ear-tags of cattle when they approach the fence, thereby training the cattle to stay away (e.g. Anderson 2007).
Revegetation: Site preparation	• Undertake weed control one season before planting, starting at the upstream end of the weed infestation. • Controlled fire may be a suitable site preparation for revegetation in some cases, e.g. in the Burrent catchment. • For non-cohesive soils, rock or log structures may be needed. • Although generally not cost-effective, for some high-value small-scale projects, or where soil degradation is severe, soil treatments such as water crystals, gypsum, mulch (free of weeds and pathogens), inoculants of soil biota (e.g. Wattle-Grow to increase the nitrogen-fixing ability of Acacias) can be added. • Broad-scale soil disturbance should be kept to an absolute. When preparing the soil for planting tube stock, cultivate (e.g. deep ripping to a depth of at least 30 cm, in contours, not down the slope) only where stock or vehicles have compacted the soil to such an extent as to limit water infiltration and root penetration. • Spot cultivation may use a spinning or auger attachment operated from a small excavator or dingo digger, or use of a hand augers at sites that machinery cannot access. Recently developed techniques for replanting, such as the waterjetting of long-stemmed tubestock of native species, have increased the range of situations where revegetation can be a successful approach to bank stabilisation.
Revegetation: Species selection	• Ideally, should reflect those that are native to the botanic region, or at least copy a reach in good conditions that has the physical and biological characteristics you want, including having a high chance of survival given they are adapted to withstand different hydro-periods (i.e. timing of access to moisture) and flow velocities. • Strive to have at least five native species as this increases the biodiversity benefits, allows for the 'failure' of some species, and provides a variety of root types to stabilise the soil. • Ensure vertical zonation. At the toe, facilitate the establishment of water-edge native grasses, rushes, reeds, sedges and shrubs with flexible stems and branches. Shrubs and small trees in the middle bank, with either an understorey of grassy species or a strong mat of fibrous roots. At the upper bank, large trees with an understorey shrubs and/or grasses. In general, dense undergrowth is preferable to more widely spaced trees, especially on the lower banks and towards the toe of the bank. • However, where riparian areas are highly degraded, pioneer species should be planted to provide rapid cover and create microhabitats which will encourage other species.
Revegetation: Establishment	• **Tube-stock planting on accessible areas**: Ensure the seedlings are about 10-20 cm tall, not root-bound, and has been 'hardened off' and acclimatised before delivery. • Spacing of plants depends on the species, where it is being planted and why it is being put in that spot. Also need to account for any natural regeneration that may already be occurring. In general, aim for woody stem densities to be relatively high along the toe of the bank (1 plant per 2.5 m^2) to achieve rapid root interlocking, 1 plant per 2 m^2 elsewhere, but low

	densities (1 plant per 64 m^2) in the frequently (annual) inundated bed areas so as not to block high flows. But problem areas may need more dense plantings for example. • Plant tube stock in hole that has been dug to the depth of the container and at least twice the width, and place seedling slightly below soil level and cover potting mixture with soil. • Tree guards (e.g. milk cartons and bamboo stakes, or tall GreenGuards™ with hardwood stakes) may be required when there is threat from browsing by animals. Only use materials that readily break down. • If tube stocks are not available for tufted plants (e.g. mat rushes, sedges), these can be dug up, divided and directly transplanted into moist soil or gravel. Alternatively they can be grown on in pots for planting during optimal conditions when the plants are more advanced. • Prior to establishment/canopy closure, re-planting may be required (e.g. post cyclone or flood damage). Re-planting will require sourcing advanced trees to ensure that the tube stock are not struggling to establish with surviving trees. • **Direct seeding on accessible areas**: Suitable for the more assessable floodplains and upland zones where it can be considerably cheaper than tube stock planting. Does not work as well in areas of high moisture with a high level of grass competition. • Rows of direct seeded belts may be established perpendicular to the direction of flow, and spaced at 1-2 m apart to allow for maintenance and some natural regeneration. • Plants will continue to germinate for several years after direct seeding takes place, e.g. a 'failed' direct seeding site in year one may become a successful site in year two or three. • **Establishment methods on steep embankments**: Use either: (i) pre-seeded matting that has seeds (generally of rushes and sedges) spread onto a fibre-mulch, or; (ii) brush of bradysporous species (e.g. *Myrtaceae* Family) harvested from plants at seed maturity, and laid along the embankment and secured using upright timber pieces. • **Establishment of grasses**: Where riparian vegetation includes grasses, or where grasses are required to take up soluble phosphorus, bare sites can be hydromulched with native seed mixes, or broadcast by hand where site access is difficult or the economy of scale makes hydromulching impractical. • Ensure that woody stem densities are low enough to allow grass growth.
Revegetation: Initial management	• **Initial watering**: Planting into moist, warm soils which also have good subsoil moisture. If planting in the dry season, watering will be essential. • **Initial weed control**[+]: If using tube stock, keep a grass and weed free zone about 1.5 metres in diameter around tube stock plants, e.g. using spot spraying grasses with a knockdown herbicide such as Roundup biactive ®, or by stem-injecting woody weeds[+]. If using direct seeding, particular attention needs to be given to weed control as part of site preparation, especially in ex-pasture areas, e.g. use grass specific weed control such as Fusilade® to ensure that seedlings are maintained above the height of weeds. • Weed control via mulching, weed mats and physical removal are unlikely to be a cost effective in large scale projects. Mowing and slashing may be cost effective in the upper banks where vegetation was established in rows, or with relatively low planting densities. • **Insect control**[+]: In areas at risk of insect attack, a systemic insecticide tablet can be placed under the seedling or systemic insecticide can be injected into the soil around root bowl before planting (usually in the nursery). Treating insect attack after planting is more difficult and costly.
On-going weed control	• Tree density often peaks 15–25 years after remediation, and active weed control should therefore occur for at least 10 years after project establishment. • Use of herbicides in wet areas must be undertaken with great care, using only low toxicity herbicides approved for use in the area[+]. The application techniques include using herbicide granules, cut and paint methods, or wick wiping using a specifically designed wick-wiping applicator. • When spraying herbicides, the area sprayed should be limited to the placement of the revegetation. That is, 1.5 m wide strips for linear plantings (direct seeding and tubestock) or 0.75 m circles for spot spraying (tubestock). This reduces chemical use (and cost) and will ensure that fewer bare areas are at risk of erosion and weed invasion. • Control of some noxious weeds in riparian areas is a legislative requirement. Neighbours in adjacent communities need to act together in order to develop the most effective approach

