Monitoring Outcomes from Murray Local Land Services Riparian Interventions: Plan and Year 1 Pilot

Arthur Rylah Institute for environmental research

Department of Environment, Land, Water & Planning

State Government Victoria

Abbreviations

CMA	Catchment management Authority
CPOM	Coarse Particulate Organic Matter
GIS	Geographic Information System
KEQ	Key Evaluation Question
LLS	Local Land Services
MERI	Monitoring, Evaluation, Reporting and Improvement
NOW	NSW Office of Water
NRM	Natural Resource Management
OEH	Office of Environment and Heritage

Citation

Brooks, S., Hale, R., Reich, P., Crowther, D., Lake, P.S. & Morris, K. 2015. Monitoring Outcomes from Murray Local Land Services Riparian Interventions: Plan and Year 1 Pilot. Arthur Rylah Institute for Environmental Research Technical Report. Department of Environment, Water, Land and Planning. Heidelberg, Victoria.

Acknowledgements

The authors would like to thank Holbrook Landcare, in particular Raylene Brown for help locating sites, coordinating with landholders and assisting with field sampling. We also thank Michael Nicol, Joanne Kearns and Ruby Campbell-Beschorner of the Arthur Rylah Institute for Environmental Research for their help with the field monitoring and Meagan Brooks for data entry.

Cover Photo

Young riparian trees planted next to Kelly Creek in 2005.

Report produced by: Arthur Rylah Institute for Environmental Research
The Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.depi.vic.gov.au/ari

Contents

1. Introduction 2

2. Monitoring and Evaluation Framework 4

3. Implementation 14

3.1 Desktop studies (GIS) 14

3.2 Field monitoring 19

4. Recommendations. 39

5. Flexible Monitoring and Research Schedule 42

6. Data management 44

7. Communication 46

8. Research Portfolio 47

9. References 59

Appendix 1 Site details 61

Appendix 2. Methods to examine the relationship between sampling effort and sampling error 62

Appendix 3. Power analysis methods 63

1. Introduction

Murray Local Land Services (LLS) invests approximately $2M annually in activities to improve the condition of aquatic ecosystems in their region. Much of this activity in the past has been driven by incentive funding to implement on-ground intervention works to address river health and water quality targets. To date there is a lack of evidence to prioritise and guide the design of these interventions and/or demonstrate the impact or effectiveness of these investments. Murray LLS has developed a Monitoring, Evaluation and Reporting and Improvement (MERI) framework (Brooks et al. 2011) to build capacity for adaptive management to improve the effectiveness and efficiency of these interventions in achieving riparian and river health outcomes.

For some management interventions there are clear links between a particular management activity and a management outcome. For example, riparian vegetation is well known as a source of allochthonous organic carbon that supports river system food webs (Reid et al 2008a, Tank et al 2010). This type of evidence supported by scientific studies provides a high level of confidence that undertaking that activity (improving riparian vegetation) is likely to achieve specific management outcomes (carbon supply to river food webs). For other relationships and outcomes there is little evidence and we rely on assumptions or expert opinion that provide only low confidence that management activity will achieve desired outcomes.

In the period 2004-2013 Murray LLS (then Murray Catchment Management Authority) have invested in approximately 300 projects to establish or manage vegetation along rivers, streams and man-made channels. Individual interventions have been implemented under larger programs targeting sediment and erosion control, water quality and salinity, habitat, and landscape connectivity (wildlife corridors) with little evaluation of whether overall program objectives were met.

This Murray LLS Aquatic Health Monitoring Program is aimed at generating the evidence required to evaluate river health outcomes and improve the adaptive management of aquatic projects in the Murray Region. It adopts the principles and structures of the Murray LLS MERI framework, in developing clear conceptual models to link management activities to intermediate and long term outcomes (Figure 1).

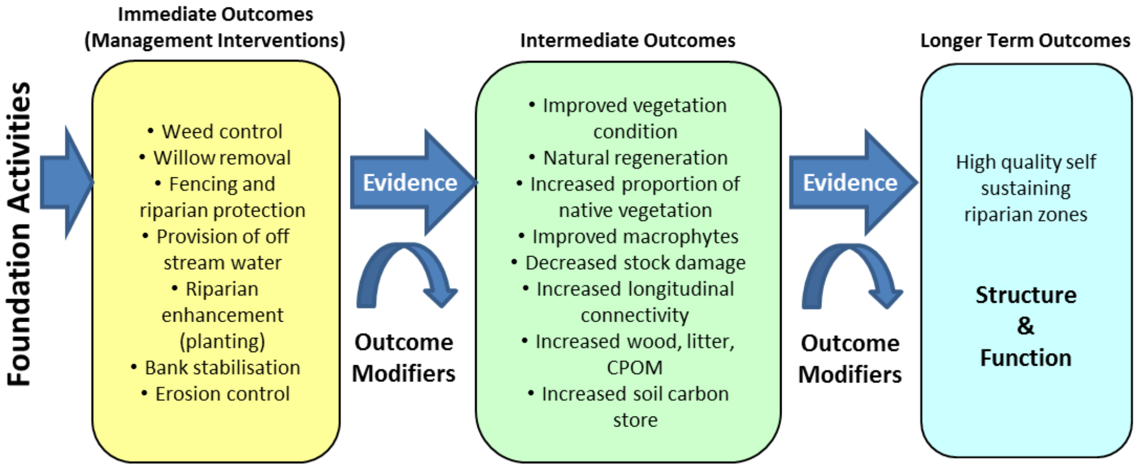

Figure 1. Simplified outcomes hierarchy for riparian zones adapted from the Murray LLS MERI framework (Brooks et al, 2011). This monitoring program is a foundation activity that will collect evidence for the achievement of outcomes and the factors that modify them, and influence subsequent riparian management.

The program is focussed on developing an understanding of the processes underpinning the observed outcomes to riparian management interventions as well as assessing patterns and causes of temporal and spatial variability in these outcomes (outcome modifiers, Figure 1). This will be accomplished using an integrated approach incorporating observational monitoring and experimental approaches that provide different but complementary information. This Multiple Lines and Levels of Evidence (MLLE) approach enables qualitative or quantitative evidence for the achievement of riparian outcomes from management interventions to be identified, and the strength of the causality demonstrated by the evidence to be considered. Multiple Lines and Levels of Evidence is a key principle of the Commonwealth Natural Resource Management MERI Framework (Commonwealth of Australia 2009) and NSW Evaluation Framework for CMA Natural Resource Management (DECC 2009) that underpin the Murray LLS MERI framework (Brooks et al. 2011).

Program Objectives:

1. To understand the impact of Murray LLS riparian interventions on the distribution, structure and composition of riparian and instream vegetation at reach and catchment scales.
2. To understand the impact of Murray LLS riparian interventions on river ecosystem functioning at reach and catchment scales. Initial target functions include:
    a. Wood and allochthonous litter delivery, retention and processing
    b. Channel migration and bank stabilisation
3. To identify factors that modify outcomes of Murray LLS riparian interventions at reach and catchment scales. Examples of potential outcome modifiers are hydrology, climate, landuse and geomorphology.
4. To ensure the monitoring and evaluation is appropriate, effective and efficient to best support Murray LLS and landholder adaptive management of riparian zones.

2. Monitoring and Evaluation Framework

The monitoring program is guided by the MERI framework and is informed by the following key principles:

1. The program is structured within a logical conceptual framework
2. Balances risk and return in terms of new knowledge generation versus the reliability of standard approaches
3. Seek to resolve broad scale, composite ecosystem outcomes at spatial scales larger than individual management interventions (e.g. at sub-catchment scales and above) to assess the overall aquatic health of streams in the Murray LLS region, examine temporal trends in condition in response to management, and validate the findings of hypothesis testing.
4. Uses best available science. Conduct hypothesis testing via targeted monitoring and research to assemble specific evidence to improve understanding of ecosystem responses to management interventions and address fundamental knowledge gaps.
5. Maintain flexibility to scale program in line with adaptive management needs and variable annual investment to help secure long-term program outcomes.
6. Adopt and improve the Murray LLS MERI framework, in particular the Riparian conceptual model, and underpinning evidence. Outputs must be capable of supporting adaptive management, informing future investment and facilitating communication with external stakeholders
7. Apply rigorous QA/QC procedures and data management to secure long term (10yr) outcomes.
8. Pursue integration and collaboration opportunities with other programs and regions that collect complementary evidence.
9. Adaptive improvement to the monitoring program in light of new evidence and changing Murray LLS needs.

Intervention monitoring and research outcomes will be integrated into Murray LLS riparian management practices via an adaptive management MERI framework (Figure 2). Key components of this integration are the ongoing collection and evaluation of evidence to improve riparian management conceptual models that underpin investment and implementation decisions (e.g. Figure 3).

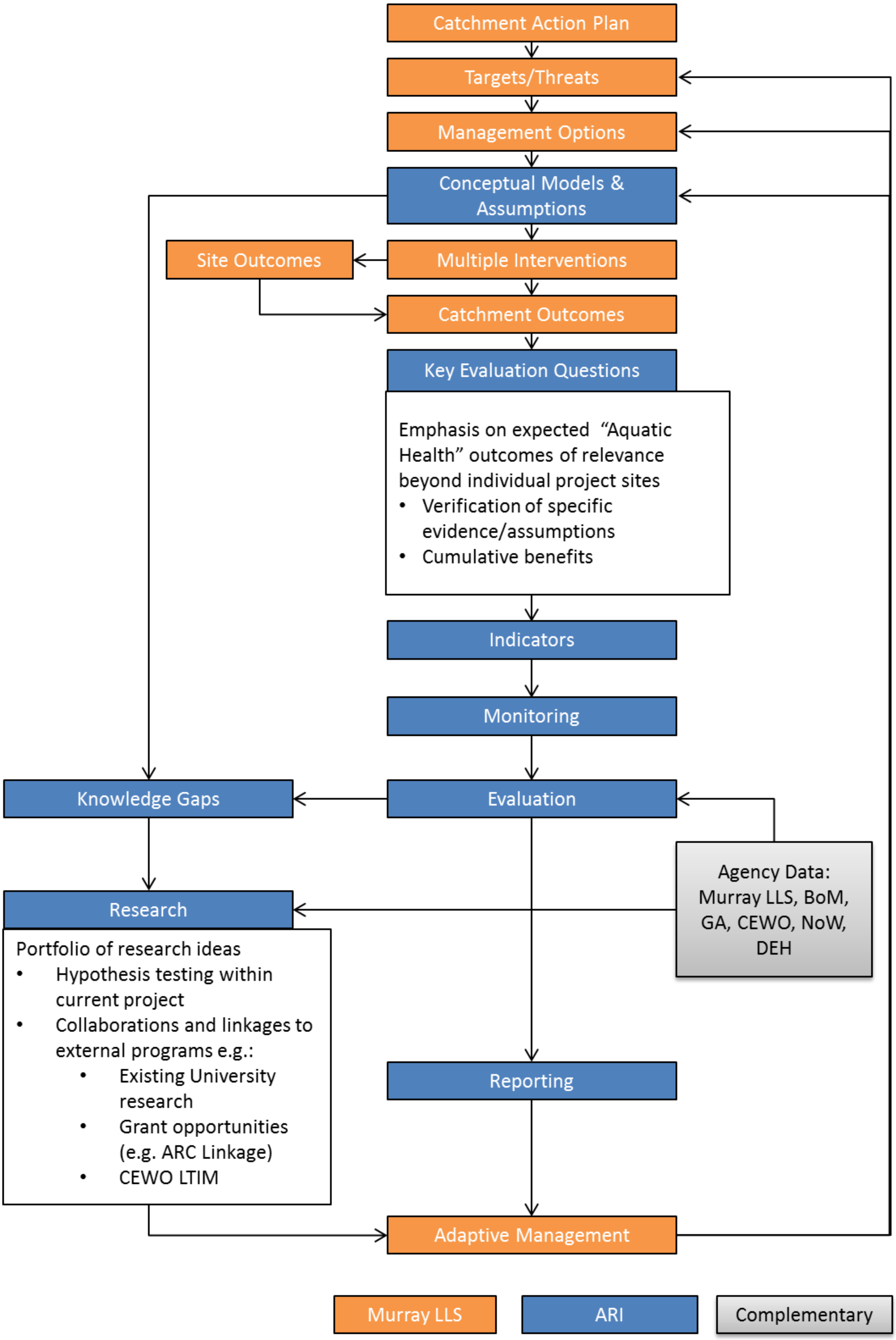

Figure 2. Framework for integrating outcomes of monitoring and research into Murray LLS adaptive management of riparian zones.

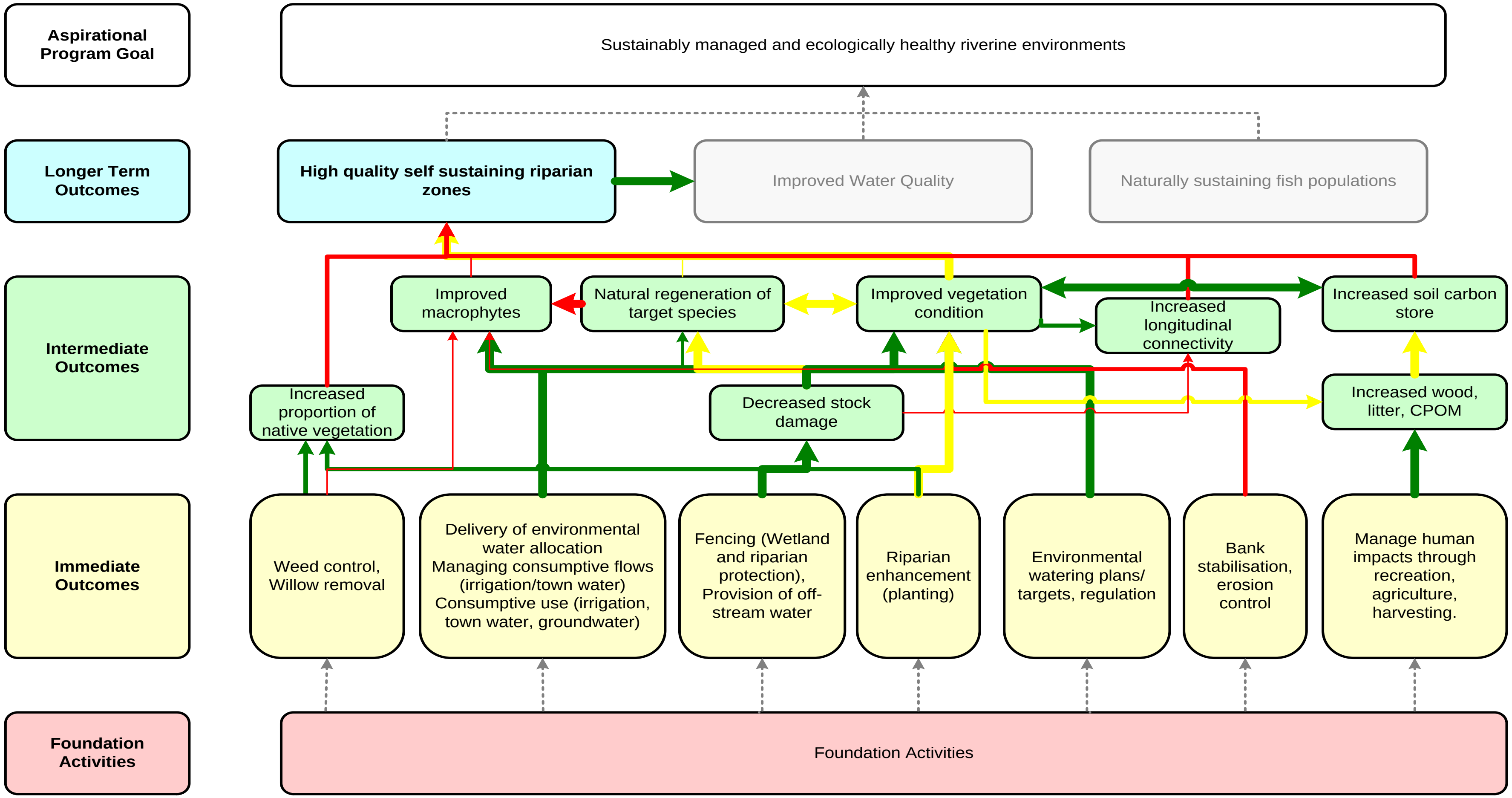

Figure 3. Riparian conceptual model from the Murray LLS (then Murray CMA) Riverine MERI framework (Brooks et al. 2011). Line width indicates relative strength of response. Colour indicates uncertainty where red=little evidence, yellow=medium, green=most evidence.

Following discussion with Murray LLS, the initial scope of the program will be constrained to interventions that include riparian vegetation enhancement (typically in conjunction with fencing, reduced grazing and weed control) as these activities are likely to be components of future interventions by Murray LLS for a range of intermediate outcomes for which evidence is incomplete (Figure 3). Another common intervention influencing riparian zones in the region is the provision of environmental water. These outcomes are excluded initially because they are the subject of investigation by the Commonwealth Environmental Water Office Long Term Intervention Monitoring (LTIM) project that will be running concurrently (2014-2020). Linkages with LTIM will be fostered to encourage exchange of ideas and data where appropriate. Outcomes from LTIM may trigger the incorporation of new evaluation questions related to environmental watering of riparian areas in later years of this monitoring program.

The Murray LLS MERI strategy riparian conceptual model (Figure 3) is necessarily simplified to represent the breadth of interrelated outcomes and levels of evidence for causal pathways. This monitoring program seeks to develop hypotheses that guide monitoring to reduce uncertainty in linkages between immediate outcomes (management interventions) and intermediate outcomes, and to understand the contribution of outcomes to improving riparian zones (Program objectives 1 and 2). Two improvements to the conceptual model that enhance this process are:

1. The identification of major sources of variability that contribute to uncertainty by modifying ecosystem responses to management interventions.
2. Expanding the complexity of pathways by which the intermediate management outcomes contribute to the longer-term riparian condition (currently just a single arrow in Figure 3).

A revised model linking intermediate management outcomes to the longer-term riparian condition with an emphasis on organic matter dynamics is proposed (Figure 4). Organic matter dynamics were chosen as a starting point for developing measurable monitoring objectives and hypotheses for linking riparian management outcomes to changes in river "health". Allochthonous inputs of organic matter from the riparian zone are a major driver of river food webs and water quality (Reid et al 2008a, Tank et al 2010), are measurable, and are expected to respond within a suitable timeframe of months to years. The model identifies *response modifiers* that are likely to contribute to variability in management outcomes at interventions sites (Figure 4). Increased understanding of the impacts of these modifiers will improve intervention design, implementation and the setting of more realistic expectations for management outcomes.

In consultation with Murray LLS, a set of key evaluation questions (KEQ) were developed from the revised conceptual model that were organised into an evaluation hierarchy (Figure 5). The hierarchical organisation of KEQ provides program logic to assist with planning and scheduling monitoring and research activities within the early years of the monitoring program. The KEQ are proposed as a starting point that will be refined and added to over time as part of the adaptive management process (Figure 2). A set of foundation activities were structured around KEQ that specifically address program objective 4: *To ensure the monitoring and evaluation is appropriate, effective and efficient to best support Murray LLS adaptive management of riparian zones*. Answering these foundation KEQs informs and validates the monitoring design and the data collection methods.

