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Changes in vegetation and geomorphological condition 10 years after riparian restoration

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Abstract:

Riparian restoration is an important objective for landscape managers seeking to redress the widespread degradation of riparian areas and the ecosystem services they provide. This study investigated the long-term outcomes of 'one-off' restoration activities undertaken in the Upper Murrumbidgee Catchment, NSW, Australia. The objective of the restoration was to protect and enhance riparian vegetation and control erosion, and consequently reduce sediment and nutrient delivery into the Murrumbidgee River. To evaluate the outcomes 10 years after restoration, rapid riparian vegetation and geomorphological assessments were undertaken at 29 sites spanning the four different restoration methods used (at least five replicates per treatment), as well as at nine comparable untreated sites. We also trialed the use of aerial imagery to compare width of riparian canopy vegetation and projective foliage cover prior to restoration with that observed after 10 years.

Aerial imagery demonstrated the width of riparian canopy vegetation and projective foliage cover increased in all restored sites, especially those with native plantings. The rapid assessment process indicated that 10 years after riparian restoration, the riparian vegetation was in a better condition at treated sites compared to untreated sites. Width of riparian canopy vegetation, native mid-storey cover, native canopy cover and seedling recruitment were significantly greater in treated sites compared to untreated sites. Geomorphological condition of treated sites was significantly better than untreated sites, demonstrating the importance of livestock exclusion to improve bank and channel condition.

Our findings illustrate the value of 'one-off' restoration activities in achieving long-term benefits for riparian health. We have demonstrated that rapid assessments of the vegetation and geomorphological condition can be undertaken post-hoc to determine the long-term outcomes, especially when supported with analysis of historical aerial imagery.

Keywords: Riparian restoration; water quality; vegetation; geomorphological condition assessment; long-term monitoring; aerial imagery

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1. Introduction

Riparian zones encompass the interface between aquatic and terrestrial ecosystems [1]. The vegetation in riparian zones is critical for river health, as it traps sediments, slows water movement and increases water infiltration and nutrient cycling [1, 2]. Riparian vegetation health in turn influences in-stream hydraulic processes [3], and larger scale fluvial and morphological river processes [4]. Globally, widespread modification of riparian vegetation has degraded many riparian zones [5] affecting geomorphological processes [6] and reducing their functional efficiency [7, 8].

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In many parts of Australia, agricultural land use has led to extensive modification and degradation of riparian vegetation [9]. Livestock are one of the main contributors of this degradation along with vegetation clearing. The direct effect of livestock in riparian zones are the erosion and compaction of river banks [10, 11], and changes to vegetation structure, composition and cover caused by grazing and trampling [12, 13]. The indirect effects include reduced soil permeability, increased surface run-off and sediment delivery to water courses, and reduced water quality and soil fertility [14, 15].

The increased recognition of the ecological value of riparian zones over the past 40 years, in combination with their declining condition, has resulted in widespread ecological restoration of these habitats [16, 17]. Much of this restoration is on private (agricultural) land and involves collaboration between landholders, land management agencies and volunteers, and is based on restoring or improving ecological function [18, 19]. These restoration actions can be considered as either active (e.g. planting and sowing seeds of native plants), or passive (e.g. promoting natural regeneration from the seedbank or surrounding remnant vegetation by excluding livestock) [16, 20]. The expected outcomes of such restoration activities include improved condition of the riparian zone, reduced sediment delivery and improvements to downstream water quality.

While riparian restoration has attracted significant public investment [21], monitoring and evaluation of restoration programs is generally rare, especially over the longer term (i.e. >5 years) [22-24], notable exceptions include Hale et al. [25] and Cavagnaro [26]. The lack of monitoring has resulted in limited information on the outcomes of restoration efforts [21], like the changes in the vegetation and river geomorphological condition [27] or the return on public investment [28]. A major contributor to this problem is a lack of dedicated funding for monitoring and the short-term funding cycle associated with restoration projects [19, 29] which preclude effective long-term monitoring and evaluation.