	to the problem. To minimise weed invasion, avoid disturbances, e.g. vehicle and equipment access.
Fire	• Exclude fire for a minimum of 10 years, longer if possible. But if fuel loads become dangerous, reduce with a short, intense 'burst' or 'pulse' of grazing whereby small pasture areas are grazed for a sort time with a large number of animals. This is repeated until the fuel load is reduced to a safe level. • In parts of the dry tropics where occasional fires may have been a natural event once every 10–25 years (e.g. where the natural riparian vegetation is a form of eucalypt woodland), it may be possible to use a burn to help reduce weed infestation along streambanks, or to provide conditions for reestablishment of native species. • The season and exact timing of the burn needs to be planned carefully to ensure that it is beneficial and not damaging. Annual burning would not meet this requirement and, in general, repeated burning damages natural riparian vegetation and encourages growth of 'fire weeds'. • In the wet tropics where there are closed forests of fire intolerant species, fire is unlikely to be a beneficial management tool in rehabilitating or managing riparian vegetation, and the emphasis is likely to be on preventing fires spreading to riparian zones, e.g. preventing fires escaping from sugarcane growing operations.
Feral animals	• Depending on location, ongoing control of feral animals may be necessary. Baiting, or long-term use of exclosures may be appropriate. • Regular fence checking is required as native fanua and feral animals may damage fences.
Monitoring	• Keep good planting records including photographs, plant survival rates, techniques used, and the effectiveness of these techniques in meeting the desired outcomes. • Such monitoring and evaluation is critical to (i) ensure that recommendations being made are actually effective at reducing sediment yield (ii) to justify the use of Government funding (iii) as a communication and marketing tool to encourage other farmers to undertake remediation. • Record: (i) location where the activity was carried out, (ii) date on which the chemical was applied (or the nonchemical technique carried out), (iii) names and contact details of those who carried out the work, (iv) target species and the type of chemical or technique that was used, (v) where chemicals are used the registered name of the herbicide (or pesticide), mixing details such as the rate at which it was applied, application method and quantity used, (vi) weather conditions preceding, during and after the activity was carried out, and (vii) an indication of the success or failure of the project, for example using 'before' and 'after' photographs

*All streambank erosion activities should be part of an integrated strategy within the priority area, and the cost of undertaking the remediation should not outweigh the anticipated benefits of the work. Engineering modification should be considered in instances of evidence of very active erosion with flow rates of >1 m yr^{-1}, and where either streambank vegetation is already extensive throughout the catchment, or where clearing has caused the power of the stream to be too high for vegetation to deal with (Wilkinson et al. 2016; ARRC 2017). Alternatively, a 'sacrificial zone' revegetated with fast-growing species may be established. In time, this may assist to slow erosion sufficiently for the larger, slower-growing species to establish further back from the bank top.

+With all chemical use in riparian areas, consider the proximity to the water and flow lines, critically assess the potential effects of the chemicals on water quality, evaluate the likelihood of sensitive environments becoming affected by the chemical, and consider the possible impact on non-target wildlife, flora, humans and livestock. Always check the labels or authorities for instructions for use, clean up of spits, storage and disposal. There are a number of laws which govern these issues - check the legislation that is appropriate for your state.

^Reinstate large woody debris at various angles to assist infiltration rates and impede water flow, thereby armouring both streambed and banks against erosion. However, large woody debris would need to occupy >10% of the cross-section of the channel before having much effect on the flow velocity and flooding.