Monitoring and desktop studies in this first year were conducted to evaluate foundation KEQ (red, Figure 5) and to collect preliminary data towards KEQs related to CPOM input, retention and standing stock (green, Figure 5). Monitoring in subsequent years will expand this data set to a greater number of sites as well as begin evaluating additional KEQ and research questions (refer section 8, Research Portfolio).

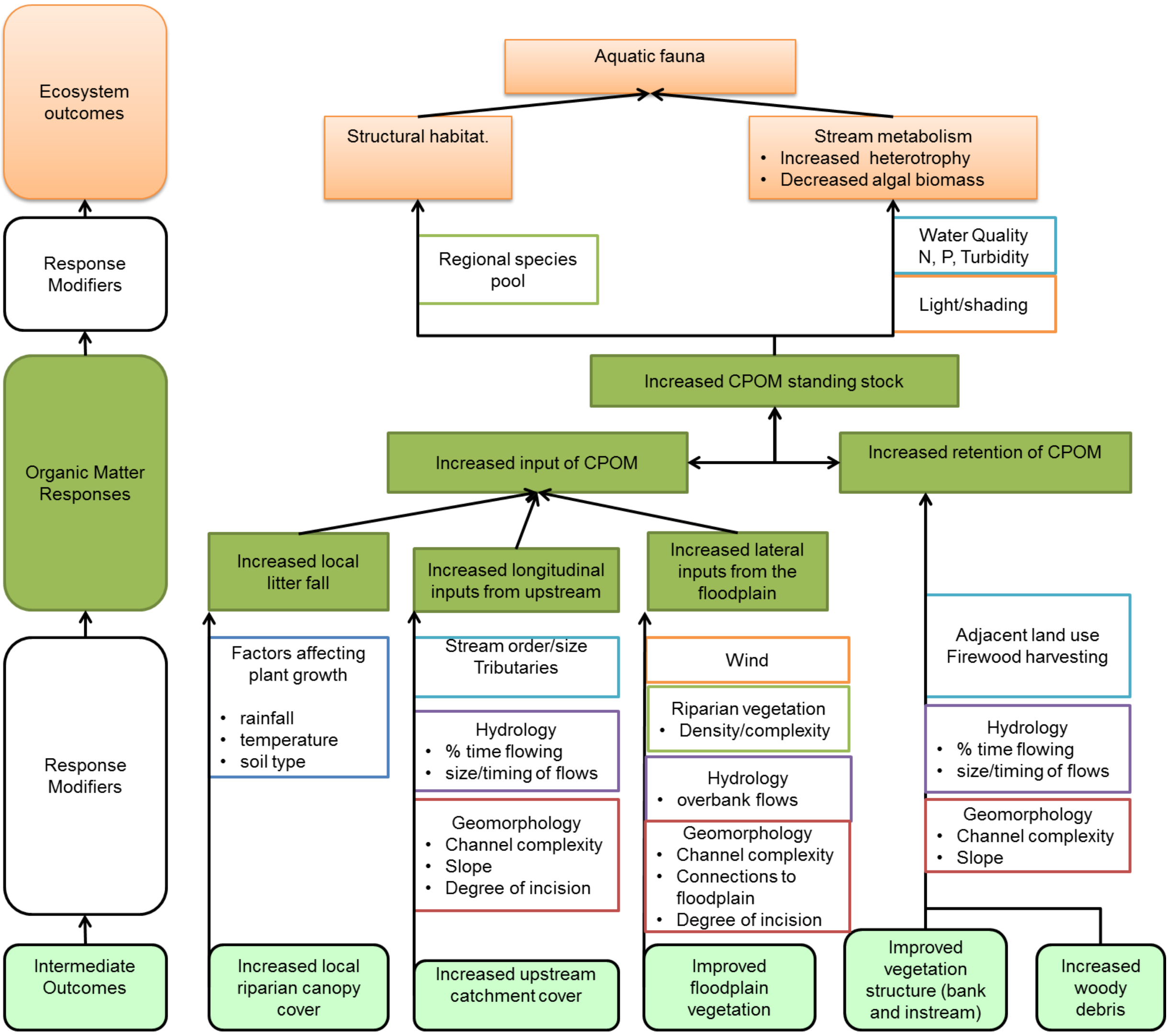

Figure 4. Conceptual model for organic matter responses and potential ecosystem outcomes arising from Murray LLS riparian interventions. Modifiers that influence organic matter dynamics are identified and will be included in the monitoring program as complementary data to explain variability in observed responses.

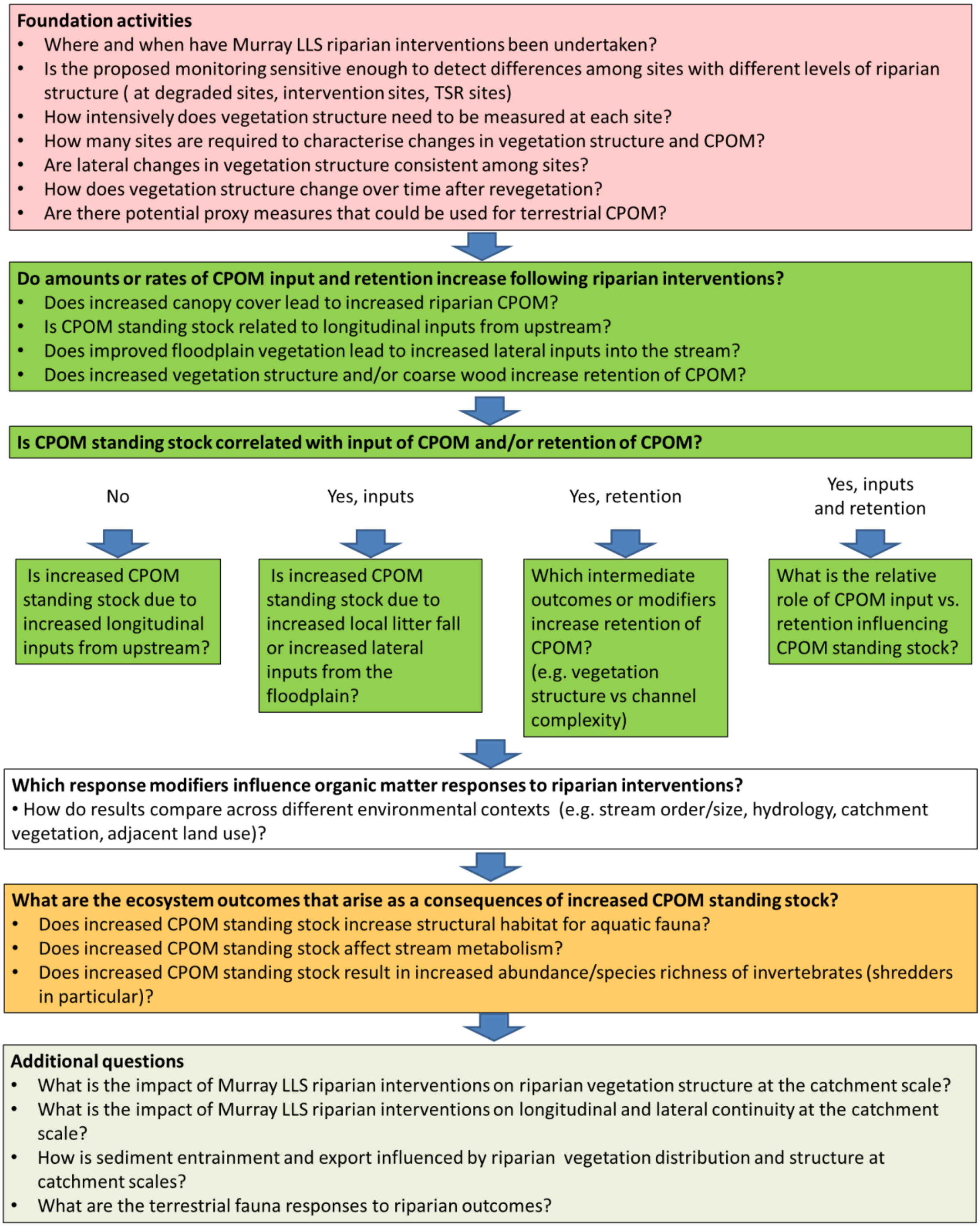

Figure 5. Key evaluation questions (KEQ) derived from the conceptual model for organic matter responses and potential ecosystem outcomes arising from Murray LLS riparian interventions (Figure 4). Year 1 monitoring activities were targeted towards answering foundation KEQ (red) and collecting preliminary data towards the intermediate outcomes relating to organic matter (green).

Three types of activities will be undertaken over a period of up to 10 years to generate the data required to evaluate the KEQ. The activities are not independent and timing and quantity of effort in each area will vary depending on lessons learned and availability of resourcing. Broadly the program will involve (Figure 6):

1. Desktop Studies. Evaluation of Murray LLS management activity data, mapping and GIS analysis to examine spatial distribution of riparian interventions (2003 to present) and potential catchment level outcomes. This is a foundation activity that will inform the field sampling design and assist with understanding outcomes in the context of how and when interventions are implemented. Analyses will be revisited as new evidence is gathered to test and calibrate predictions.
2. Monitoring. Field based monitoring of riparian structure and condition at existing and new sites will be repeated at different intervals over a number of years to build and validate outcome response curves and collect evidence to support the improvement of conceptual models. Monitoring will also identify and quantify those factors that modify responses (sources of variability).
3. Specific investigations will focus on developing an understanding of patterns and processes by which riparian outcomes (e.g. vegetation structure and condition) influence aquatic ecosystem health (not captured in Murray LLS MERI conceptual models currently). Organic matter retention and processing will be an initial focus, with additional priorities and ideas being recorded in a research portfolio to be developed and/or implemented at the appropriate time yet to be determined. These investigations are likely to be of shorter duration (1-2 years), but initial findings may seed longer term investigations as the program develops.

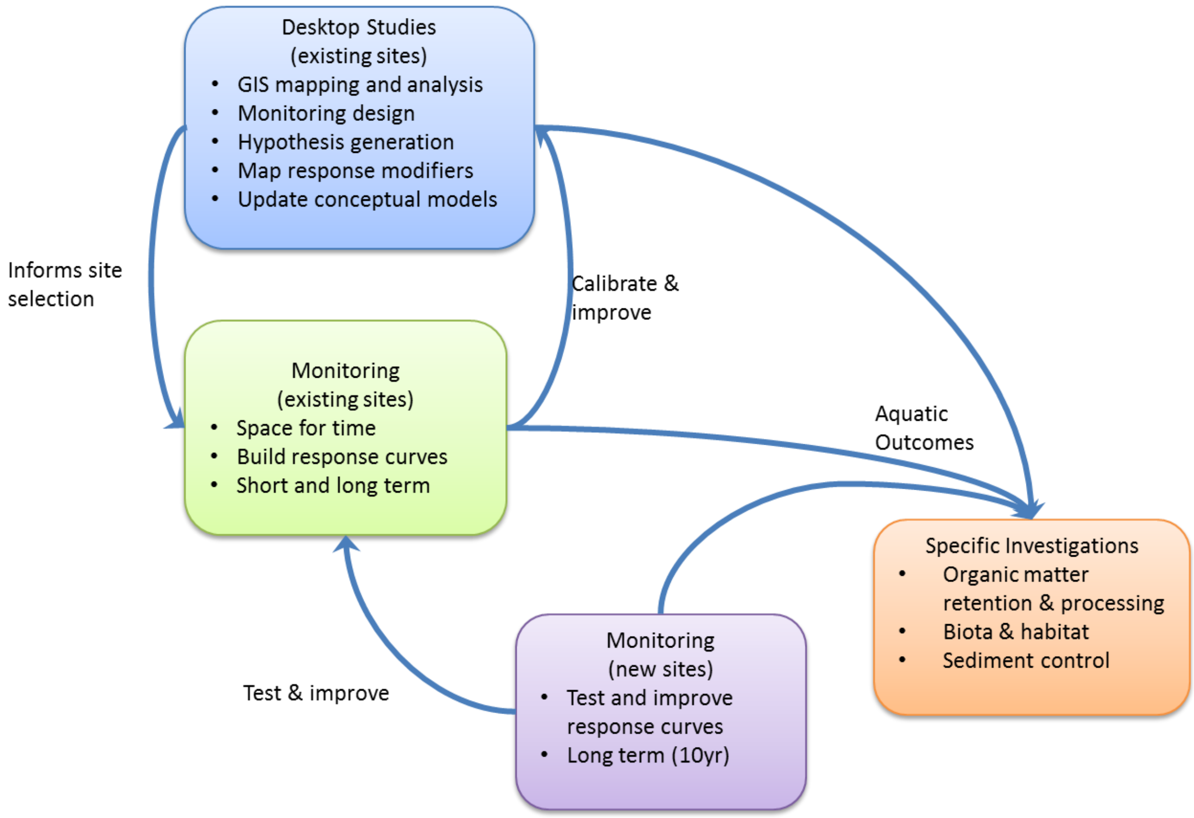

Figure 6. Components of the monitoring program.

Broad-scale monitoring will identify ecosystem level responses to management that influence aquatic condition at large spatial scales, however this approach is unlikely to provide strong evidence about the mechanisms causing trends. Approaches that substitute space-for-time can provide more detailed information about the likely trajectory of responses (e.g. timing and magnitude). Experiments will test specific hypotheses about the mechanisms of changes in aquatic condition, with their design based on results from observational studies. Subsequent broad scale monitoring will corroborate experimental results and further explore the conditions under expected outcomes occur. The adaptive management loop is closed by iterative improvement of the conceptual models and refinement of KEQ (Figure 6).

Two approaches are identified for “scaling up” intervention monitoring to evaluate the cumulative outcomes of Murray LLS riparian management at catchment and regional scales (Table 1). Firstly, catchment level outcomes can be estimated by <u>aggregating</u> outcomes monitored at multiple intervention sites. This could involve exhaustive monitoring of all intervention sites within a catchment; however a more cost effective approach is to monitor a subset of sites and extrapolate to the catchment scale using complementary spatial data sets in GIS. For example, magnitudes and rates of change in canopy cover quantified at selected intervention sites can be modelled across all intervention sites in GIS to estimate the cumulative outcomes in terms of canopy cover and connectivity at larger catchment scales. The level of sophistication of the analysis and confidence in the modelled outputs will vary depending on the availability of relevant spatial datasets and the level of understanding for critical response modifiers that may also operate at catchment scales (e.g. soil type, climate, vegetation community types).

Secondly, a <u>hierarchical</u> approach could be implemented, whereby monitoring is undertaken at multiple scales to quantify outcomes at intervention sites as well as measure cumulative impacts of multiple interventions at larger (i.e. catchment or end of valley) scales. For example, assessing whether riparian management leads to catchment-scale increases in the production and retention of organic matter could incorporate (1) intervention site monitoring of organic matter inputs and loads along with key drivers such as riparian canopy cover and coarse wood, (2) experimental manipulations of retention or organic matter inputs at the reach scale, and (3) end-of-catchment monitoring of exported organic matter loads. A recent study in Iowa USA demonstrates a similar approach (Palmer et al. 2014). At the local scale, Palmer et al. (2014) inventoried stream banks at a selection of sites to quantify severe bank erosion and measure rates of erosion using erosion pins. Palmer et al. (2014) then compared the site level data to measurements of suspended sediment loads at the catchment scale to evaluate the contribution of stream bank sediment relative to other sources.

Table 1 Approaches for collecting evidence for monitoring indicators at local and catchment scales.

Theme	Monitoring targets	Reach scale evidence collected by:	Example site scale indicators	Approach for scaling up	Is spatial data available to assist scaling up?	Catchment scale evidence collected by:	Example catchment scale indicators
Riparian structure	Groundcover vegetation	Monitoring	Bare ground, litter, plant cover	Aggregation	Yes (intervention sites, catchment vegetation cover)	GIS modelling	Catchment canopy cover, longitudinal and lateral connectivity
	Mid-storey vegetation	Monitoring	Shrub cover	Aggregation	Yes (intervention sites, catchment vegetation cover)	GIS modelling	Catchment canopy cover, longitudinal and lateral connectivity
	Over-storey vegetation	Monitoring	Canopy cover, longitudinal connectivity, riparian zone width	Aggregation	Yes (intervention sites, catchment vegetation cover)	GIS modelling	Catchment canopy cover, longitudinal and lateral connectivity
	Littoral and in-stream vegetation	Monitoring	Macrophyte cover, cover of key species	Aggregation	No	Monitoring	Proportion of channel vegetated
	Channel geomorphology	Monitoring	Slope, channel shape and dimensions, sinuosity,	Aggregation	Possibly LiDAR for individual catchments	Monitoring	Channel complexity
Riparian function	Shading	Monitoring	Canopy cover	Aggregation	Low confidence that vegetation cover =shading. Additional monitoring required	Monitoring GIS Datasets	Catchment canopy cover
	Organic matter dynamics	Monitoring and Experiments	CPOM loadings (instream and riparian), rates of lateral and direct inputs	Hierarchical monitoring	No	Monitoring and Experiments	CPOM transport rate, end of valley loadings

Riparian function (...cont)	Coarse woody debris	Monitoring and Experiments	Instream and riparian wood loadings	Aggregation	No	Monitoring and Experiments	
	Bank stabilisation, erosion control, channel avulsion (event triggered)	Monitoring	Incidence of erosion	Hierarchical monitoring	No	Monitoring and Experiments	End of valley sediment loads
	Nutrients and water quality	Monitoring	N, P, C Dissolved oxygen, temperature, conductivity, pH	Hierarchical monitoring	No	Monitoring	End of valley nutrient loads/measurements
Fauna	Macroinvertebrates	Monitoring	Species richness, functional groups	Aggregation	unknown	Monitoring and Experiments	Species richness, functional groups
	Fish	Monitoring	Species richness, functional groups, proportion native	Aggregation	unknown	Monitoring and Experiments	Population size and condition

3. Implementation

This section describes the initial monitoring and supporting foundation activities proposed to begin collecting evidence in support of each of the program objectives, with preliminary results from the first year of pilot sampling. The pilot provides a robust starting point to examine viability of methods and statistical power relative to variance in measurements, but will require more data from additional sites (Yr2-3 sampling) before conclusive evidence can be levelled against the objectives in a formal evaluation. Progress summaries and identified requirements to improve the effectiveness and/or efficiency of the approach are presented at the end of each section.

3.1 Desktop studies (GIS)

Related KEQ:

- Where and when have Murray LLS riparian interventions been undertaken?
- What is the impact of Murray LLS riparian interventions on riparian vegetation structure at the catchment scale?
- What is the impact of Murray LLS riparian interventions on longitudinal and lateral continuity of vegetation at the catchment scale?