To help address this problem, we revisited a subset of sites previously restored by a third party, as part of a large-scale publicly funded riparian restoration project, to determine the long-term outcomes of restoration. Our aims were to determine if (1) independent evaluations could be made 10 years after restoration using rapid appraisal methods, given the constraints of the original program (i.e. it was never established as an experiment), (2) changes in the vegetation and geomorphological condition could be observed, and (3) we could develop additional methods to account for the constraints of the original design that also occur in many other similar projects (i.e. no baseline data and/or the absence of untreated sites for comparison). Subsequently we aimed to provide insights for restoration management based on our observations of one-off management actions to restore degraded riparian sites.

2. Materials and Methods

2.1 Study site

This study was undertaken in the Upper Murrumbidgee River Catchment (UMRC) in southern NSW and the ACT (Figure 1). Land-use across the catchment over the past 120 years has predominantly been livestock grazing [30]. Past land management practices (e.g. clearing of riparian vegetation for livestock, firewood and fencing) along with the introduction of non-native animals and plants, have degraded the riparian zones in many parts of the catchment [10, 30], increasing erosion rates, widening stream-channels, and contributing to poor water quality [31, 32].

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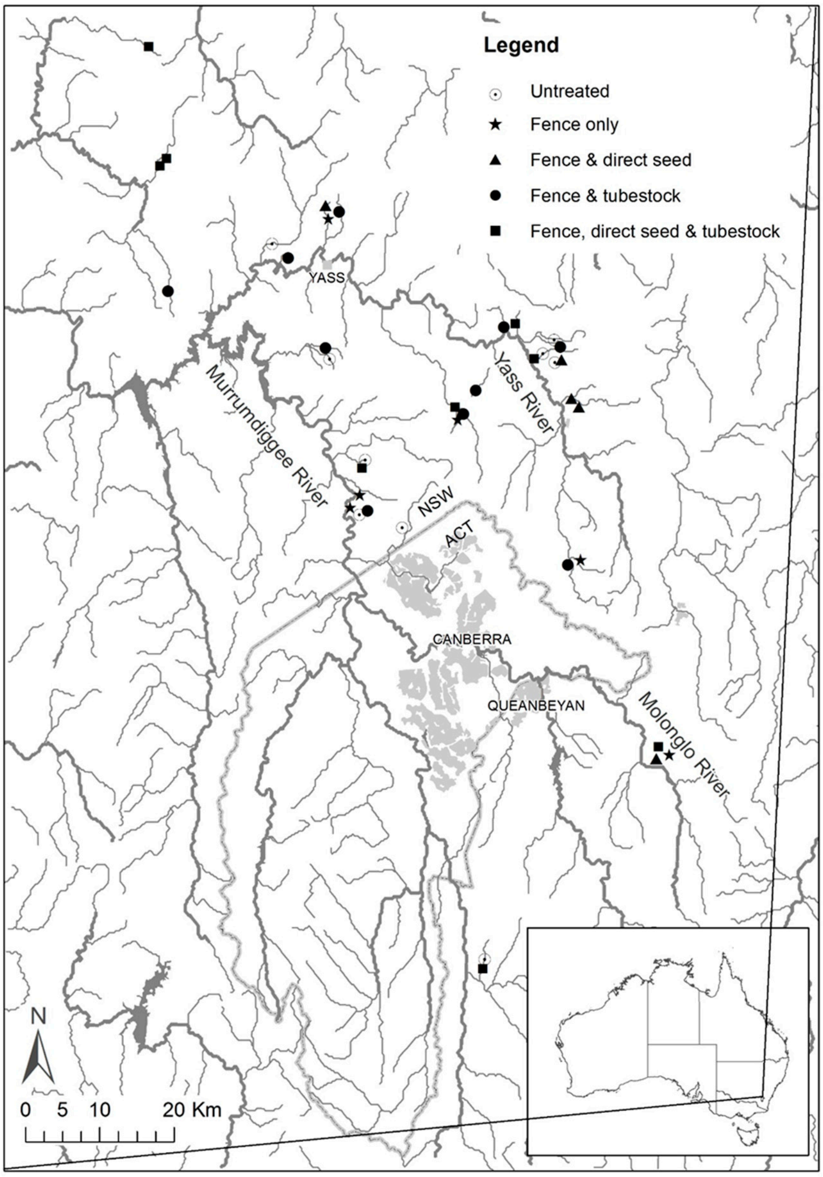

Figure 1. The location of the 29 restoration sites from the Bidgee Banks Restoration Program (BBRP) and 9 untreated sites in the Upper Murrumbidgee River Catchment. Sites are classified by restoration method.