APPENDIX B: MAPS OF STUDY SITE LOCATIONS

Figure 10: Location of the nine project sites assessed in the Cairns Coastal sub-region of the Wet Tropics NRM, wet tropics. Sites are situated within the Mulgrave Russell river catchments and the Johnstone river catchment.

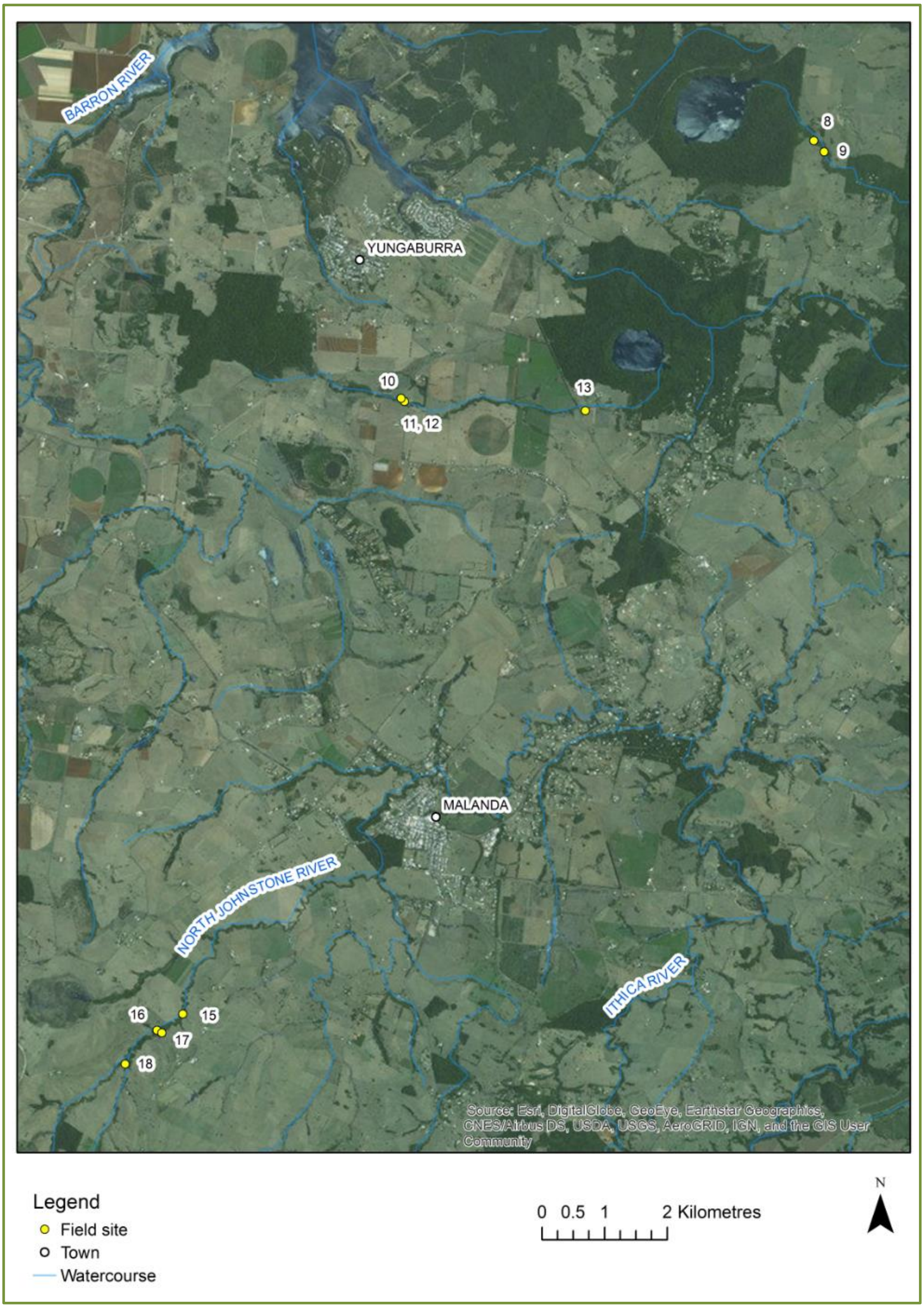


Figure 11: Location of the ten project sites assessed in the Atherton Tablelands sub-region of the Wet Tropics NRM, wet tropics. Sites are situated within the Barron river catchment and the Johnstone river catchment.

Figure 12: Location of the five project sites assessed in the Upper Fitzroy sub-region of the Fitzroy NRM, dry tropics.

Figure 13: Location of the five project sites assessed in the Dawson catchment sub-region of the Fitzroy NRM, dry tropics.