Approach:

- Locate past interventions and extract catchment attributes that potentially influence outcomes (hydrology, vegetation cover, longitudinal and lateral continuity of riparian vegetation)
- Quantify the potential impact of existing Murray LLS projects in space and time relative to naturally occurring remnant riparian zone. Potential impact is evaluated assuming all projects develop mature riparian vegetation communities. It will be important to distinguish different vegetation types as a response modifier.
- Quantify potential change in riparian width and longitudinal continuity at a range of nested catchment scales.
- Quantify management intensity (total project area) at a range of nested catchment scales. Identify catchments with high and low proportion of managed riparian zone relative to naturally occurring riparian vegetation (high and low potential impact). This will inform selection of contrasting catchments for investigating functional outcomes.
- The scope of this work will encompass all Murray LLS riparian projects 2003 to present.

Murray LLS supplied two GIS data sets that map locations of past interventions from 2003-2008, and from 2008-present. A limited amount of information regarding the objectives of the interventions sites is included in the data sets as broad subject categories. Additional detail on site design characteristics and implementation is held separately within Murray LLS.

Year1 Outcomes:

Year 1 activities concentrated on data required for site selection and initial selection of catchment indices that might modify responses to riparian interventions.

KEQ: Where and when have Murray LLS riparian interventions been undertaken?

- 372 project sites were identified from Murray LLS GIS databases 2004-2013 as having project objectives related to the establishment or management of vegetation or specifically identified as riparian vegetation
- Of these 287 were located within 250m of a waterway (NSW drainage mapping) suggesting a potential riparian focus however this is an over-estimate as it will also include remnant terrestrial vegetation management projects that are coincidently close to a mapped drainage line, some that may never have flowing water.
- The 287 “Riparian” sites were linked to the Australian Hydrological Geospatial Fabric (Geofabric) (v2.1.1) (http://www.bom.gov.au/water/geofabric/) and the associated National Environmental Stream Attributes v1.1.5 data set (Stein et al, 2012) to allow catchment attributes upstream of each site to be estimated (Table 2).
- 66% of projects (184) were located within 60km of the town of Holbrook within a rectangle that encompasses the Murray LLS region in a band stretching 100km eastward from the town of Howlong (Figure 7). This region was chosen as a focal area for year1 field investigations to provide the largest number of sites possible from within a limited range of landscape, and landuse types. Reducing variability in the landscape setting under which monitored interventions are conducted is expected to reduce noise in the monitoring data that can obscure evaluation of outcomes.
- Cumulative frequency histograms for catchment and hydrological attributes were plotted to compare the range of values for the entire Murray LLS region compared to the range of values encountered in the focal area. This comparison showed that selecting monitoring sites from within the focal area near Holbrook could substantially lower the among site variability in hydrology, catchment disturbance (e.g. Figure 7).
- Review of aerial photography showed many sites were located on minor, undefined drainage depressions that were unlikely to be riverine (i.e. rarely or never flow). In the absence of hydrological data, identifying sites located on named streams was used as an imperfect proxy for identifying sites on larger channels that were more likely exhibit riverine characteristics and have flowing water during the year, albeit intermittently. These sites were given preference to best support program objective 2, to understand the impact of Murray LLS riparian interventions on river ecosystem functioning at reach and catchment scales.
- Of the 184 candidate sites, only 55 were located within 250m of a named stream. Reviewing aerial imagery resulted in 29 of these being later rejected as being non-riparian (e.g. plantings on dam walls to reduce erosion), or located on minor side tributaries that approached named streams. This reduced the pool of candidate sites on named streams within the focal area to 26 revegetation areas that were associated with 12 Murray LLS intervention projects. An additional subset of 10 interventions for which the project objectives were not documented were also identified as some of these may be riparian projects (resolving these objectives is an ongoing task for year 2).

- 10 Travelling Stock Reserve (TSR) sites were also identified as being on named streams. TSR sites were chosen to monitor the least degraded riparian vegetation that potentially represents a realistic end-point for riparian improvement in the area.

Table 2. Attributes for the catchment upstream of intervention sites and the area immediately surrounding the intervention reach (Geofabric stream segment) extracted from the National Environmental Stream Attributes v1.1.5 data set (Stein et al, 2012).

Catchment Attributes	Definition
SiteName	Name of the monitoring site
SegmentNo	Geofabric reach (segment) identification code
CATFORESTS	% forest in the upstream catchment
STRFORESTS	% forest local to the stream segment
STRWOODLAN	% woodland local to the stream segment
CATWOODLAND	% woodland in the upstream catchment
CATWOODFOR	% (forest+woodland) in the upstream catchment
STRWOODFOR	% (forest+woodland) local to the stream segment
DISTUPDAMW	max distance upstream to a dam wall
TOTLEN	total length of stream upstream
CDI	catchment disturbance index
FRDI	flow regime disturbance index
CATMOD	% catchment modified (not under conservation reserves or parks)
RUNANNMEAN	Modelled Hydrology - annual mean flow
RUNSUMMERMEAN	Modelled Hydrology - summer mean flow
RUNAUTUMNMEAN	Modelled Hydrology - autumn mean flow
RUNWINTERMEAN	Modelled Hydrology -winter mean flow
RUNSPRINGMEAN	Modelled Hydrology -spring mean flow
RUNPERENIAL	Flow Pereniality index
RUNMEANMIN	Modelled Hydrology - mean annual minimum flow
RUNMEANMAX	Modelled Hydrology - mean annual maximum flow
CATAREA	catchment area
ORDER	stream order
VALLEYSLOPE	The slope of the stream segment (elevation range/length)
CATSLOPE	Average catchment slope

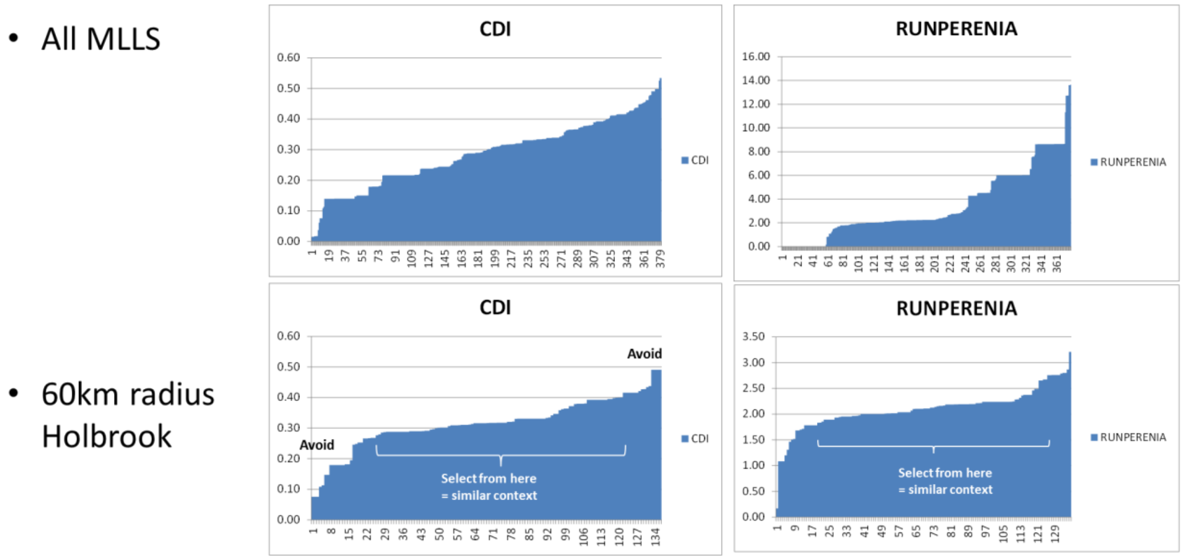

Figure 7. Example comparison of two landscape context indicators (CDI=catchment disturbance index, and RUNPERENIA= modelled pereniality of surface flows) showing potential for choosing similar sites located in proximity to each other.

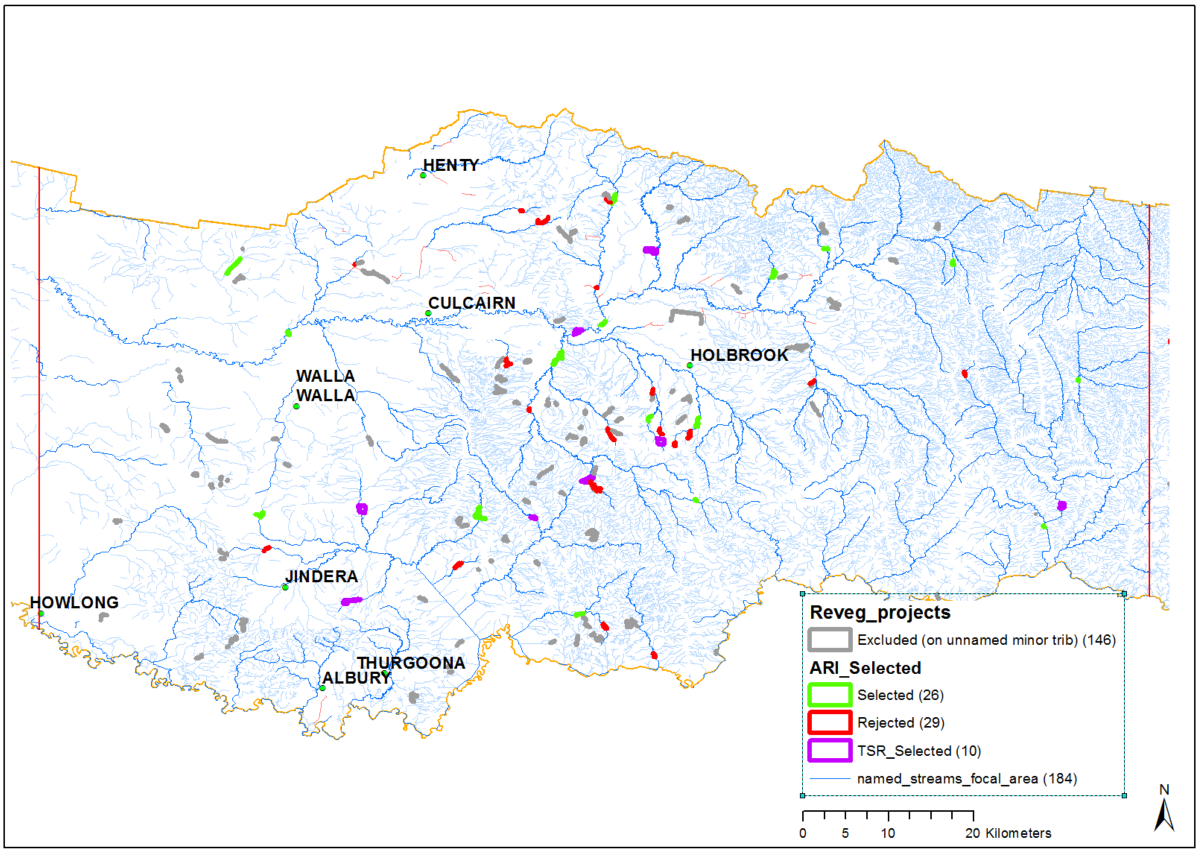

Figure 8. Location of candidate sites within the focal area.

Summary

Table 3 summarises the progress made this year in the desktop study component and draws attention to emerging issues that will inform activities in subsequent years. Recommendations are grouped together in section 4.

Table 3. Summary table of progress and emerging issues from desktop analysis

	Desktop study (GIS) summary
Status	Program Logic developed and key evaluation questions identified. Murray LLS vegetation sites mapped to Geofabric and catchment indices extracted to describe the landscape context complete. Resolution of catchment level summaries of management impacts is premature at this point as many visited sites were shown to be severely compromised.
Scheduling	Ongoing activity required for mapping and attribution of new sites, resolution of interventions where objectives are currently unknown. Catchment level summaries of intervention impacts in yr 2-3 after an audit of past sites to identify the proportion of sites still contributing to expected riparian outcomes vs those compromised (e.g.by flooding, fire, stock, or neglect).
Needs	Murray LLS to locate project files for selected site interventions Resolve subset of sites where intervention objectives and methods are unknown Determine failure rate, from flooding of
Emerging considerations	The majority of intervention sites (70%) are located on minor ephemeral tributaries or unnamed streams. Examination of more project files, or intent of past programs might shed light on whether these represent riparian interventions that require further consideration as ephemeral contributors to river health.

3.2 Field monitoring

Related KEQ:

- How does vegetation structure change over time after revegetation?
- Does improved vegetation structure lead to increased CPOM standing stock?
- Does increased local riparian cover lead to increased CPOM standing stock?
- Are instream CPOM loadings related to longitudinal inputs from upstream?
- Are instream CPOM loadings related to direct litter fall or lateral inputs?
- Are instream CPOM loadings correlated with potential drivers/modifiers of CPOM retention?

Approach

Long-term plan for building response trajectories

We proposed monitoring of intervention sites in year 1 and repeated at different intervals over a number of years to document different indicator response trajectories and to collect evidence to support and improve conceptual models. Constructing the response trajectories requires:

- Substituting space-for-time to quantify development trajectories of riparian vegetation structure primarily as a function of the time since implementation. Sampling undertaken in Year 1 at 12 sites enabled preliminary power analyses
- In year 1, we limited environmental variability by constraining the study area to a single landscape context (e.g. Holbrook area). This focussed approach will maximise likelihood of detecting responses and influence of contextual response modifiers. Scope will be expanded in subsequent years.
- Information from Year 1 to guide future resampling of initial sites and addition of new ones e.g. based on likely timing of responses to Murray LLS riparian interventions
- Maximise contrast in sampling (e.g. ensure low and high impact catchments) to establish detection limits
- Indicators to be monitored for the development of response trajectories have been selected on basis of likelihood to detect a response and influence on aquatic ecosystem processes and services e.g. CPOM supply and retention (:
    - Bare ground
    - Shrubs (cover, stem density)
    - Trees (stem density)
    - Canopy cover (% cover)
    - Riparian zone width
    - Longitudinal continuity (e.g. prop bank with veg, number of gaps)
    - Macrophytes (some measure of capacity for retention)
    - Coarse wood (volume/density)
    - Debris dams (number, volume)
    - Fine woody debris (density, volume)
    - Slope
    - Channel shape (i.e. width/depth ratio)
    - Channel structure
    - Evidence of erosion
    - Bank profile

    - Evidence of avulsion
- Additional covariates to explain variability will include the implementation method (e.g. direct seeding vs ripping and planting tubestock) and catchment information largely derived from the desktop study
    - Channel sinuosity index
    - Stream order
    - Hydrology (e.g. from Janet Stein network)
    - Distance to nearest upstream woodland/forest
    - % upstream catchment woodland/forest
    - Upstream barriers (no. above site in catchment, distance downstream of nearest barrier) (some derived from desktop GIS work)

Site selection criteria

- Initial focus on sites around Holbrook region (approx. 60km radius)
- Additional sites from across the catchment- adding sites closest to Holbrook- expanding the area for inclusion once these are exhausted

Sites should be evaluated on the following criteria:

- Information available to characterise riparian interventions (timing, length/width, one vs both banks)
- Details of implementation methods (e.g. direct seeding vs. tubestock)
- Inclusion of some sites to provide indication of 'reference' condition e.g. travelling stock reserves, remnant sites.
- Avoid sites with known factors that could confound responses (e.g. high salinity, water/soil/sediment pollution)
- Accessibility (e.g. access allowed, avoid sites where monitoring is difficult/impossible i.e. long distance from roads etc)
- Prioritise sites with historical data to characterise environmental history/legacy (e.g. land use: stock rates, fertiliser applications)
- Prioritise sites with relevant auxiliary data (e.g. flow gauges)
- Prioritise sites already being sampled by Murray LLS (or as part of other programs e.g. ANU surveys)
- Spatial independence (e.g. avoid sites on same channel where longitudinal inputs may be similar).

Field Method

We propose the program adopts vegetation monitoring methods that have developed for the Victorian Riparian Intervention Monitoring program (DEPI 2014a) providing a number of significant advantages to the monitoring program.

1. Using a method that is compatible with state-wide riparian monitoring in Victoria will allow integration of results from similar Victorian catchments, including those close to the Murray catchment (e.g. the Goulburn and Broken river catchments).
2. The specific indicators and methods are associated with key evaluation questions linked to common site-level riparian objectives that are compatible with Murray LLS riparian

intermediate outcomes (e.g. Increase native vegetation cover, improve native vegetation extent and longitudinal continuity, reduce excessive channel migration; refer DEPI 2014a).

3. The methods are modular to optimise the monitoring effort to the specific indicators of interest.
4. The methods use a point-intercept method that has been demonstrated to have high precision with reduced operator bias to quantify cover of structural vegetation.
5. The methods have been documented in a user manual (DEPI 2014b) and initial data management tools (data sheets and electronic storage) have been developed that can be used by Murray LLS.

Coarse woody debris and coarse particulate organic matter (CPOM) are sampled following commonly used methods. At each transect, loadings of coarse wood were estimated in a 20 m wide belt transect following similar methods to Gippel et al. (1992), Webb and Erskine (2003) and Reich et al. (2009). The length and diameter of all individual pieces and accumulations of coarse were measured and expressed as volume per unit area. Separate loadings are calculated for the bank, top of bank and in-stream zones.

CPOM is collected from the three zones using a plastic bucket with the bottom removed (27 cm diameter) as a sampling device using the methods of Reich et al. (2009). Five samples are taken within each zone at transects by randomly placing the sampling device and collecting all non-living organic matter. A small amount of ethanol is added to samples for preservation. In the laboratory, samples are air dried and weighed, with CPOM expressed as dry weight per unit area. At all transects, results were delineated according to whether samples were collected on the stream bank, or the top of bank. This stratification is to allow examination of potential differences related to lateral distance from the stream.

Analyses to test for key relationships in response curves

Space-for-time studies are typically analysed in either of two ways:

1. Time is considered a categorical variable (i.e. years are classed into short, medium, long times since restoration) and analysis of variance models used to test for differences between these treatments, potentially also with the inclusion of covariates (i.e. ANCOVA).
2. Time is considered a continuous variable, and regression models used to assess potential linear, non-linear or threshold responses over time. Covariates are also often included in these models.

We will treat time-since-restoration as a continuous variable, as this will provide more detailed information about the timing and shape of any change. We will initially examine response trajectories for relevant indicators (e.g. structural vegetation, organic matter standing stock, invertebrate taxonomic richness), by plotting these variables along the chronosequence (i.e. time-since-restoration). We will use generalized linear and non-linear models and piece-wise regression to test for potential linear, non-linear and threshold responses. Where appropriate, these models will also be used to test for the potential effects of relevant covariates (e.g. sites classified into intermittent/permanent categories).

For organic matter standing stock and invertebrate indicators, we will conduct further analyses to explore potential relationships with key drivers using generalized linear (or non-linear) models (following methods outlined in Logan 2010). For example, we will model in-stream organic matter standing stock against the range of potential drivers of local (e.g. canopy cover, floodplain CPOM, CWD, littoral vegetation, slope) and catchment (e.g. upstream canopy cover, presence of barriers to movement) inputs/retention of CPOM (identified in our conceptual models). These analyses will also include relevant covariates (e.g. hydrology, stream order). We will prune the large list of potential independent variables in this analysis to reduce collinearity, including only the most relevant ones. We will use a stepwise, iterative approach based on the Akaike Information Criteria to select the most parsimonious model.

On-going analyses to support future monitoring

The data collected during the space-for-time survey will provide an important knowledge based upon which to refine future monitoring efforts. For example, it will be possible to use the results, along with other relevant information (e.g. from the Riparian Restoration Experiment – Hale et al. 2011 a), to conduct power analyses to determine what effects are likely to be detected in the future. In addition, we will examine the relationship between sampling effort and the precision of monitoring. These analyses will allow us to estimate the minimum sampling effort (i.e. no. of sites, no. of samples within sites) required to detect future changes in riparian condition.

Year 1 Outcomes

Our monitoring in Year 1 was aimed at providing preliminary information to:

1. Assess if riparian interventions result in hypothesized intermediate outcomes (e.g. changes in structural vegetation)
2. Guide the efficiency of future sampling, in particular by assessing the number of sites and number of samples within sites that are needed to assess potential responses to riparian interventions
3. Collect preliminary information to assess if intermediate responses to riparian interventions lead to the hypothesized organic matter responses, and more generally to explore potential drivers of organic matter inputs and retention.

Field work was undertaken between 16 October and 27 November, at 12 sites- 4 riparian intervention sites, 4 TSRs and 4 degraded sites. Nine additional work sites that were identified as being potentially suitable from desktop analyses were rejected after subsequent field inspections because:

- The sites had an insufficient area for sampling.
- It was not possible to safely undertake sampling (e.g. too steep, heavily incised and unstable banks)
- The interventions were unsuccessful (e.g. few surviving tubestock, evidence of recent grazing, open gates etc.) or had been severely damaged and compromised. Vegetation at four intervention sites had been largely destroyed following flooding in 2010.

All contacted landholders were very supportive of the project and keen to have their properties included. All landholders allowed permanent markers to be placed throughout sites to allow future resampling of the same transect locations to monitor changes over time.

1. Assessing if riparian interventions lead to hypothesized intermediate outcomes

Relevant KEQ

- How does vegetation structure change over time after revegetation?
- Is the proposed monitoring approach sensitive enough to detect differences among sites with different levels of riparian structure (i.e. between degraded, intervention sites, TSRs)

Year 1 Outcomes

Structural vegetation differed considerably between the three site types, with TSR sites having lowest cover of bare ground (~20%), highest longitudinal continuity of canopy, and highest overall canopy cover (>50%), litter cover, and loadings of organic matter (Table 4, Figure 9). Bare ground was also lower at intervention sites than degraded sites, indicating a potential short-term response to livestock removal and replanting. However, intervention sites were still more similar to degraded sites in terms of other responses (e.g. canopy cover) (Figure 9). In general, our results were consistent with previous studies which have demonstrated decreased bare ground and increased litter shortly after livestock removal and replanting (e.g. Roberston and Rowling 2010) before the canopy begins to develop several years later (e.g. Burger et al. 2010, Hale et al. 2014).

Significant differences in coarse wood were not detected between site types (Table 4, Figure 10). While coarse wood is expected be affected by the condition of sites, it is also likely to be influenced by land use activities such as fire wood collection, clearing obstructions, or bush fire fuel reduction. Loadings of coarse wood on the top of bank are consistent with other published studies. However, loadings were very high within the bank and instream zones at some sites, reflecting large debris dams that have potentially accumulated since flooding in 2010-2011. For example, a large debris dam (~20 m x ~10 m) was sampled at Forestvale, which is one of the sites classified as being degraded. The lack of trees at the site indicates the accumulated wood was washed in from upstream sources.

While not statistically significant, an overall trend for higher organic matter at TSR sites was observed in the top of bank and instream zones (Figure 11). We explore some of the potential drivers of these patterns below. In general, CPOM loadings were similar than those observed in comparable studies (e.g. Reid et al. 2008b).

Examination of bank stability shows currently active scour and mass failure of banks was not different among sites (Figure 10), possibly reflecting a lack of damaging high flow events within the previous season. Evidence of <u>past</u> scour and mass failure of the banks that is now healing over was present along a significantly greater proportion of the banks at degraded sites compared to intervention sites or TSRs (Table 4, Figure 10). This supports the hypothesis that bare banks at degraded sites are more susceptible to erosion from high flows, or conversely that riparian vegetation improves bank stability in Murray LLS streams. There is an indication that riparian replanting does improve resistance of banks to mass failure, but not to scour (Figure 10). This observation should be explored further in future monitoring activities.

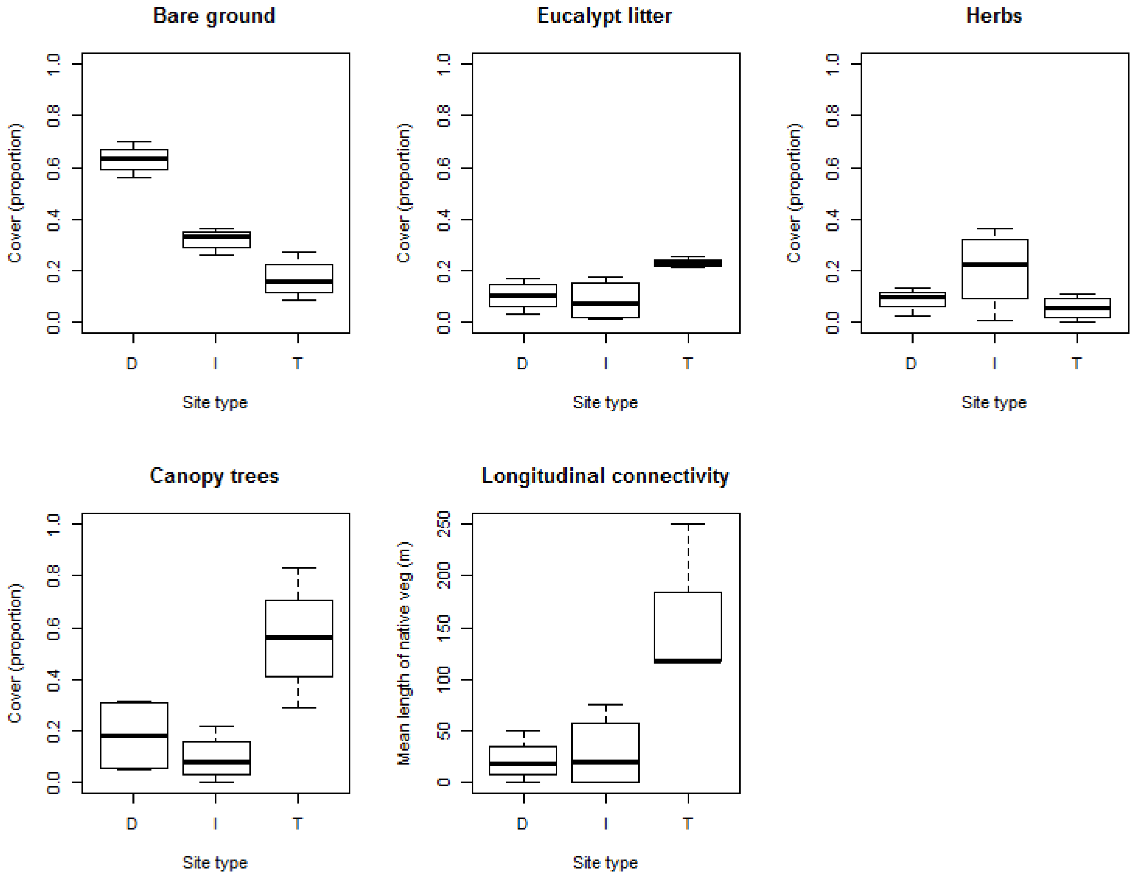

Figure 9. Box plots illustrating differences in structural vegetation between degraded (D), intervention (I) and TSR (T) sites.

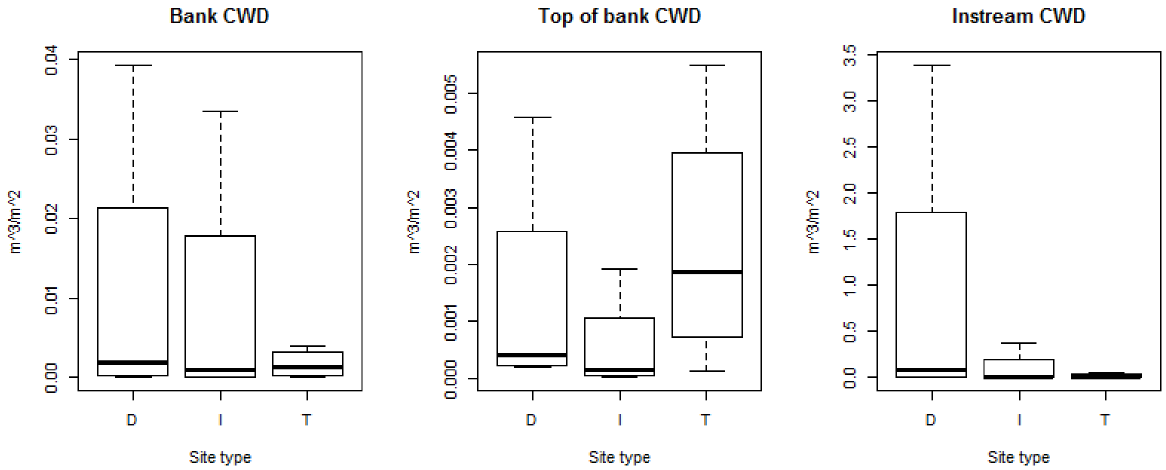

Figure 10. Box plots of coarse wood (CWD) in the bank, top of bank and instream zones at degraded (D), intervention (I) and TSR (T) sites. The bank and top of bank zone are incorporated into a 20 m long x 20 m wide transect moving out from the stream. The bank zone represents the area from the toe to top of bank. The top of bank extends from the top edge of the bank to the end of the 20m sampling transect. The instream zone represents the area of stream bed between the left and right bank.

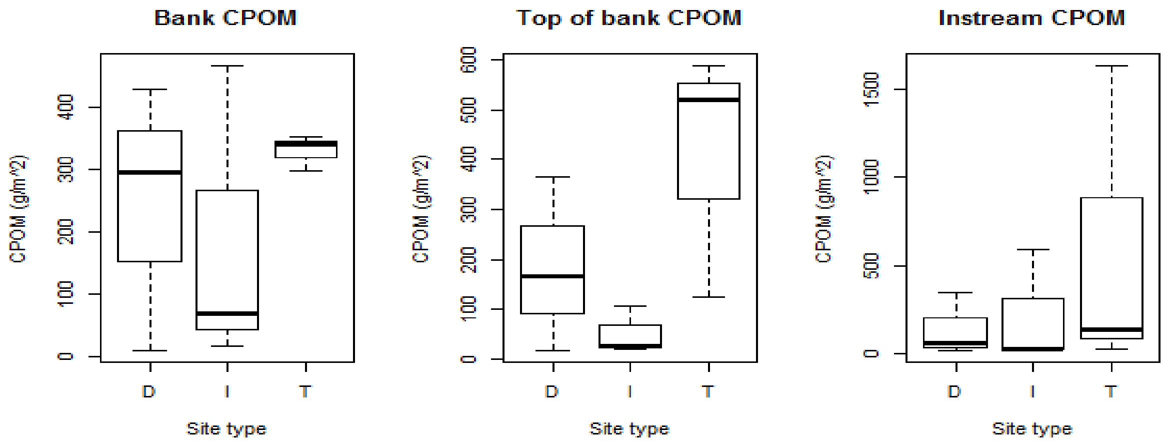

Figure 11. Box plots of coarse particulate organic matter (CPOM) in the bank, top of bank and instream zones at degraded (D), intervention (I) and TSR (T) sites. The bank zone represents the area from the toe to top of bank. The top of bank extends from the top edge of the bank to the end of the 20m sampling transect. The instream zone represents the area of stream bed between the left and right bank.

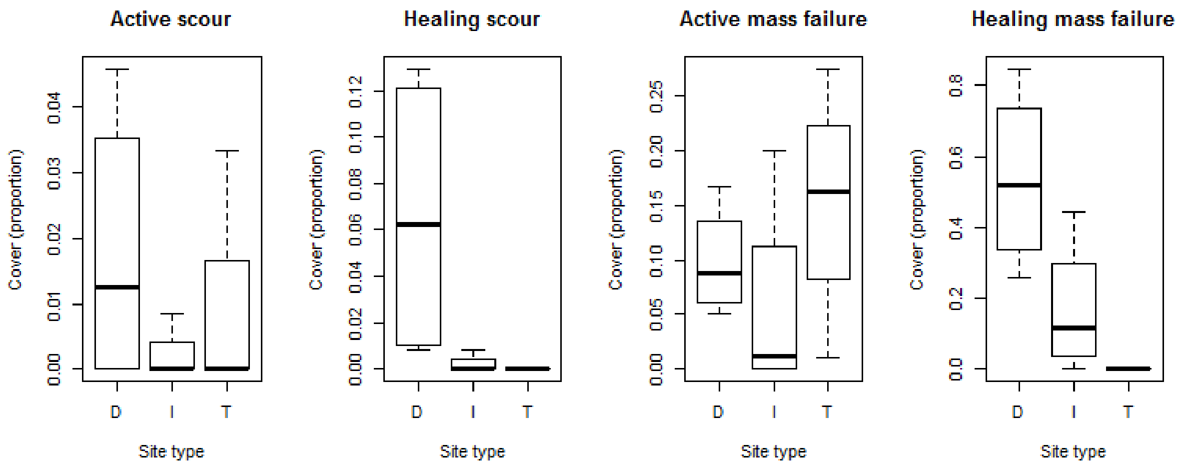

Figure 12. Box plots illustrating differences in four measure of bank stability between degraded (D), intervention (I) and TSR (T) sites.

Table 4. Results of analyses testing for potential differences between riparian intervention sites, degraded sites and TSR sites. Analysis of variance models were used to test for differences between sites (Treat). Where applicable, models also tested for differences between two lateral zones at sites (Zone), and whether differences between sites were consistent across zones (Treat*Zone interaction term). P-values from models show below, with values <0.05 indicating statistically significant differences (green).

	Treat ($F_{2,18}$)	Zone ($F_{1,18}$)	Treat*Zone ($F_{2,18}$)		Treat ($F_{2,9}$)
Understorey				**Longitudinal connectivity**	
Bare ground	**<0.01**	**<0.01**	0.21	Native gaps	0.15
Moss and lichen	**0.02**	0.05	**0.03**	Mean length of native vegetation	**<0.01**
All leaves	**<0.01**	**0.02**	0.85	Max length of native vegetation	**<0.01**
Woody litter	**0.01**	0.65	0.59	Mean length of native gaps	0.09
Eucalypt litter	**<0.01**	0.71	0.95		
Dicot litter	0.12	0.06	0.10	**Coarse wood (instream)**	0.40
Monocot litter	**<0.01**	**0.03**	0.95	**CPOM (instream)**	0.58
Herbs	**0.04**	0.57	0.69		
Grasses	**0.04**	0.77	0.87	**Bank stability**	
Rushes	0.65	0.14	0.95	Active scour	0.42
Sedges	0.32	0.48	0.99	Healing scour	0.06
Logs and rocks	0.63	0.28	0.69	Active mass failure	0.35
Base of plants	0.08	0.11	0.83	Healing mass failure	**<0.01**
Mid-storey					
Shrubs	0.60	0.85	0.25		
Trees	0.68	0.61	0.44		
Over-storey					
Shrubs	0.20	0.94	0.98		
Trees	**<0.01**	0.32	0.80		
Coarse wood (riparian)	0.73	0.19	0.58		
CPOM (riparian)	0.11	0.52	0.27		

2. Foundation activities to guide monitoring program design

Relevant KEQ

- How intensively does vegetation structure need to be measured at each site (how many intercept points)?
- How many intervention monitoring sites are required to characterise changes in vegetation structure?
- Are lateral changes in vegetation structure consistent among sites?
- Are there potential proxy measures that could be used for terrestrial CPOM?

Year 1 Outcomes

KEQ: How intensively does vegetation structure need to be measured at each site (how many intercept points)?

We used point-intercept methods to sample structural vegetation, with 486 points collected at each site (every 0.25 m at six 20 m long transects at each site) (Refer DEPI 2014b). However, it may be possible to reduce this number to reduce the sampling time if a smaller number of points provide a similar estimate. We examined the relationship between sampling effort and sampling precision (see Appendix 2 to for details of the method). Our aim was to identify if there was a maximum number of samples above which sampling precision does not significantly improve.

We conducted these analyses for four indicators likely to represent to encapsulate the range of potential relationships. For all four variables (cover of bare ground, logs and rocks, grasses and canopy trees), sampling precision was low (i.e. estimates are likely to be close to the sample mean) with >100 points per site (Figure 13). Our results suggest that approximately 300 samples per site are likely to be required as a minimum to maximise sampling precision and increasing to 486 points brings additional, albeit modest improvement. Staying with the Victorian method that collects 486 point is the pragmatic recommendation to ensure good estimates of vegetation structure can be achieved at sites where one or more of the 6 transects must be shortened or excluded from sampling due to site features (e.g. by fencing, roadways, backwaters).