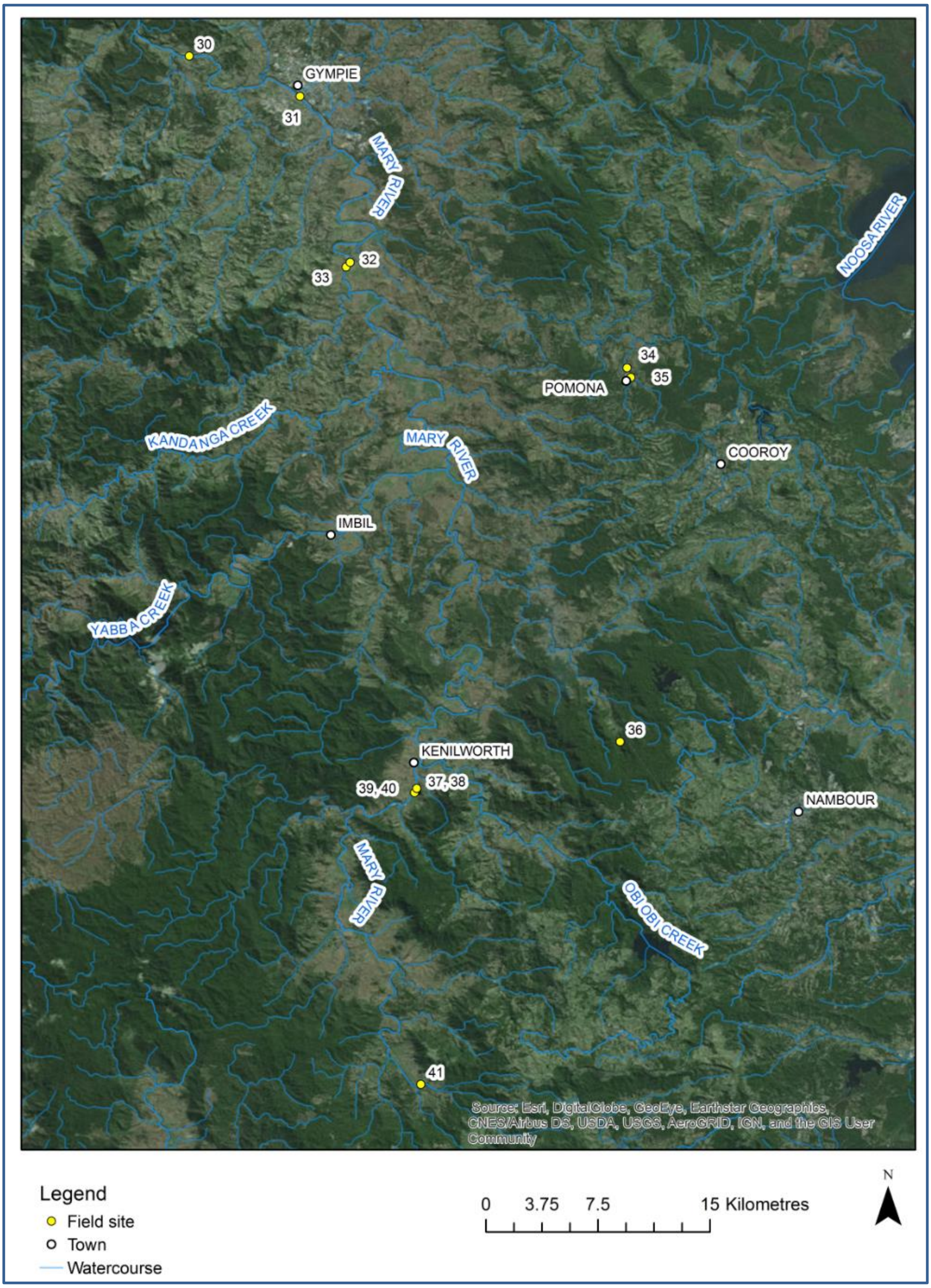
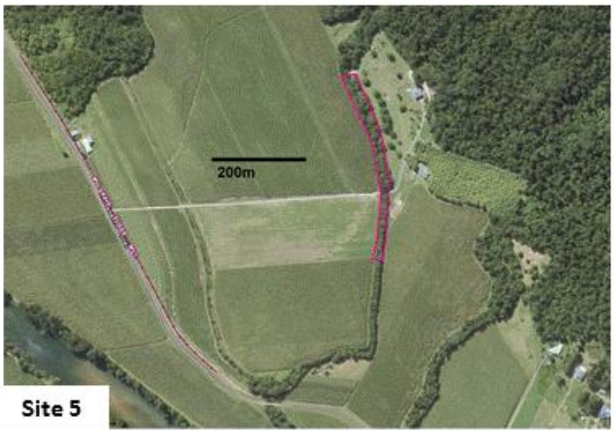
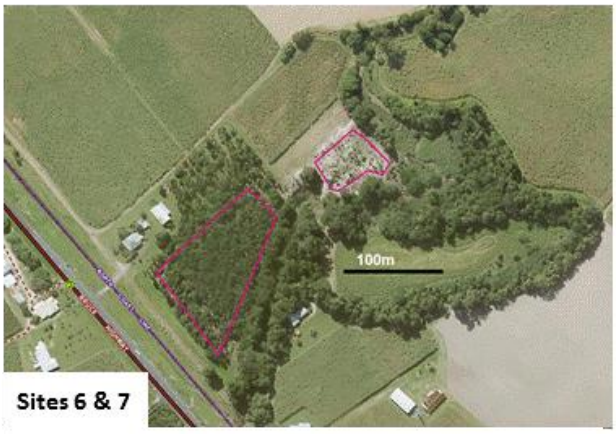
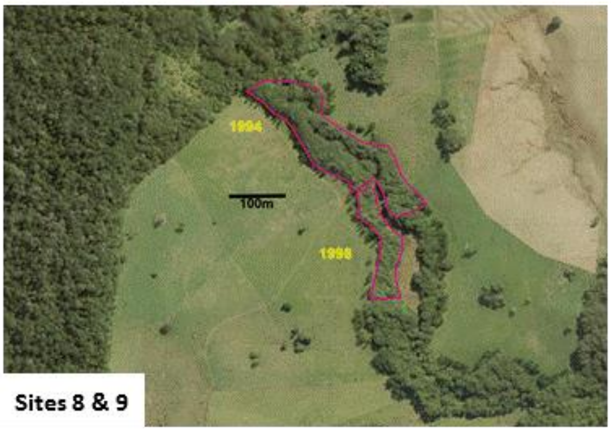