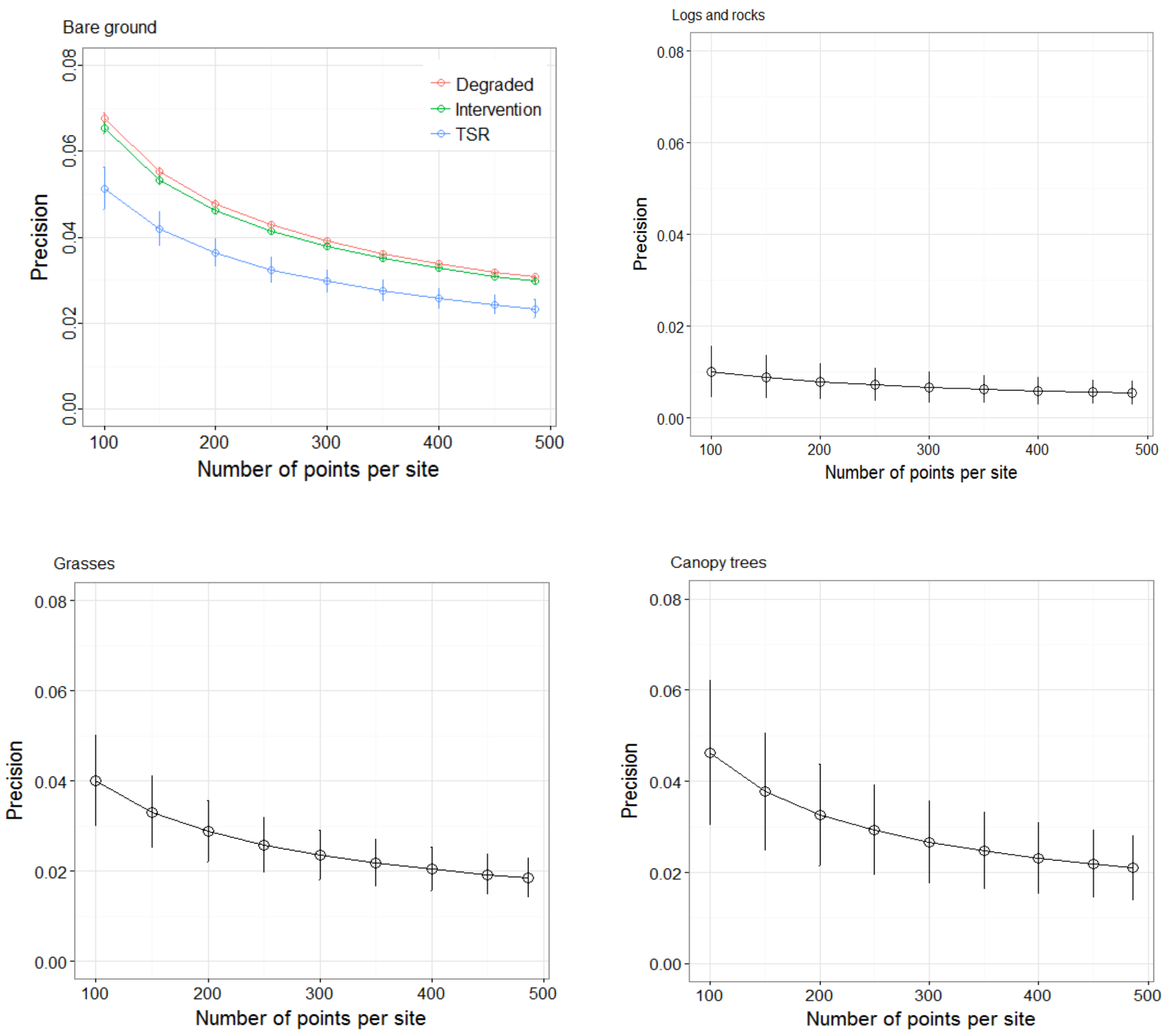

Figure 13. Examining the relationship between sampling precision and the number of points sampled at each site for cover of four structural vegetation indicators: bare ground, logs and rocks, grasses and canopy trees.

KEQ: How many intervention monitoring sites are required to characterise changes in vegetation structure?

The required number of intervention sites depends on the background variability of an indicator (i.e. in the absence of any intervention) and the magnitude of change that occurs following riparian intervention. The number of sites will represent a trade-off between the number required to reliably detect a response, the resources available for monitoring, and the number of suitable sites. Fewer sites will be needed if responses to interventions are large and background variability is low, more when responses to interventions are smaller and site-to-site variability is high.

We conducted power analyses using preliminary data collected in Year 1 to assess the likely number of sites required for future monitoring. Power is the probability of detecting a response to interventions if such a response actually exists (Quinn and Keough 2002) and power analyses are commonly used in environmental monitoring programs to guide decisions about how many sites should be monitored. Power is related to the effect size (i.e. how big a change is of interests), the number of samples, and the variance between sampling units.

Our analyses explored the number of sites required to detect responses to riparian interventions under different scenarios of variance (see Appendix 3 for details of methods). Results for percent cover of bare ground are presented in Figure 14 to demonstrate the approach. The analysis examined the ability to detect a range of biologically realistic effect sizes (e.g. annual decreases in percent cover of bare ground of between 2 and 10%) given a range of variability in the data (e.g. annual temporal changes in percent cover of bare ground not related to the interventions of 5-25%) under four hypothetical levels of replication (5, 10, 15 or 20 sites). Figure 14 shows that five samples (=interventions sites) may only provide adequate power to detect quite large effects (>4% change) when variability is low (std Dev = 5%). In comparison, monitoring 15-20 sites provides higher power to detect a range of effects even when background variability is high (std Dev >= 15%).

We conducted similar analyses to assess our ability to detect a range of potential changes in benthic organic matter following riparian planting (Figure 15). These results show that <20 sites is likely to be adequate to detect a range of different biological meaningful effect sizes, even if background variability is very high.

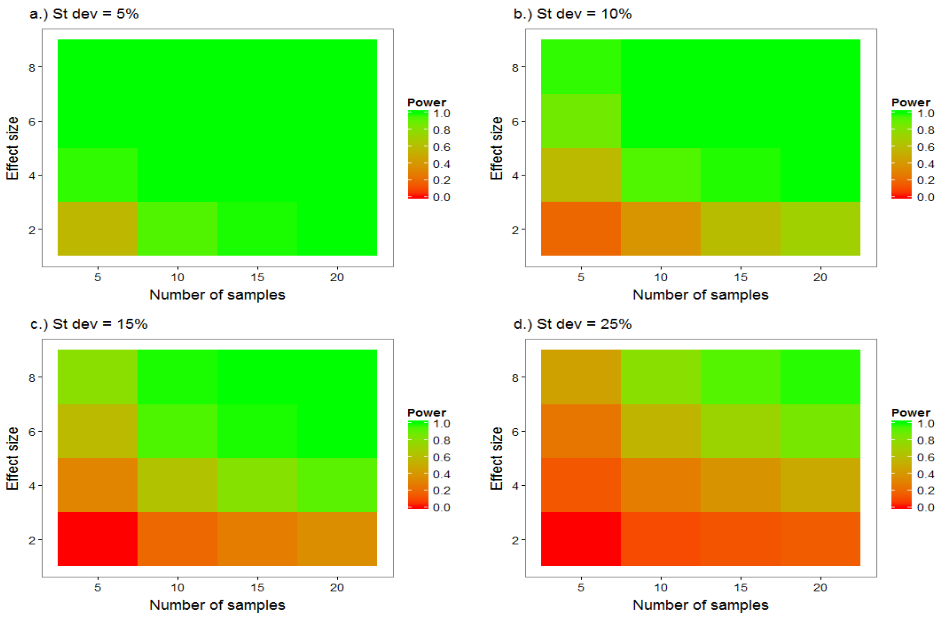

Figure 14. Results of power analyses undertaken to assess the likelihood of detecting changes in bare ground using between 5 and 20 sites. Analyses were repeated based on four estimates of background variability in bare ground not due to the interventions (standard deviation of between 5 and 25%). Refer to Appendix 3 for description of power analysis methods and justification for effect sizes and estimates of variability.

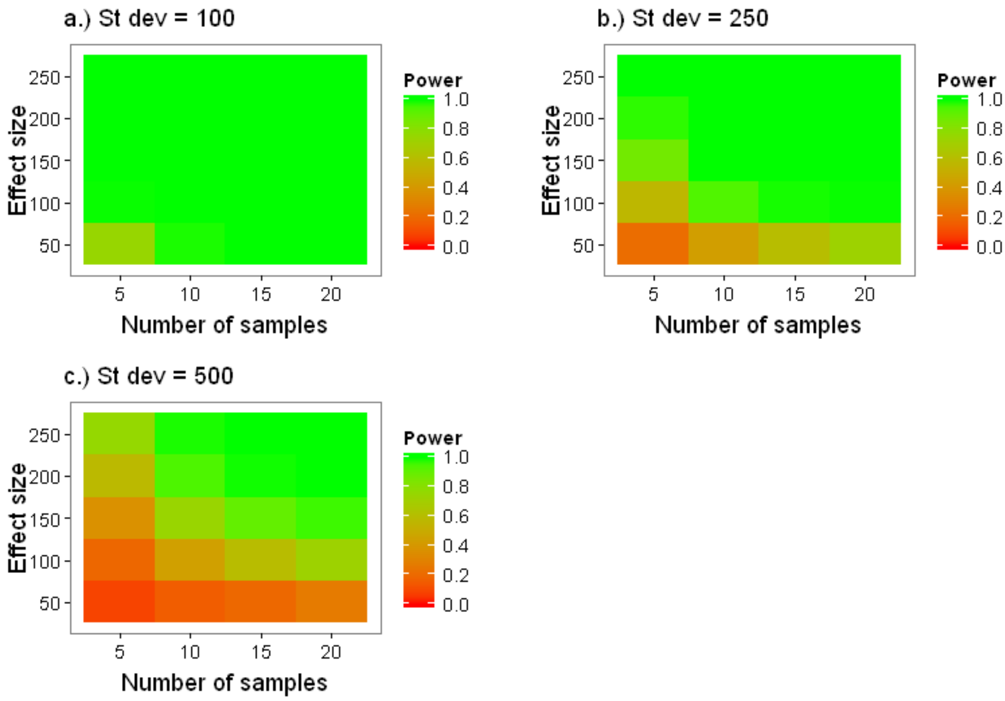

Figure 15. Results of power analyses undertaken to assess the likelihood of detecting changes in CPOM using between 5 and 20 sites. Analyses were repeated based on four estimates of background variability in bare ground not due to the interventions (standard deviation of between 100 and 400). Refer to Appendix 3 for description of power analysis methods and justification for effect sizes and estimates of variability.

KEQ: Are lateral changes in vegetation structure consistent among sites?

We sampled structural vegetation, organic matter and coarse wood in two zones moving laterally out from the stream, the bank face and the top of bank, on the basis that there may be differences between these zones in terms of potential responses to the interventions that are largely implemented on the top of bank area. If such differences exist, this will be an important consideration for future sampling, requiring them to be sampled separately. However, if responses are consistent across zones, then it will be possible to combine zones.

For most variables, keeping the two lateral zones separate is not warranted if the aim is to detect overall differences between sites. Most indicators did not vary between the two (e.g. leaf litter, herbs, grasses, shrub and canopy cover; Figure 16). While cover of some indicators did vary among sites, in general differences between sites were consistent across the two zones. For example, bare ground was higher overall on the bank but overall differences between sites (i.e. cover highest at degraded sites, lowest at TSRs) was consistent in both zones. There may be specific instances where keeping the lateral zones separate provides a clearer picture of potential responses. For example, the cover of moss and lichen was highest at TSR sites, and this response was considerably stronger in the bank zone (Figure 16). Overall, we recommend that the bank and top of bank zones are kept separately in future sampling given that this does not add any more time to the field work and data can be pooled later if no differences exist between zones, or these differences are not of interest.

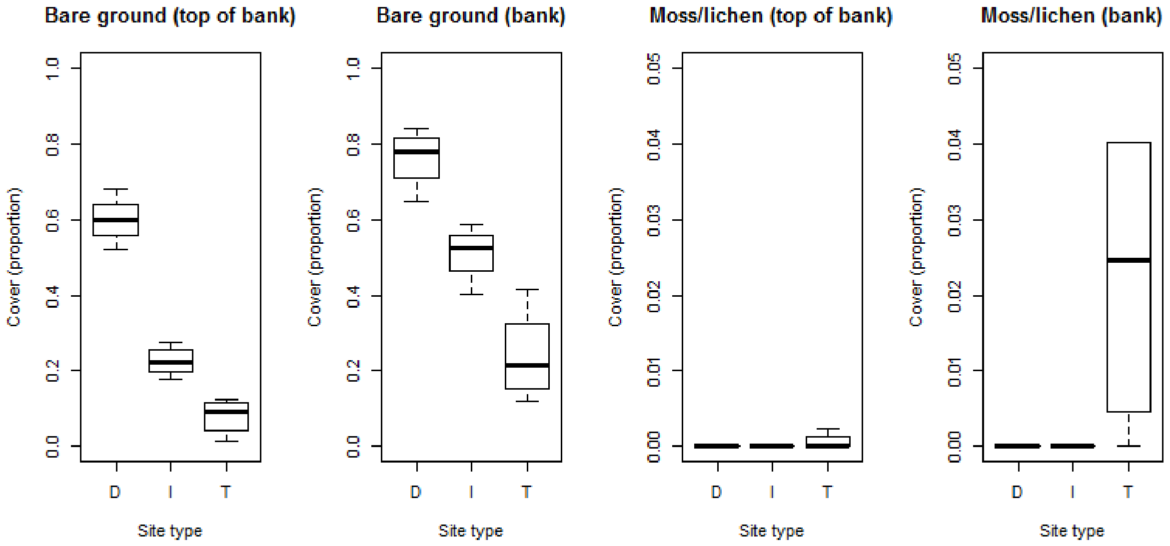

Figure 16. Box plots illustrating differences in the cover of bare ground and moss/lichen on the bank and top of bank between degraded (D), intervention (I) and TSR (T) sites.

KEQ: Are there potential proxy measures that could be used for terrestrial CPOM?

Collecting CPOM samples in the field can be time intensive, and these must then be dried and weighed in the laboratory (Hale et al. 2011b). We investigated whether the cover of leaves or woody debris as estimated from point-intercept surveys might be a quick, inexpensive proxy for CPOM. CPOM was not strongly related to leaf cover but our results suggest woody litter may be an adequate proxy (Figure 17).

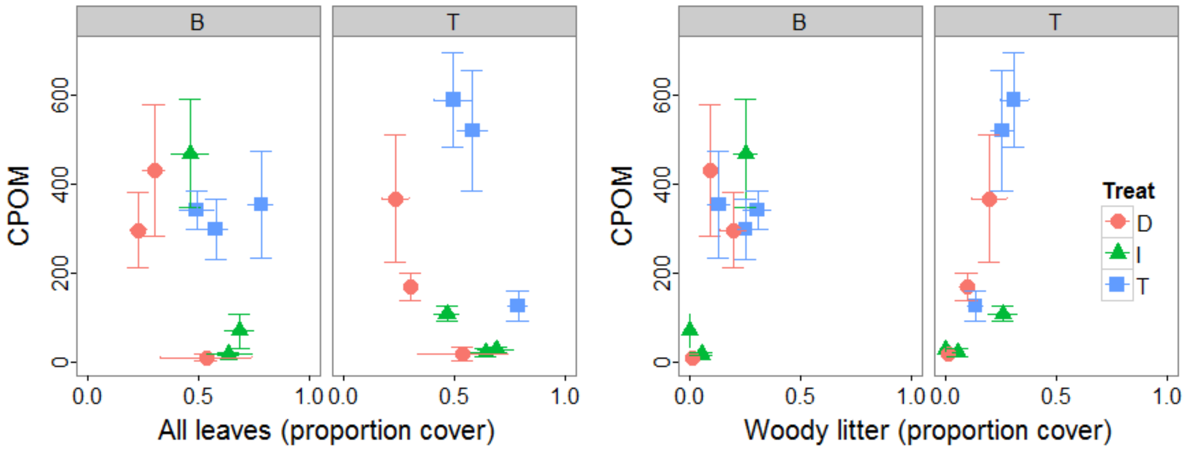

Figure 17. The relationship between terrestrial CPOM (g/m^2 dry weight) and cover of all leaves and woody litter in the bank (B) and top of bank (T) zones at degraded (D), intervention (I) and TSR (T) sites.

3. Preliminary information to explore potential changes and drivers of organic matter inputs and retention.

Related KEQ:

- Does increased canopy cover lead to increased riparian CPOM?
- Is CPOM standing stock related to longitudinal inputs from upstream?
- Does improved floodplain vegetation lead to increased lateral inputs into the stream?
- Does increased vegetation structure and/or coarse wood increase retention of CPOM?
- Is CPOM standing stock correlated with input of CPOM and/or retention of CPOM?

Year 1 Outcomes

Benthic CPOM standing stock is a function of CPOM inputs, retention, and losses through processing and removal by water and wind. We hypothesized that changes in structural vegetation could lead to increased inputs of CPOM in three ways, via: local litter fall as the canopy develops, longitudinal inputs from upstream vegetated areas, and lateral movements from the floodplain. Whether these inputs are lost or retained depended on the various retention mechanisms (e.g. vegetation structure and coarse wood) and other modifying factors (e.g. hydrology, geomorphology). We collected preliminary information to begin to test these various mechanisms.

KEQ: Does increased canopy cover lead to increased riparian CPOM?

We assessed if riparian CPOM was related to riparian canopy cover, as higher canopy cover may mean that sites have a greater source of CPOM that could move laterally into the stream zone. CPOM was low both on the bank and top of banks when canopy cover was low, and we observed a strong positive linear relationship between CPOM and canopy cover on the tops of banks (Figure 18). However, two TSR sites with highest canopy cover had lower than expected CPOM loadings on the bank face.

Previous research by Reid et al. (2008b) has demonstrated that benthic CPOM begins to accumulate when canopy cover is higher than ~30% but there is significant variability in the relationship above this threshold i.e. higher canopy cover does not necessarily always equate to higher CPOM. We plotted our data against that from Reid et al. (2008b) for comparison, and our results conformed to this general pattern (Figure 19). We used bank canopy cover as a proxy measure of direct litterfall – it will be important to directly measure stream channel canopy cover in the future to properly evaluate this relationship.

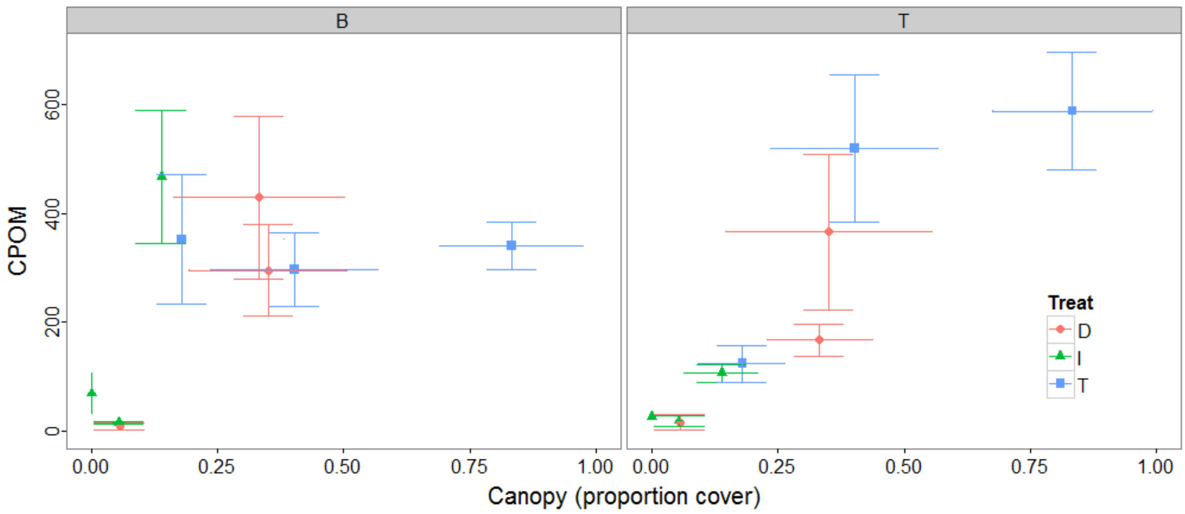

Figure 18. Top two panels show the relationship between coarse particulate organic matter (CPOM – g/m²) and canopy cover on the bank (B) and top of bank (T) within the riparian zone.

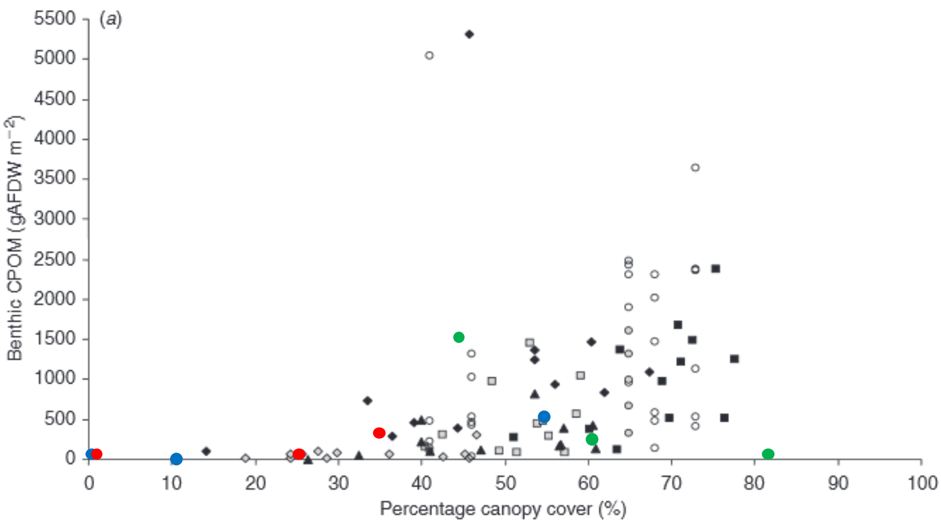

Figure 19. Examining the relationship between instream CPOM and canopy cover. Results from Year 1 sampling show benthic CPOM vs. bank canopy cover, with TSR (green), intervention (blue) and degraded (red) sites, and are plotted against data from Reid et al. (2008b).

KEQ: • Is CPOM standing stock related to longitudinal inputs from upstream?

If longitudinal CPOM inputs from upstream are a strong determinant of local loadings, then instream CPOM is likely to be highest at sites with large forested catchments i.e. those likely to receive more CPOM from upstream. We explored this possibility by examining the relationship between instream CPOM and five proxies describing the likely pool of upstream CPOM, based on catchment size and vegetation condition (Table 2). It is important to note that here that our results are very preliminary, and properly evaluating these potential relationships will require a significantly larger pool of sites than the 12 sampled in Year 1.

Instream CPOM was highest at sites in larger catchments (except for one site), but in general was only weakly related to our five proxy measurements of longitudinal transport (Figure 20). There are a number of possible explanations for these observations. First, instream CPOM loadings may reflect processes occurring at the site rather than catchment level – a likely possibility, given the intermittent nature and small size of the sites (further explored below). Second, our proxy measures for availability of upstream CPOM may be poor, and attaining better estimates of longitudinal sources will be an aim in coming years. For example using better resolution vegetation mapping of the different catchment vegetation communities that influence amounts and timing of leaf litter delivery. Third, a range of factors may influence the likelihood of CPOM being transported downstream (e.g. stream flow, connectivity, channel complexity), and these, rather than the pool of available CPOM may be stronger influences on longitudinal transport. Fourth, as outlined above, it is highly likely that 12 sites is an insufficient number to properly characterise potential relationships.

We examined if instream CPOM loadings were related to five likely modifiers of the movement of organic matter into sites from upstream (Figure 21). Instream CPOM loadings were higher at sites with shallower slopes and more perennial flows. All sites that were within 10km of an upstream dam had low loadings, and the sites with highest instream CPOM were all >12km downstream of a dam (Figure 21).

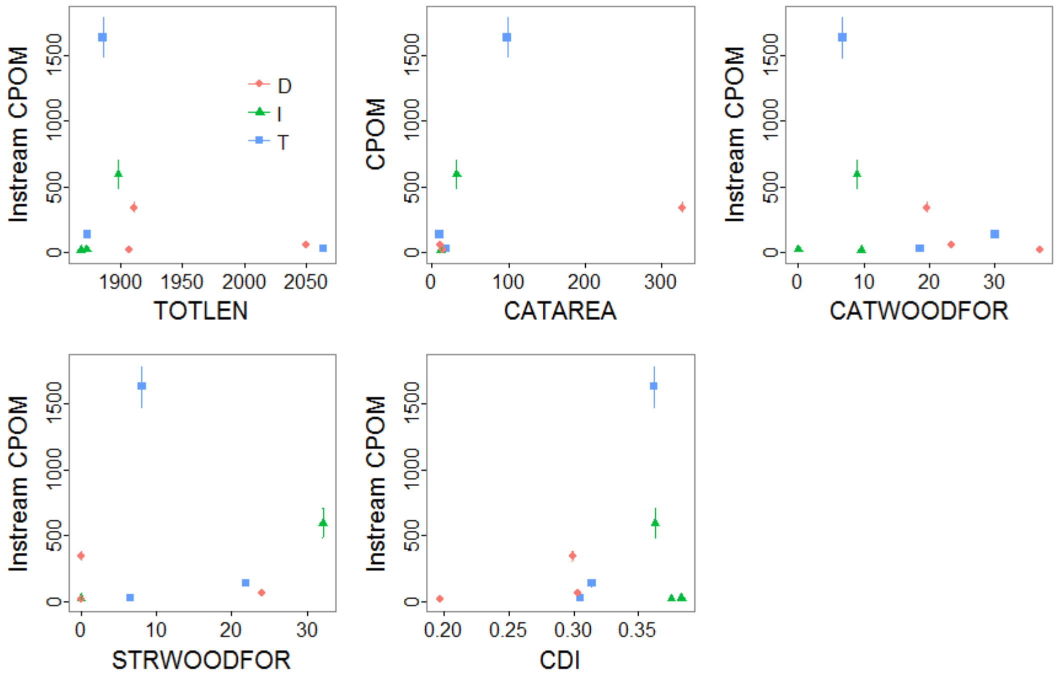

Figure 20. The relationship between instream CPOM loadings (g/m2) and five proxy measures of the likely pool of upstream CPOM that could be transported longitudinally to sites. D: degraded sites, I: intervention sites, T:TSR sites. The five proxy variables are: total length of stream upstream (TOTLEN), catchment area (CATAREA), woodland and forest in the catchment (CATWOODFOR) and stream (STRWOODFOR) and catchment disturbance index (CDI). Refer Table 2 for all catchment indices that were considered.

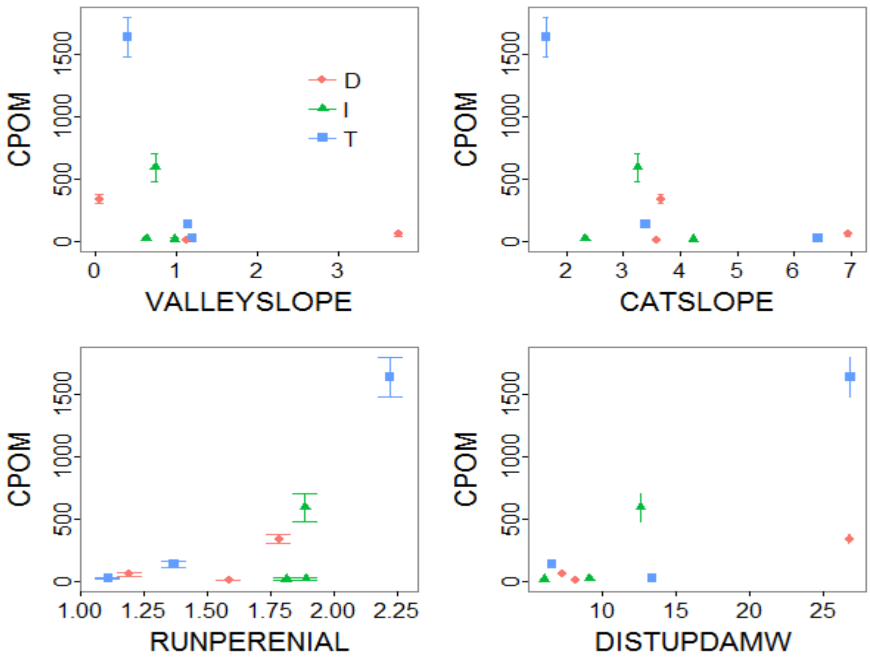

Figure 21. The relationship between instream CPOM (g/m^2) and five variables likely to influence the likelihood of longitudinal transport of CPOM into sites. D: degraded sites, I: intervention sites, T:TSR sites. The five variables are: valley (VALLEYSLOPE) and catchment (CATSLOPE) slope, hydrology (RUNPERENIAL) and distance to nearest upstream dam (DISTUPDAMW).

KEQ: Does improved floodplain vegetation lead to increased lateral inputs into the stream?

Sites with higher canopy cover may have a greater pool of organic matter that can move into the stream channel. This could occur either via litter falling directly from the canopy into the stream channel, or via litter falling into the riparian zone and then moving laterally into the stream. The movement of litter from the riparian zone into the stream may also depend on the nature of the stream channel, for example, litter may move more frequently off the banks if the banks of the channel are steeper.

Instream CPOM loadings were higher at sites with higher bank loadings of organic matter, suggesting that lateral movement of CPOM may be important (Figure 22). However, instream CPOM and top of bank CPOM were not related. More organic matter accumulated both on the bank and instream at sites with greater channel slope

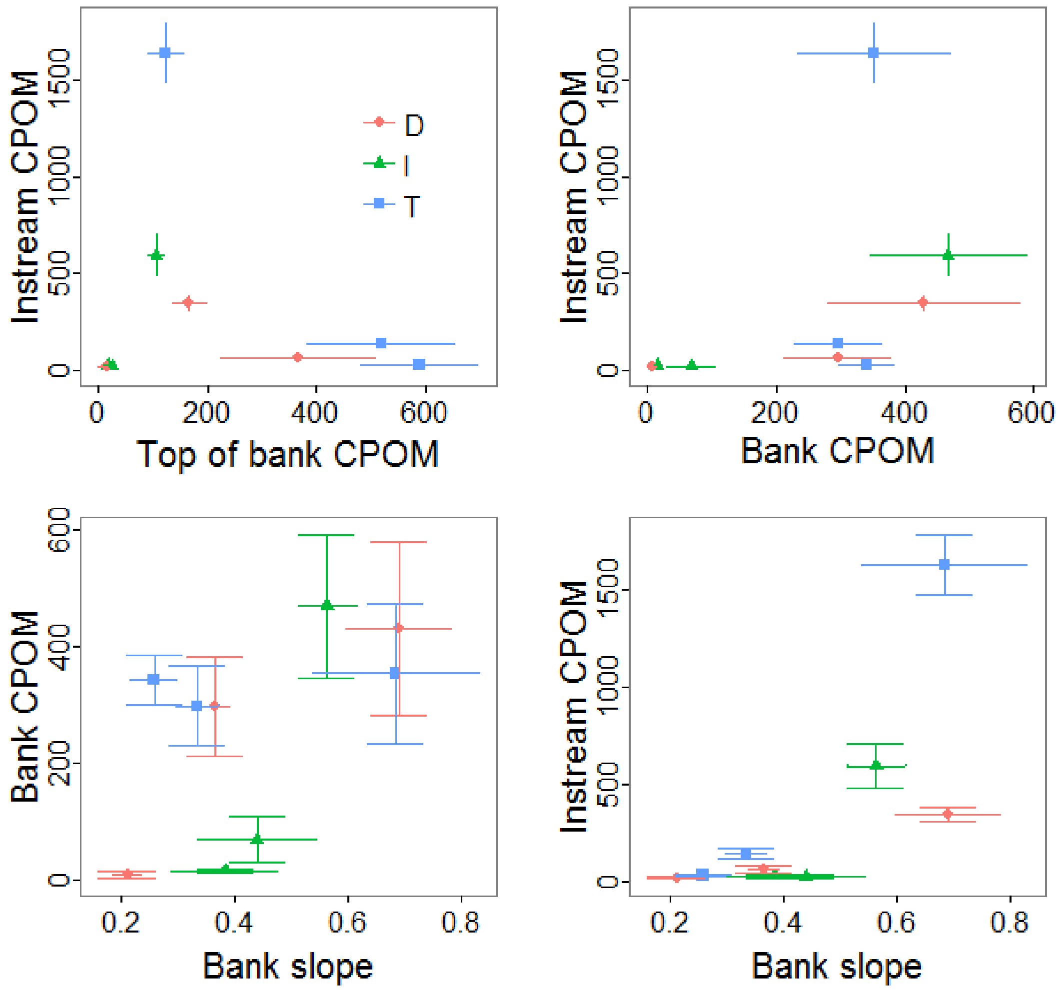

Figure 22. Examining the potential influence of lateral inputs on instream CPOM. Plots are instream CPOM (g/m^2) vs. instream CPOM vs. top of bank canopy cover (%), instream CPOM vs. bank CPOM, bank CPOM vs. slope and instream CPOM vs. slope).

KEQ: • Is CPOM standing stock correlated with input of CPOM and/or retention of CPOM?

Instream CPOM will reflect the amount of CPOM moving into sites whether from upstream or local sources but also whether this CPOM is retained or lost from sites. We hypothesized that instream CPOM may be higher at sites with higher loadings of coarse woody debris, but did not find any evidence supporting this prediction (Figure 23). However, CPOM could potentially be retained in a range of ways that we were not able to consider in year one (e.g. by macrophytes, by streambed features such as exposed tree roots, or backwaters) – exploring the potential for local retention will be important as monitoring program continues.

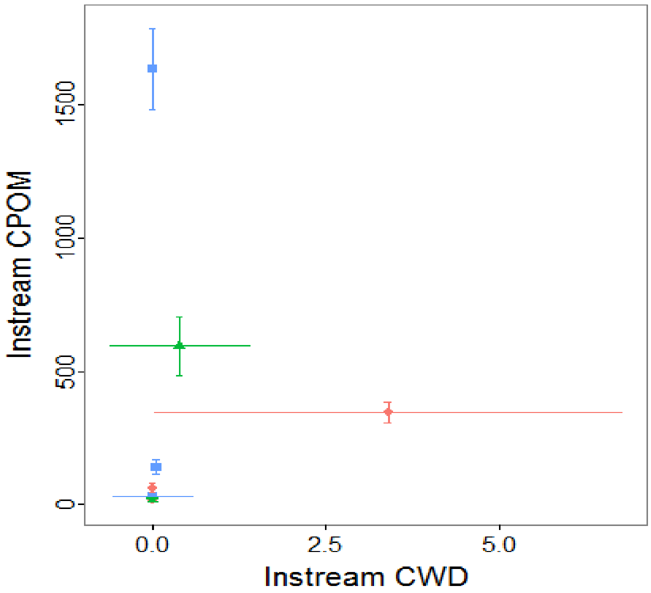

Figure 23. Instream CPOM (m/g^2) vs. instream coarse woody debris (m^3/m^2) (red=degraded, green=intervention, blue=TSR sites)

Summary

Table 5 summarises the progress made this year in the field monitoring component and draws attention to emerging issues that will inform activities in subsequent years. Recommendations are grouped together in section 4.

Table 5. Summary of progress and emerging issues from field monitoring program

	Field monitoring program summary
Status	Initial 12 sites monitored included 4 degraded sites, 4 intervention sites, and 4 TSRs. Power analyses indicate methods and design is appropriate and effective for discriminating evidence to evaluate the KEQ. Additional sites are required to increase confidence in observed difference and to allow robust evaluation of each KEQ.
Outcomes	1. Differences between intervention, degraded and TSR sites in terms of structural vegetation and bank stability were largely consistent with expected responses based on previous published research. TSR sites can be used as proxies for estimating 'remnant' conditions within the region to act as targets following revegetation for some variables (e.g. canopy cover). However, for other variables (e.g. cover of understorey vegetation) they may be less suitable, due to the effects of grazing. 2. Intensity of sampling within sites is sufficient to characterise vegetation structure and organic matter dynamics with appropriate precision. 3. 12 sites is insufficient to properly characterise response trajectories using a space-for-time approach. More sites are needed that span the chronosequence from immediately after interventions have been undertaken to ~20 years following are required. Older sites are particularly important (and hardest to locate). If 10-15 more sites that span across this chronosequence can be identified, there would be merit

	in conducting future sampling using the same methods used here to expand the existing pilot data set. However, if addition sites cannot be located, it would be better to invest time and resources in other activities (e.g. tracking current sites through time, targeted experiments, and end of catchment sampling). 4. Our preliminary results indicate that a variety of processes occurring at both local- and catchment- scales may be driving instream CPOM loadings at sites. We suggest a range of potentially fruitful avenues for future work in the research portfolio that will improve current understanding of the processes driving local variation in CPOM production and retention, as well as evaluating the potential consequences of these local-scale dynamics for ecosystem functioning at the catchment level.
Scheduling	Yr2 - sample additional intervention sites to increase pools of data from sites of different ages needed to develop response trajectories. TSRs were adequately described with just 4 sites.
Needs	• Identify additional sites on larger unnamed streams to augment the small pool of sites on named streams. • Clarify the type of intervention that was applied at sites currently missing a description in the Murray LLS GIS data sets (19 sites from 2003-2007) to identify any revegetation sites that can be added to the site pool. • Audit sites to resolve the integrity of past interventions.
Emerging ideas/issues	There was a large number of identified sites that could not be sampled because the intervention had been failed or been destroyed, or for other reasons (access, safety). Locating sites was time intensive and wasteful of field resources.

4. Recommendations.

Sampling in Year 1 has provided important preliminary information to guide the future development of the monitoring program, and maximise the efficiency of future sampling.

Recommendations for future monitoring:

1. Investigate suitability of using sites with other conservation area with more intact understorey (e.g. Woomagama National Park) in addition to TSRs to improve resolution of the structure and litter inputs from high quality vegetation that represent theoretical end-points of vegetation response trajectories.

2. Continue to use the Victorian riparian vegetation assessment methods. This will also facilitate broader analysis with the Victorian data in nearby catchments in later years.

3. An important task for year 2 will to locate additional existing revegetation sites from examining additional Murray LLS data files, Landcare and other relevant organisations (e.g. Greening Australia), and relaxing the site selection criteria applied to date (e.g. identifying appropriate sites on unnamed streams that were currently excluded). If sufficient additional sites can be located the field monitoring in year2 will double the size of the current data set and many of the pilot analyses will be repeated providing much stronger evidence from which to more formally evaluate the KEQ.

Recommended actions for Murray LLS to improve the monitoring program efficiency and effectiveness:

1. It will be important that the project is periodically reviewed over its 10 year life span to synthesize results, and to identify key research gaps and opportunities to develop linkages with other relevant projects, programs and personnel. We recommend that a steering committee be established with representatives from relevant organisations, and that biannual meetings be held to present key findings and guide future directions (refer section 7: Communications)
2. Improve resolution of the current status of existing intervention sites to assess the state of the original implementation (e.g. are fences still standing, did planted vegetation survive, what is the spatial extent of the site that was revegetated), and also characterise important environmental characteristics of sites that could modify responses (e.g. current land use, access by grazing livestock).
3. Clarify the type of intervention that was applied at sites currently missing a description in the Murray LLS GIS data sets (19 sites from 2003-2007) to identify any additional revegetation sites that could be monitored.
4. Locate the original planning materials for all selected intervention sites to improve communication of access, and spatial arrangement of planting relative to monitoring. This was achieved for some sites sampled in year 1, but not all.
5. Assess the map of named vs unnamed streams to help locate additional sites on larger unnamed watercourses that were excluded from the selection process. This task could be supported by a year2 desktop study using gauge data and/or the Geofabric hydrology

attributes rather than relying on the existence of a name in the data layers to identify larger streams.