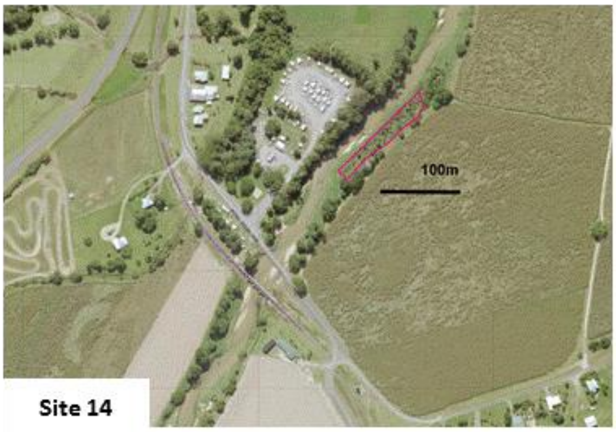
Figure 14: Location of the twelve project sites assessed in the Mary River catchment sub-region of the Burnett Mary NRM, Subtropics.

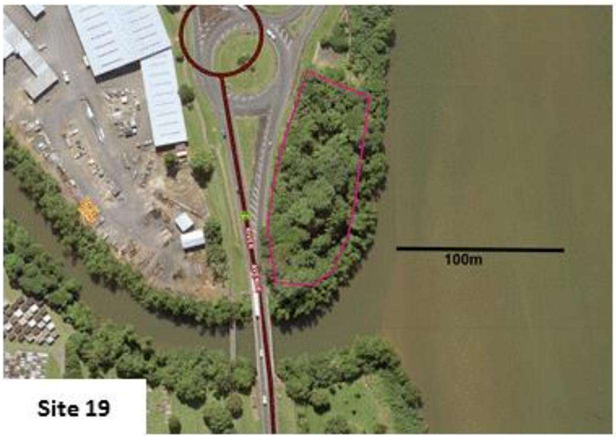
APPENDIX C: PHOTOS

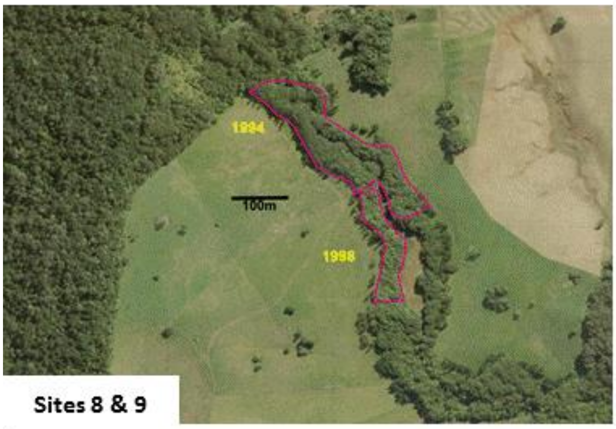


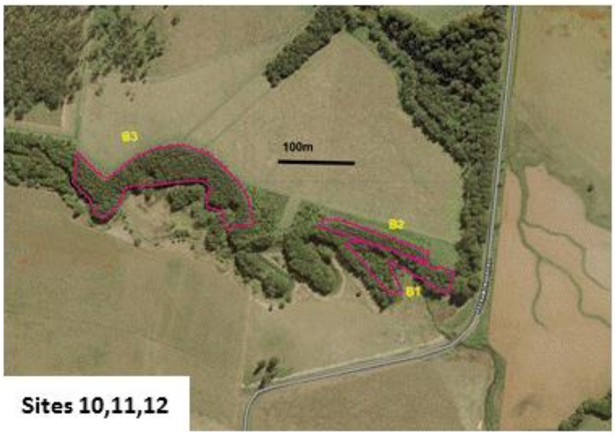

100m
Sites 6 & 7


1994
100m
1998
Sites 8 & 9