Recommended priorities for year 2 monitoring:

1. Generating better response curves to document trajectories and magnitudes of change following riparian interventions.
2. Improving current understanding of mechanisms driving CPOM retention and how these may change following riparian revegetation.

1. Generating better response curves to document trajectories and magnitudes of change following riparian interventions.

Relevant KEQs

- How does vegetation structure change over time after revegetation?
- Does increased canopy cover lead to increased riparian CPOM?
- Are instream CPOM loadings related to longitudinal inputs from upstream?
- Are instream CPOM loadings related to direct litter fall or lateral inputs?
- Are instream CPOM loadings correlated with potential drivers of CPOM retention?

Why is this important?

Monitoring in Year 1 has illustrated that broad differences exist between three different groups of sites with contrasting histories of riparian management (TSRs, degraded sites, revegetation sites). However, it is not possible at this stage to adequately use a space-for-time approach to develop trajectories from which to assess the likely timing and magnitude of system response indicators to the interventions. Additional sites are therefore needed to better document indicator response trajectories and to update conceptual models.

What methods would be used?

Continuation of the methods used in year 1 to increase the size of the current data set to include more sites distributed along the response chronosequence. Preliminary power analyses indicate that another 12-20 sites would need to be included for this to be an effective exercise. The first step would be to assess if attaining these additional sites is realistic. The focus should primarily be on sampling additional intervention sites across a wide range of ages since implementation.

Whether additional suitable intervention sites exist could be undertaken by considering potential sites from a number of sources:

1. Those identified in the audit of riparian intervention sites to be conducted by Murray LLS
2. New intervention sites in the Holbrook region
3. Developing links with other on-going projects (e.g. Victorian RIM monitoring, Unimelb ARC Linkage) to identify nearby sites outside the Murray LLS region that are likely to have similar environmental conditions (e.g. within the Goulburn and Broken catchments).
4. Relaxing some the criteria we used to select sites within the Murray catchment.

2. Improving current understanding of mechanisms driving CPOM retention and how these may change following riparian interventions.

Relevant KEQs

- Which drivers are increasing CPOM retention? Channel complexity vs. structural vegetation?
- How is sediment entrainment and export influenced by riparian vegetation distribution and structure at catchment scales

Why is this question important?

- The space-for-time analysis may provide some correlative evidence about relationships between CPOM and mechanisms of retention, but the evidence is indirect and will not quantify rates or factors that influence those rates.
- While coarse wood loadings were monitored in Year 1, other potential retention mechanisms may be important, and be directly relevant to the Murray LLS Aquatic Health plan (e.g. instream aquatic macrophytes and channel complexity)
- Determining the relative importance of different retention mechanisms could guide future efforts to improve effectiveness of investment e.g. if retention is most strongly drive by coarse wood loadings then adding coarse woody debris may be the most effective management technique.
- There may also be differences in the relative importance of different retention drivers during base-flow vs. high discharge events.
- It would be easy to extend the approach to also examine how sediment entrainment and export might be affected by structural vegetation and other factors

What methods would be used?

- Similar methods to Quinn et al. (2007) could be used to:
    - Select sites with a range of different environmental characteristics (i.e. geomorphology, structural vegetation condition). Likely 15-20 sites required.
    - Release and track CPOM- either artificial (e.g. dowel) or real (e.g. marked/painted leaves) – over relatively short distances.
    - Use experimental releases of solutes to examine solute retention
    - Analyses to relate mean retentive distance to the suite of environmental variables
- The suite of environmental variables would include
    - Basic site characteristics (e.g. hydrology, geomorphology)
    - Potential mechanisms for retention e.g. CWD, fine woody debris, macrophyte structure
- Study undertaken in spring/winter when sites are likely to be flowing.
- Having an event-based trigger for re-sampling sites after high discharge events.

5. Flexible Monitoring and Research Schedule

An important attribute of this program is to retain the flexibility for the project to be as adaptable as the needs/priorities of Murray LLS and available resourcing change. In addition, the direction of the program should change as results come to hand, by proposing and testing hypotheses to improve understanding of likely responses to riparian interventions. We propose a timeline for the first two years of the project below. We also propose that space-for-time sites are re-sampled after six and tens year of the project to update our assumptions about the likely timing of responses to these riparian interventions. These intervals are based on the likely rate of change in riparian structural vegetation.

We propose a series of potential studies in the research portfolio (Section 8) that could be included within the overall project, with outlines of their likely feasibility, costs and outputs. These could be inclusion within the project in years when no monitoring has been currently scheduled.

Table 6.Timeline illustrating progress undertaken to date and planned future activities. Information to answer potential research questions could be collected when suitable gaps in the timeline exist, as indicated below.

	Years									
	1	2	3	4	5	6	7	8	9	10
Pilot studies to refine design										
Monitoring of riparian structure and organic matter space-for-time sites (new sites Year 2, all sites repeated in later years)										
Murray LLS to conduct audit of sites and ensure implementation plans for new sites										
Improving current understanding of mechanisms driving CPOM retention and how these may change following riparian interventions - experimental releases of CPOM										
Monitoring and research to answer key evaluation questions										

6. Data management

This monitoring program intends to collect data for at least 10 years and will include monitoring and experimental results gathered to evaluate short term (months to years) responses to riparian interventions as well as long term changes over the 10 years (e.g. changes in catchment scale vegetation cover and connectivity). Over that time, staff and contractors will change, memories will fade and computers and software will become obsolete. Good data management is therefore essential to secure the long-term success of the program. Data management for this program is guided by the following principles:

- **Good governance** - ARI will coordinate monitoring and data delivery to Murray LLS.
- **Custodianship** - Data should be centrally maintained by Murray LLS in one location as the authoritative source for the dataset that is archived and maintained. Other research partners will have shared access to the data and all evaluation should be conducted on data that is extracted from the source to ensure all edits and updates are incorporated prior to the data being used in for evaluation.
- **Shared responsibility** - Those collecting the data are responsible for the quality of the data. Murray LLS is responsible for the integrity of the dataset and accessibility to data. Data users are responsible for wise and appropriate use of the data.
- **High quality data** - Comprehensive but achievable quality assurance and quality control (QA/QC) procedures ensure the collection of high quality data that is fit for purpose.
- **Metadata** - Accurate metadata accompanying the dataset provides contextual information on where, who, how and why the data were collected and documents known assumptions or limitations to guide interpretation. This will add value by facilitating wider use of the data.

QA/QC Guidelines

Regular re-evaluation should be undertaken to ensure:

- Standard monitoring methods are being adhered to and are consistent across sites and years.
- Data management is following prescribed methods and standards with adequate crosschecking
- Training (e.g. if bringing in new monitoring partners) where necessary has been completed to satisfactory standard

All field sheets and electronic records should be checked for completeness, consistency and potential errors. Any confirmed errors should be corrected and a record kept of the correction.

Data should be entered from the field sheets into a computer as soon as possible after collection. Any digital photos from the photo-point monitoring must be extracted to disk, and a log of photo details updated and stored (currently included on site data sheets and electronic workbooks).

Metadata records should be completed for each dataset record and photo collection.

Electronic data storage

Initially data will be entered into Microsoft Excel data templates that were designed to capture the Victorian RIM program monitoring method being used here (with appropriate modification to include the CPOM and wood load data collected in this first year). The data templates house the raw data and calculate the various response indicators at a range of spatial scales (e.g. lateral zones within transects within sites. The spreadsheet format is compatible with a wide range of organisations and analytical software and provides flexibility b ecause they can easily be modified to incorporate new indicators, contextual data, and novel ways of processing the raw data. A number of data macros have been programmed to assemble data from multiple workbooks into matrices for input into multi-site analyses.

7. Communication

The aim of the strategy is to inform, consult and involve stakeholders and partners to:

- communicate program evaluation outcomes and engender support amongst stakeholders and interested groups.
- foster existing partnerships and develop new collaborations (eg for access to complementary data, expansion to include sites in adjacent LLS regions and Victorian CMAs).
- To communicate results and recommendations to improve the design and implementation of riparian interventions
- Build a strong foundation for adaptive management with increased transparency of decision making

Communication and engagement needs to service the communication needs of multiple stakeholders (e.g. Murray LLS, Holbrook Landcare, landowners, research partners) that will each have unique messages and media formats for effective communication in addition to sharing in common "broadcasts" of outcomes riparian management (e.g. Table1)

Table 7. A broad range of stakeholders and communication tools that will be required for effective communication.

Action	Stakeholders	Communication Tools
INFORM	General public Landholders Community groups CMAs, LLS Scientific community	Factsheets Social media Media releases Journal publications
CONSULT	Community groups CMAs Scientific Community	Direct discussions Group meetings and workshops
INVOLVE	Murray LLS Monitoring Project Team Research partners Holbrook Landcare Neighbouring LLS Victorian CMAs	Monitoring outcomes and conceptual models Technical workshops and meetings Progress reporting

It will be important that the project is periodically reviewed over its 10 year life span to synthesize results, and to identify key research gaps and opportunities to develop linkages with other relevant projects, programs and personnel. We recommend that a steering committee be established with representatives from relevant stakeholder groups, and that biannual meetings be held to:

(1) present key findings and reflect on their significance to improving the impact and effectiveness of riparian management practices (closing the adaptive management loop); and

(2) review or reaffirm program objectives to keep the monitoring program on relevant to Murray LLS needs, to review emerging issues and new priorities, and to re-evaluate the KEQ and research portfolio.

8. Research Portfolio

The research portfolio will be developed as a list of research ideas, generally for short-term projects that contribute to understanding the outcomes of riparian restoration. Project questions are to seed activities within this program or to identify opportunities for linking to complimentary research by external collaborators. The portfolio projects should be regularly reviewed to assess ongoing relevance given program outcomes, changing levels of project resourcing, and emerging opportunities following discussions with potential collaborators. The research portfolio should be a living repository of ideas that are regularly updated, improved and prioritised at minimum on an annual basis. A simple initial rankings scheme has been applied as follows (Table 8):

1. High relevance to program objectives and/or high feasibility for inclusion in the program within next 2-3 years given expected resourcing and partnerships. Further development of logic and rationale may still be required.
2. Relevant ideas that may require additional thinking, external partners or additional resourcing before feasible to implement.
3. Lowest priority. Continue development of logic and rationale. Reserve for future partnership and funding opportunities.

As additional research ideas are added to the portfolio, and/or additional monitoring program partnerships are developed there may be a requirement to increase the sophistication and transparency of the ranking, e.g. to rank research questions by multiple criteria such as perceived importance, likelihood of success, critical knowledge gaps, resource intensity and timing.

Table 8. Research portfolio questions and nominal ranking

Research Questions	Rank
What are the rates of lateral and longitudinal transport and retention of CPOM as a function of catchment characteristics?	1
Is increased local CPOM due to increased vertical or lateral CPOM inputs?	1
What are the volumes/rates of longitudinal transport and processing of CPOM?	1
Is increased local CPOM driven more by increased retention or increased CPOM inputs? Or are both important?	1
What factors modify the pathway between increased local CPOM standing stocks and drivers of increased CPOM inputs/retention?	1
What are the consequences of increased CPOM standing stock for aquatic fauna?	2
What are the consequences of increased CPOM standing stock for stream metabolism?	1
How is sediment entrainment and export influenced by riparian vegetation distribution and structure at catchment scales	2
Terrestrial Fauna response to riparian outcomes	3
What effect does riparian improvement have on aquatic macrophyte abundance and distribution?	2

Research Question	What are the rates of lateral and longitudinal transport and retention of CPOM as a function of catchment characteristics?
Related KEQ	Is CPOM standing stock related to longitudinal inputs from upstream? Is increased local CPOM due to increased vertical or lateral CPOM inputs? Which catchment scale response modifiers influence organic matter responses to riparian interventions?
Rationale	Landscape context is a determinant (modifier) of organic matter transport and retention rates through combined effects of factors such as riparian corridor vegetation structure and cover, catchment slope, roughness and complexity, instream channel complexity, climate and flow regime. Understanding the magnitude of variability attributable to these factors is fundamental to being able to scale up monitoring and experimental results from the intervention sites scale to larger catchment and landscape scales
Approach	GIS spatial data sets and field monitoring can quantify response modifiers that influence lateral and longitudinal transport of organic matter among distributed intervention sites. Catchment attributes can be sourced or calculated from a range of spatial data sources and included as co-variates to partition variation in experimentally measured CPOM transport rates. Likely modifiers to include will be indicators of climate, soil type, extreme events. adjacent and catchment land use, topography, hydrology. vegetation condition. land use history, channel incision, vegetation type)
Spatial Scale	intervention site to landscape
Temporal Scale	Short term experiments (days to weeks), could be distributed across multiple years expanding a data set over time.
Resourcing	Low to moderate depending on complexity and number of field measurements. Catchment attributes will have value to other questions and evaluations within the program.
Critical Timing / Dependencies	None identified
Opportunities / Collaborators	None identified
Risks	None identified

Research Question	Is increased local CPOM due to increased vertical or lateral CPOM inputs?
Rationale	CPOM can come from three sources: vertically from the canopy above, laterally from the floodplain, or via longitudinal advection from upstream areas. Examining the relative contribution of these different sources will help guide where riparian projects should be focussed to maximise inputs. If vertical inputs are most important, then replanting in the riparian zone should be prioritised but if most CPOM is being supplied laterally, then replanting/management of the floodplain will be vital.
Approach	Use litter traps to quantify vertical and lateral inputs of CPOM under different levels of vegetation structure. Following methods of previous studies (e.g. Wallace et al. 1995, Reid et al. 2008b).
Spatial Scale	Intervention site
Temporal Scale	seasonal (weeks to months) coinciding with summer leaf fall periods.
Resourcing	Moderate - can install traps at monitored sites.
Critical Timing / Dependencies	Timed to summer leaf fall
Opportunities / Collaborators	Melbourne University Riparian ARC Linkage project
Risks	None identified

Research Question	What are the volumes/rates of longitudinal transport and processing of CPOM?
Related KEQ	Is CPOM standing stock related to longitudinal inputs from upstream? Which catchment scale response modifiers influence organic matter responses to riparian interventions?
Rationale	Estimates of volumes/rates facilitate prediction of catchment scale outcomes and influences at the site level. If longitudinal inputs of CPOM are substantial then local-scale responses to riparian interventions can be overridden by the condition of the catchment upstream of sites. If increases in CPOM standing stocks are not related to increases in local inputs from the canopy or floodplain, then this raises the potential that longitudinal imports/exports are more important.
Approach	Quantify rates, volumes, and transport lengths of longitudinal CPOM movement using drift experiments Controlled experiments to augment local CPOM (small scale additions or reach level using chipper mulch or similar)
Spatial Scale	reach scale processing to extrapolate up.
Temporal Scale	seasonal (weeks to months) coinciding with summer leaf fall periods.
Resourcing	unknown - potentially quite high depending on scale of experiments. Suggest start small and work up to reach level.
Critical Timing / Dependencies	seasonal influences (temperature, water availability)
Opportunities / Collaborators	none identified
Risks	none identified

Research Question	Is increased local CPOM driven more by increased retention or increased CPOM inputs? Or are both important?
Related KEQ	What is the relative role of CPOM input vs. retention influencing CPOM standing stock?
Rationale	Examining the relative importance of increased retention vs. increased CPOM is important, as it will help identify the likely impacts of different riparian management techniques. If local CPOM inputs are most important, then replanting in the riparian zone or on the floodplain will most effectively increased local CPOM standing stock In comparison, increasing retention of CPOM e.g. through additions of coarse woody debris, will be more effective if retention is a stronger driver of local inputs.
Approach	Establishing a BACI type experiment with replicated treatment (replanted) and control (unmanaged) sites that are monitored through time. Pairs of treatment and control sites located on geomorphically simple and complex channels Experimental additions of CPOM into sites using a two-factor design, with CPOM additions (Yes/No) and underlying retentive capacity (e.g. High – low slope, complex channel, high coarse wood, Low- high slow, low sinuosity, low coarse wood) as factors.
Spatial Scale	reach
Temporal Scale	seasonal - related to seasonal hydrology.
Resourcing	unknown
Critical Timing / Dependencies	seasonal influences (temperature, water availability)
Opportunities / Collaborators	Melbourne University Riparian ARC Linkage project
Risks	none identified

Research Question	**What factors modify the pathway between increased local CPOM standing stocks and drivers of increased CPOM inputs/retention?**
Related Questions/Links	How do results compare across different environmental contexts (e.g. stream order/size, hydrology, catchment vegetation, adjacent land use)? What are the rates of lateral and longitudinal transport and retention of CPOM as a function of catchment characteristics?
Rationale	Our focus (at least initially) will be on the area around Holbrook, to reduce potential environmental heterogeneity Assessing how our findings translate into other environmental contexts will shed light on their potential generality. If responses differ significantly between contexts, then it will be necessary to tailor management activities to suit.
Approach	Undertaking similar studies to above (starting with the space-for-time) in other areas of the Murray catchment. Expanding monitoring approach to neighbouring LLS as a collaboration Incorporating data from the Victorian RIM program
Spatial Scale	Catchment and Landscape
Temporal Scale	Long term research questions.
Resourcing	High, but collaborative and shared among multiple organisations
Critical Timing / Dependencies	Victorian RIM data will come online for new interventions being implemented 2015-2016 only and then track through time.
Opportunities / Collaborators	Victorian CMA, Western LLS, Riverina LLS, potentially South East LLS
Risks	none identified

Research Question	What are the consequences of increased CPOM standing stock for aquatic fauna?
Related Questions/Links	Does increased CPOM standing stock increase structural habitat for aquatic fauna? Does increased CPOM standing stock result in increased abundance/species richness of invertebrates (shredders in particular)?
Rationale	CPOM is a basal resource that underpins aquatic ecosystem food webs. Riparian interventions are implemented to support aquatic health, not just local vegetation gains.
Approach	Examine influence of increased organic matter accumulation on biota (e.g. shredders), food web structure (e.g. shift from autotrophy to heterotrophy), decomposition rates, dissolved organic carbon (DOC).
Spatial Scale	Intervention site. Some potential to extrapolate up
Temporal Scale	Variable - short term sampling could examine variability in local assemblage structure. Long term monitoring required to develop population models (e.g. LTIM fish models)
Resourcing	scalable low -high
Critical Timing / Dependencies	seasonal influences (temperature, water availability)
Opportunities / Collaborators	LTIM in Edward Wakool is measuring reach level metabolism
Risks	none identified

Research Question	What are the consequences of increased CPOM standing stock for stream metabolism?
Related Questions/Links	Does increased CPOM standing stock affect stream metabolism?
Rationale	CPOM is a basal resource that underpins aquatic ecosystem food webs. Riparian interventions are implemented to support aquatic health, not just local vegetation gains.
Approach	Examine influence of increased organic matter accumulation on biota (e.g. shredders), food web structure (e.g. shift from autotrophy to heterotrophy), decomposition rates, dissolved organic carbon (DOC).
Spatial Scale	Intervention site. Some potential to extrapolate up
Temporal Scale	Multiple short term investigations
Resourcing	scalable low -high
Critical Timing / Dependencies	seasonal influences (temperature, water availability)
Opportunities / Collaborators	LTIM in Edward Wakool is measuring reach level metabolism
Risks	none identified

Research Question	How is sediment entrainment and export influenced by riparian vegetation distribution and structure at catchment scales
Related Questions/Links	Links between turbidity and metabolism (autotrophy vs heterotrophy). Nutrient transport associated with sediment
Rationale	Riparian vegetation was shown in the pilot to reduce bank erosion. Stabilising banks/channels is a common goal for riparian interventions
Approach	• Understand sediment retention in space for time study - this is likely to involve the positioning of fibrous sediment mats at multiple sites and leaving for a duration of time before collecting to measure sediment accrual. Suggest a full year minimum to see results. Potential to deploy fibre mats in one season for retrieval in future years. • Investigation of the efficacy of Murray LLS erosion control works in riparian zone. ○ Examine the effectiveness of the use of riparian management as for erosion control and sediment reduction. Initial discussions had with Geoff Vietz, Melbourne University to roughly scope requirements in 2014.
Spatial Scale	Catchment (some reach)
Temporal Scale	Sediment matts accumulate data over months to years
Resourcing	variable
Critical Timing / Dependencies	opportunistic monitoring of high flow events in addition to base flows
Opportunities / Collaborators	Separate body of work headed by Geoff Vietz (Melbourne University)
Risks	loss of fibre mats (cattle, floods) - mitigate by installing more than required.