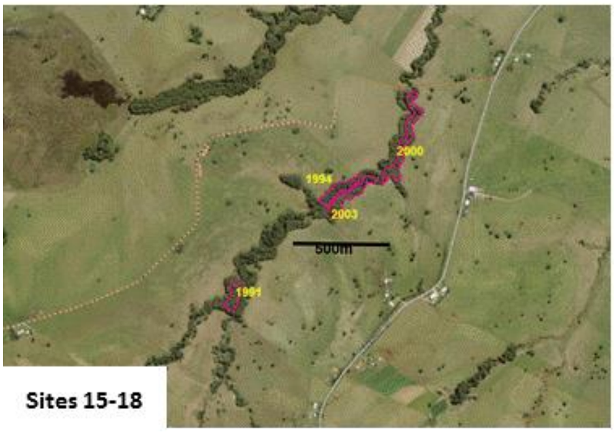

100m
Site 14

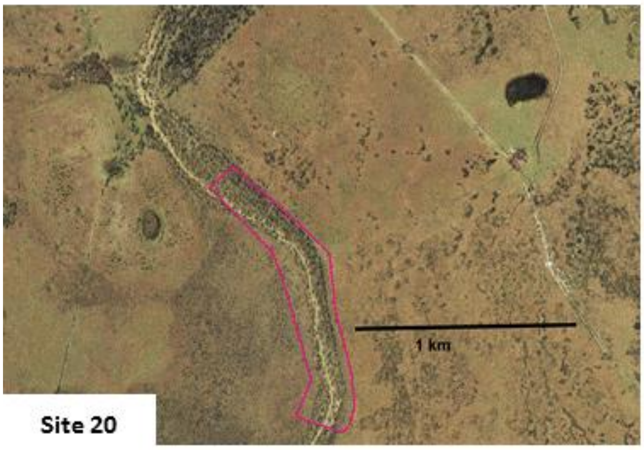

100m
Site 19

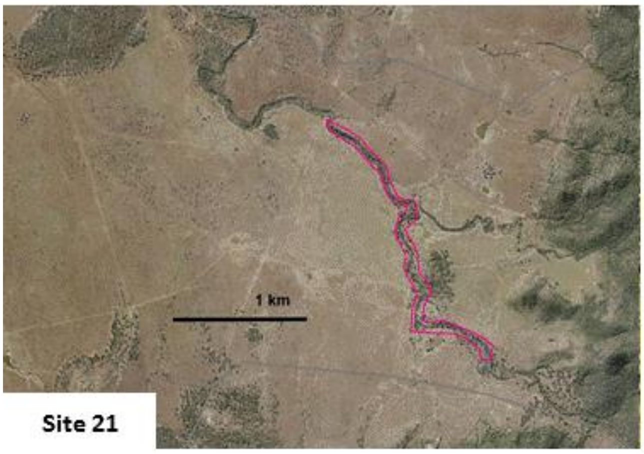

1994
100m
1998
Sites 8 & 9

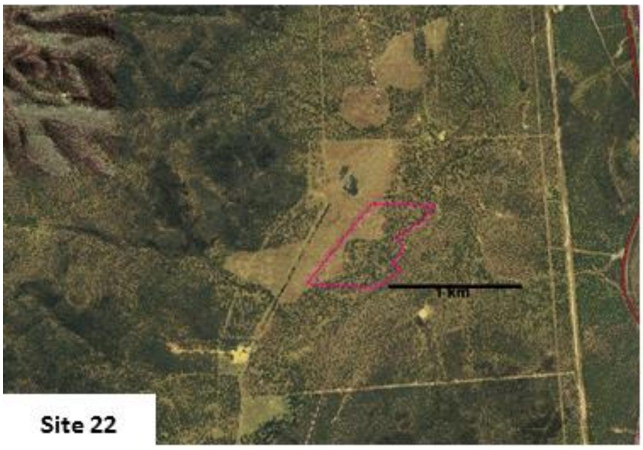

B3
100m
B2
B1
Sites 10,11,12

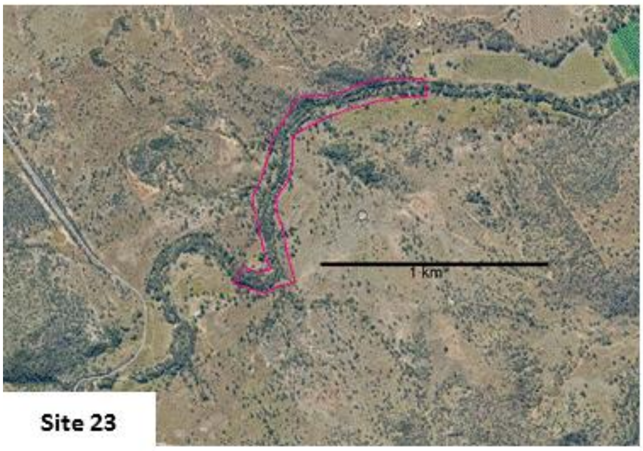

100m
Site 13

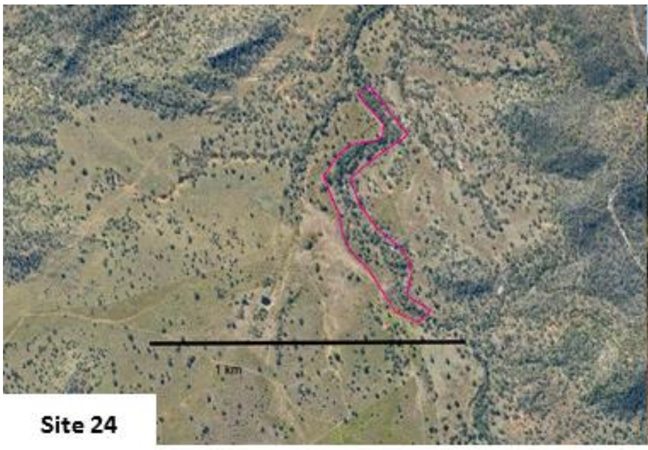

2000
1994
2003
500m
1991
Sites 15-18


1 km
Site 20

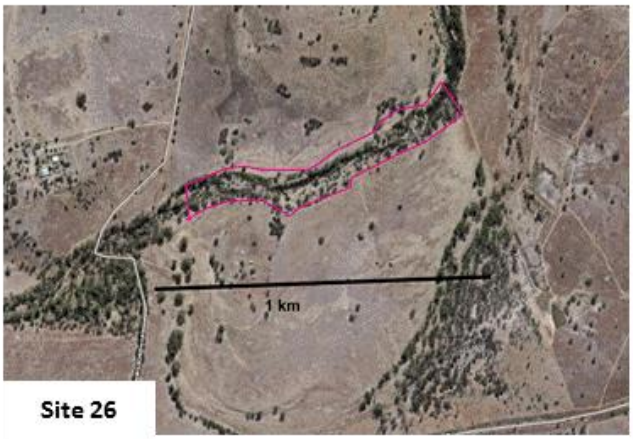

1 km
Site 21

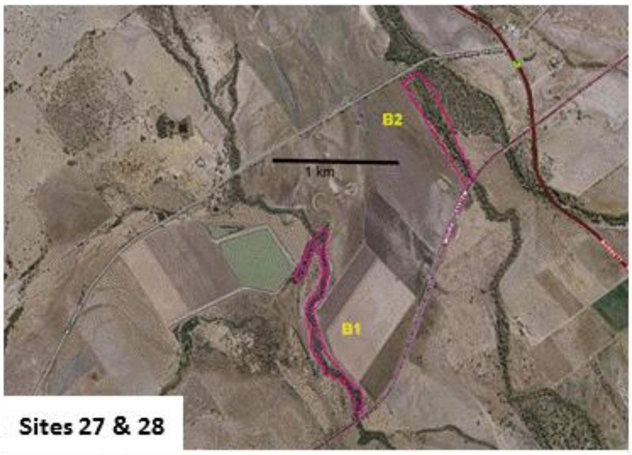


1 km
Site 22

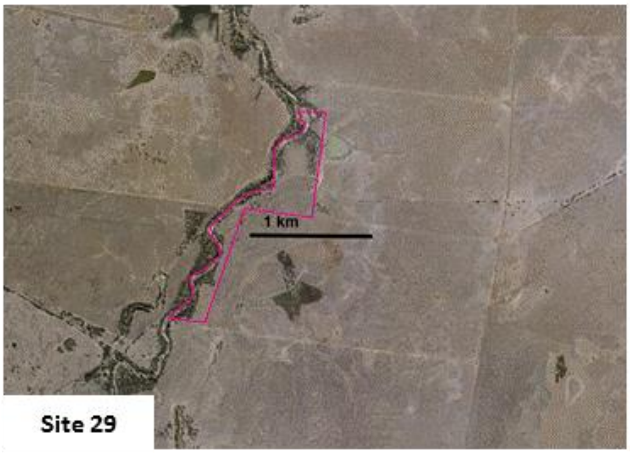

1 km
Site 23

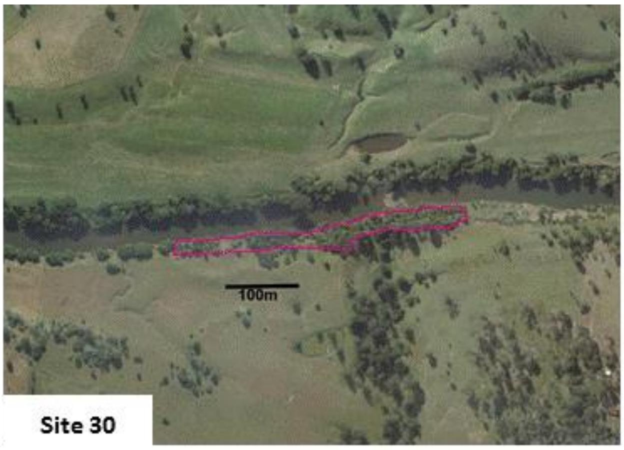

1 km
Site 24


1 km
Site 25

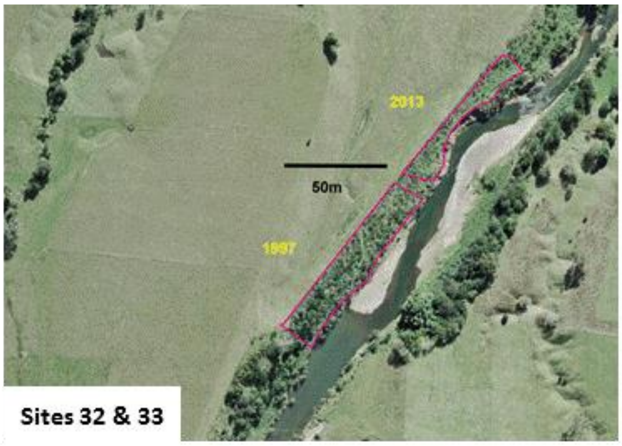

1 km
Site 26



B2
1 km
B1
Sites 27 & 28