Research Question	Terrestrial Fauna response to riparian outcomes
Related Questions/Links	• Terrestrial macro-fauna response to riparian vegetation. Questions include: o Are restored riparian corridors being used by macro-fauna o How is riparian use by macro-fauna influenced by connectivity to adjacent vegetation (laterally, longitudinally) o How is riparian use by macro-fauna influenced by structural development of vegetation over time
Rationale	Riparian vegetation enhancement influences terrestrial riparian habitat structure and food webs in addition to aquatic. Improved riparian habitat, especially longitudinally as wildlife corridors is an explicit aim of some Murray LLS riparian programs
Approach	Potential to pilot test acoustic monitoring method for crude monitoring of terrestrial mega-fauna outcomes at a small number of highly contrasting sites (e.g. no riparian zone, sparsely vegetated site, fully vegetated travelling stock reserve) to pilot test method and determine detection probabilities - explore avenue for further
Spatial Scale	intervention site
Temporal Scale	short term habitat use to multiple year population dynamics
Resourcing	unknown
Critical Timing / Dependencies	none identified
Opportunities / Collaborators	Establish links with ANU biodiversity group. Review existing ANU project sites and research outcomes to identify current understanding of biodiversity outcomes of increasing riparian structure.
Risks	none identified

Research Question	What effect does riparian improvement have on aquatic macrophyte abundance and distribution?
Related Questions/Links	Water regime management (Delivery of environmental water allocation, managing consumptive flows, Environmental watering plans/targets)
Rationale	Macrophytes play a number of key roles in healthy riparian zones, including • helping improve water quality through the uptake and processing of nutrients, and also providing carbon to the stream • increasing bank stability and decreasing erosion (Abernethy and Rutherfurd 1999) • providing an important food source for macroinvertebrates, as well as substrata for algal and bacterial growth. Macrophytes are influenced by, riparian shading, water regime management (environmental water allocations, consumptive flows), livestock exclusion and direct planting of macrophytes
Approach	Include monitoring indicators related to macrophytes cover (e.g. total % cover, % cover of key species, % cover of functional groups). Could also examine indicators related to diversity (e.g. species richness/abundance: total, natives, exotics, native: exotics, key species, functional groups i.e. submerged/aquatic/terrestrial.
Spatial Scale	intervention site, with a view to extrapolating to catchment level improvement from riparian program
Temporal Scale	Highly seasonal
Resourcing	unknown
Critical Timing / Dependencies	Macrophytes can be highly seasonal - likely to require summer monitoring
Opportunities / Collaborators	none identified
Risks	Macrophytes can be highly variable (e.g. seasonal fluctuations up to 60% cover due to seasonal changes in flow - Nielsen and Chick 1997) and it may therefore be difficult to demonstrate effects. Complex interactions between a number of factors may determine the distribution and composition of macrophyte assemblages and these may influence their potential use as ecological indicators (Reid and Brooks 2000). These factors include hydrology, nutrient and light availability, pre-existing differences in macrophyte communities, grazing pressure from cattle, sediment type, and the presence of carp (due to increased turbidity).

(Intentionally blank template for future additions)

Related Questions/Links	
Rationale	
Approach	
Spatial Scale	
Temporal Scale	
Resourcing	
Critical Timing / Dependencies	
Opportunities / Collaborators	
Risks	

9. References

Abernethy, B. & Rutherfurd, I. D. 1999. *Guidelines for stabilising streambanks with riparian vegetation*. Cooperative Research Centre for Catchment Hydrology.

Brooks, S., Hale, R., Reich, P., Lake, P.S., Crook, D., and King, A. 2011. Murray CMA Riverine MERI framework: Monitoring, Evaluation, Reporting and Improvement. Unpublished Client Report for the Murray Catchment Management Authority by the Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Burger, B., Reich, P. & Cavagnaro, T.R. 2010 Trajectories of change: riparian vegetation and soil conditions following livestock removal and replanting. Austral Ecology, 35, 980-987.

Commonwealth of Australia, 2009. Natural Resource Management Monitoring, Evaluation, Reporting and Improvement Framework.

DECC 2009. Evaluation framework for CMA natural resource management., N.S.W.: Dept. of Environment & Climate Change NSW. Sydney, Australia.

DEPI 2014a. DRAFT Riparian Intervention Monitoring Program Version 1. Arthur Rylah Institute for Environmental Research Technical Report. Department of Environment and Primary Industries , Heidelberg, Victoria.

DEPI 2014b. Victorian Riparian Intervention Monitoring Users Manual. Arthur Rylah Institute for Environmental Research Technical Report. Department of Environment and Primary Industries , Heidelberg, Victoria.

Gippel, C.J., O'Neill I., C. & Finalyson, B.L. 1992. The hydraulic basis for snag management. University of Melbourne, Melbourne.

Hale, R., Reich, P., Lake, P.S., Thomson, J.R., Williams, L., Cavagnaro, T.R., Daniel, T. & Johnson, M. 2011a. An assessment of ecological indicators for monitoring responses to riparian restoration in lowland streams of the southern Murray-Darling Basin. Murray Darling Basin Authority technical report

Hale, R., Brooks, S., Reich, P., Crook, D., Lake, P.S. & King, A. 2011b. Review of ecological indicators for MERI program performance. Report to the Murray Catchment Management Authority. By Arthur Rylah Institute for Environmental Research Technical Report. Department of Environment and Primary Industries, Heidelberg, Victoria.

Hale, R., Reich, P., Johnson, M, Lake, P.S., Hansen, B., Thomson, J. & Mac Nally, R. 2014. Bird responses to riparian management along degraded lowland streams. Restoration Ecology. DOI: 10.1111/rec.12158.

Logan, M. 2010. Biostatistical Design and Analysis Using R: A Practical Guide. Wiley-Blackwell Publishing.

Nielsen, D. L., & A. J. Chick. 1997. Flood-mediated changes in aquatic macrophyte community structure. Marine and Freshwater Research 48: 153-157.

Palmer, J.A., Schilling, K.E., Isenhart, T.M., Schultz, R.C., & Tomer, M.D., 2014. Streambank erosion rates and loads within a single watershed: Bridging the gap between temporal and spatial scales. Geomorphology 209: 66-78.

Quinn, G.P. & Keough, M.J. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge.

Quinn, J.M., Phillips, N.R., & Parkyn, S.M. 2007. Factors influencing retention of coarse particulate organic matter in streams. Earth Surface Processes and Landforms **32**: 1186–1203.

Reich, P., Lake, P.S., Johnson, M., Daniel, T., Cavagnaro, T.R., Ladson, A.J., Anderson, B. & McMaster, D. 2009. Draft monitoring protocol for a dedicated experiment to evaluate the effectiveness of riparian restoration on lowland streams in the southern Murray - Darling Basin Draft Report to the MDBA for Project MD606, Monash University, Melbourne, Australia.

Reid, M. A., & J. J. Brooks. 2000. Detecting effects of environmental water allocations in wetlands of the Murray–Darling Basin, Australia." Regulated Rivers: Research & Management 16: 479-496.

Reid, D.J., Quinn, G.P., Lake, P.S., & Reich, P. 2008a. Terrestrial detritus supports the food webs in lowland intermittent streams of south-eastern Australia: a stable isotope study. Freshwater biology 53: 2036–2050.

Reid, D.J., Lake, P.S., Quinn, G.P. & Reich, P. 2008b. Association of reduced riparian vegetation cover in agricultural landscapes with coarse detritus dynamics in lowland streams. Marine and Freshwater Research, 59: 998-1014.

Robertson, A.I. & Rowling, R.W. 2000. Effects of livestock on riparian zone vegetation in an Australian dryland river. Regulated Rivers: Research and Management, 16: 527-541.

Stein, J.L., Mutchinson, M. & Stein, J.A. 2012. National Environmental Stream Attributes v1.1.5., Geoscience Australia.

Tank, J.L., Rosi-Marshall, E.J., Griffiths, N.A., Entrekin, S.A., & Stephen, M.L. 2010. A review of allochthonous organic matter dynamics and metabolism in streams. Journal of the North American Benthological Society 29: 118–146.

Webb, A.A. & Erskine, W.D. 2003. Distribution, recruitment and geomorphic significance of large woody debris in an alluvial forest stream: Tonghi Creek, southeastern Australia. Geomorphology 51: 109-126.

Wallace, J.B., Webster, J.R. & Meyer, J.L. 1995 Influence of log additions on physical and biotic characteristics of a mountain stream. Canadian Journal of Fisheries and Aquatic Sciences, 1995, 52(10): 2120-2137.

Appendix 1 Site details

Type	ID	Monitoring Dates	Murray LLS Site No	Site Name	Creek Name	Implemented	CPOM (Y/N)
Reference	TSR1	17-18/10/2014	14090		Back Creek		Y
	TSR2	19-20/10/2014	51282		Billabong Ck		N
	TSR3	27-28/10/2014	50475		Four Mile Creek		Y
	TSR4	29-30/10/2014	2533		Daly Creek		Y
Intervention	W1	20-21/10/2014	ER022a	Spring Valley	Sandy Creek	2009/2010	Y
	W2	22/10/2014	2005JB073d	Allawah	Kelly Creek	2005/2006	Y
	W3	24-25/11/2014	.	Forestvale North	Forest Creek	2008/2009	Y
	W4	26-27/11/2014	2003KMD042	Karoo	Jingellic Creek	2006/2007?	N
Degraded	D1	10-11/11/2014	.	Forestvale	Little Billabong Creek		Y
	D2	12/11/2014	.	Wingadel	Reedy Creek		Y
	D3	13/11/2014	.	.	Forest Creek		N
	D4	25-26/11/2014	.	Warranboo	Four Mile Creek		Y

Appendix 2. Methods to examine the relationship between sampling effort and sampling error

Background

Examining the relationship between sampling effort and sampling precision can help identify the minimum number of samples required to provide an adequate estimate of different indicators. Sampling can then be adjusted accordingly – if more samples have been taken then it will be possible to increase sampling efficiency by taking fewer samples.

Methods

486 points were sampled at each of the sites (i.e. every 0.25 cm along six 20 m long transects). We examined the relationship between sampling effort and precision, calculated by rearranging the formula below from Ezringa et al. (2008):

$$n = \frac{(Z_\alpha)^2(s)^2}{(B)^2}$$

Where:

n = The uncorrected sample size estimate.

Z_α = The standard normal coefficient from the table below.

s = The standard deviation.

B = The desired precision level expressed as half of the maximum acceptable confidence interval width. This needs to be specified in absolute terms rather than as a percentage. For example, if you wanted your confidence interval width to be within 30% of your sample mean (i.e., $\bar{x} \pm 30\% * \bar{\chi}$) and your sample mean = 10 plants/quadrat then B = (0.30 x 10) = 3.0.

For each site, we calculated precision based on random subsets of the total number of points (i.e. 100 points, 200 points, 250 points etc). This process was bootstrapped (i.e. repeated) 100 times for each site. We then calculated the mean (and standard error) precision across the 12 sites.

Reference

Ezringa C.L., Salzer D.W., & Willoughby J.W. 2008. Monitoring and measuring plant populations. Bureau of Land Management, California, USA.

Appendix 3. Power analysis methods

<u>Background</u>

Statistical power is proportional to the following: (Quinn and Keough 2002):

1. An estimate of the effect size- how big of a change of is interest?
2. Sample size (n)
3. Variance between sampling/experimental units
4. Significance level to be used, commonly set at 0.05.

Power analysis requires estimating an effect size and the likely variance between sampling/experimental units.

<u>Setting an effect size</u>

While setting an effect size is a critical element of power analyses, there are few protocols for doing this in ecology (Downes *et al.* 2012). We used a linear regression model to regress bare ground vs. time since intervention at the three different types of sites, with degraded sites set at time = 0, and TSR sites at time = 10 years post intervention. In this model, bare ground was decreasing at ~4.5% per year. Using this value as the basis, we selected effect sizes ranging from a 2 to 8% decrease in bare ground (Figure 1).

<u>Estimating variance between sampling units</u>

In previous analyses undertaken as part of the DEPI Riparian Intervention Monitoring Program, we found that groundcover vegetation can vary by ~5-10% annually in the absence of any riparian intervention. Based on this, we conducted power analyses based on four estimates of potential variability – a 5 to 25% annual change in bare ground not related to any response to the interventions.

<u>Power analysis methods</u>

We followed the example outlined in Bolker (2008) to estimate the statistical power of detecting linear increases in groundcover over the first five years following the intervention, using the potential effect sizes and levels of background variability outlined above. Based on the Melbourne Water dataset, we set the initial groundcover at 40%. Power was estimated based on four sampling designs: n = 5,10,15,20 pairs of intervention /control sites.

We also used a similar methodology to conduct power analyses for instream CPOM. We selected effect sizes based on a 50-200 g/m^2 yearly increase in CPOM over 10 years, to simulate likely eventual loadings of 1000-2500 g/m^2 based on values in Reid et al. (2008b). We used unpublished results from the Riparian Restoration Experiment to select three levels of background variability, standard deviations of 100, 250, 500 g/m^2.

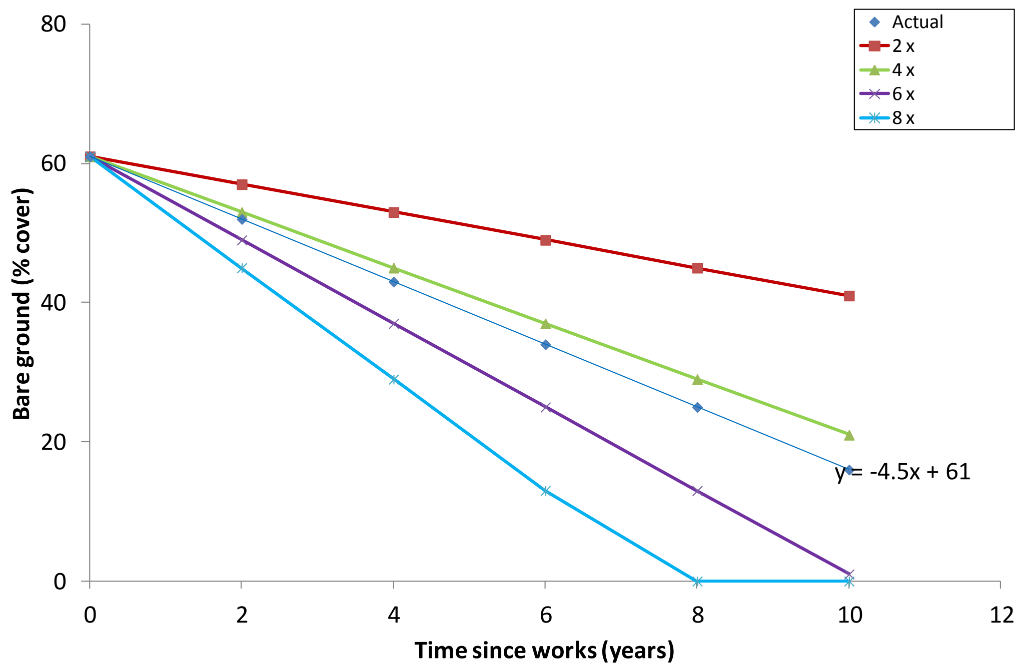

Figure 1. Four modelled trajectories for 2 to 8% annual decrease in groundcover following an intervention at time zero.

Some potential caveats with our approach

It is important to acknowledge that it was necessary to make some assumptions to undertake these power analysis, and these can be updated as more information comes to hand.

First, we have assumed that it is appropriate to set TSR sites as being equivalent to sites 10 years post-intervention. However, it is likely that changes in variables such as bare ground occur over a shorter time period. If TSR sites were set as 5 rather than 10 years, then bare ground in our data set would be decreasing at a rate of ~6% rather than 4.5% - within the range of the effect sizes we have used.

Second, we have assumed that changes following intervention will be linear, in the absence of more detailed information about the potential trajectory of any response. This may be overly simplistic (e.g. the different degradation-recovery pathways outlined by Sarr 2002) and a rang e of complex, non-linear responses are possible. Better documenting trajectories after the intervention will allow this assumption to be tested, and further analyses re-run to examine the likely power to detect more complex, and potentially more realistic response trajectories.

Third, we have assumed that variance between sampling units will stay consistent over time. This may also be too simplistic - riparian zones are highly dynamic systems, and there may be considerable site-to-site and year-to-year variability. Also, variance is an important ecological attribute (Benedetti-Cecchi 2003), and there is the potential that changes in variance represent meaningful responses to riparian interventions. Further monitoring of intervention sites over time would allow this assumption to be tested.

References

Benedetti-Cecchi, L. 2003. The importance of the variance around the mean effect size of ecological processes. Ecology, 84, 2335-2346.

Bolker, B.M. 2008. Ecological models and data in R. Princeton University Press, Princeton.

Downes, B.J., Baramuta, L.A., Fairweather, P.G., Faith, D.P., Keough, M.J., Lake, P.S., Mapstone, B.D., and Quinn, G.P. 2005. Monitoring ecological impacts: concepts and practice in flowing waters. Cambridge University Press.

Quinn, G.P. & Keough, M.J. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge.

Reid, D.J., Lake, P.S., Quinn, G.P. & Reich, P. 2008b. Association of reduced riparian vegetation cover in agricultural landscapes with coarse detritus dynamics in lowland streams. Marine and Freshwater Research, 59: 998-1014.

Sarr, D.A. 2002. Riparian livestock exclosure research in the western United States: A critique and some recommendations. Environmental Management, 30, 516-526.

www.delwp.vic.gov.au