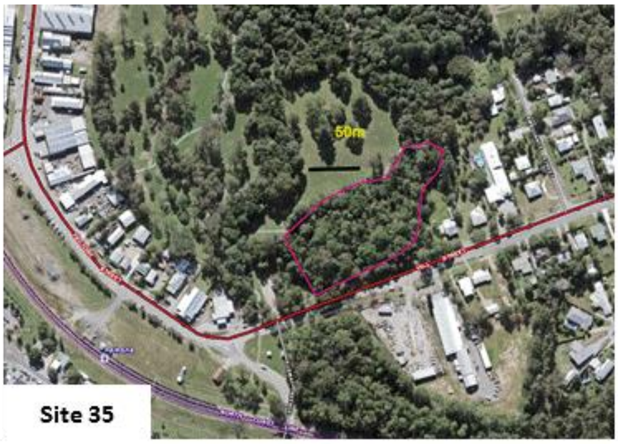

1 km
Site 29

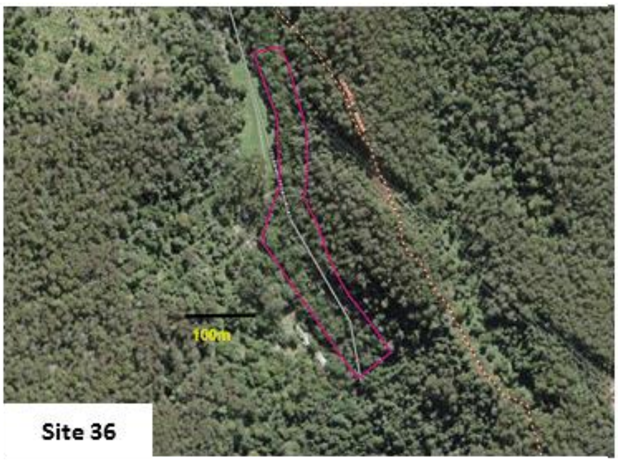

100m
Site 30

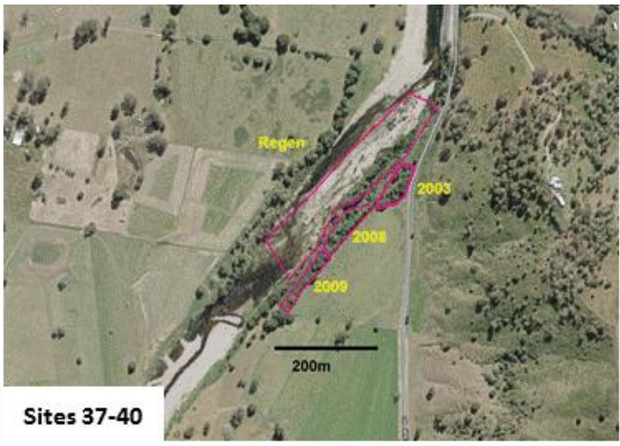

100m
Site 31

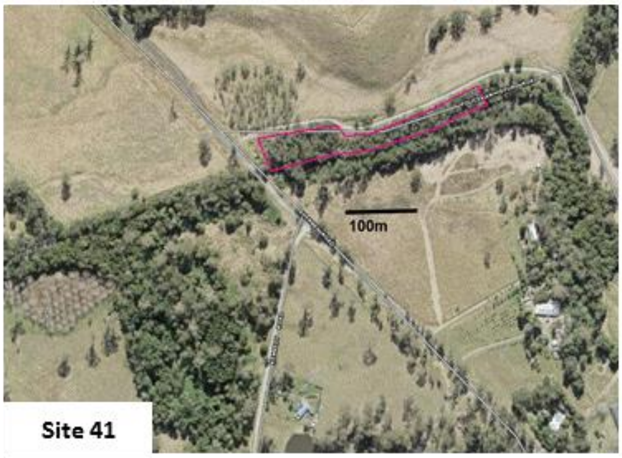


2013
50m
1997
Sites 32 & 33


100m
Site 34


50m
Site 35


100m
Site 36


Regen
2003
2008
2009
200m
Sites 37-40


100m
Site 41

Reef & Rainforest
RESEARCH CENTRE