2.2 Riparian restoration program

Between 2000 and 2004 a large scale publicly funded riparian restoration project (the Bidgee Banks Restoration Project: hereafter BBRP) was undertaken across the UMRC. The BBRP was a collaborative on-ground restoration partnership between the NSW Government, Greening Australia (a conservation Non-Government Organisation), and private landholders. The aim of the BBRP was to reverse vegetation loss and deteriorating water quality in the UMRC by protecting and rehabilitating degraded riparian areas [BBPSC 33]. An initial assessment identified 104 sites across the UMRC as potential sources of high sediment and nutrient loads because of poor riparian vegetation and active erosion, and thus these sites became the priorities for restoration in the BBRP [34].

Implementation of the BBRP involved a single restoration event using one of four restoration methods: (1) fence only; (2) fence and direct seed; (3) fence and tubestock (planting seedlings), and; (4) fence, direct seed and tubestock (Table 1). The 104 sites were assigned one of these four restoration methods based on an initial site evaluation. Thus, the restoration methods (i.e. treatments) applied

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during the BBRP were not randomly applied. While initial assessments considered the BBRP to be successful [29, 35], further evaluations were needed to determine the longer term outcomes.

Table 1. The number of sites revisited 10 years after they were treated under the Bidgee Banks Restoration Program (BBRP), the number of sites with remnant trees, and the restoration methods used. Untreated sites were added in 2014 (see text for details).

Restoration type	Restoration action undertaken	Number of sites examined	Number of sites with remnant trees
1. Fence Only	Fencing off sections of the riparian vegetation to exclude grazing and access to the river by livestock.	6	4
2. Fence and Direct Seed	Seeds of a range of native plant species endemic to the region were dispersed (seeded) over the site.	5	3
3. Fence and Tubestock	Seedlings of a range of native plants endemic to the region were planted.	10	8
4. Fence, Direct Seed and Tubestock	A combination of the other three methods.	8	4
5. Untreated sites	No restoration action taken.	9	5
	Total	**38**	

2.3 Evaluation 10 years post restoration

In May/April 2014, 10 years post restoration, 29 of the 104 BBRP restored sites were revisited to determine the current vegetation and geomorphological condition. We could only sample a subset of the original sites because permission to access some sites could not be obtained. Priority was given to ensuring that a representative sample of the four restoration methods (Table 1) and the original site distribution (Figure 1) was encompassed during the selection of the 29 sites. As the BBRP did not include baseline data, it was impossible to ensure the sites were representative of a range of initial vegetation condition. Thus, the fact that we sampled a pre-existing study and have incomplete information about the original site conditions (see above) needs to be considered when interpreting our evaluation of the outcomes.

Nine untreated sites from within the original BBRP area were added to the sampling in 2014 because untreated reference sites were not part of the BBRP. These untreated sites were selected to provide a proxy benchmark for degraded sites. Advice from the Greening Australia (capital region) BBRP manager was used to guide the selection of untreated sites to those of a similar character to sites which would have been targeted for restoration as part of BBRP. These untreated sites were selected based on the following criteria: (a) representative of the vegetation condition and type used in the BBRP with no evidence of prior restoration, (b) livestock could readily access the riparian zone, (c) the type of livestock encompassed the two main species farmed in the region (cattle (n=4 sites) and sheep (n=5 sites)), (d) there was evidence of active bank and gully erosion, and (e) the presence of remnant (n=5 sites) and no remnant vegetation (n=4 sites). While the authors attempted to select representative untreated sites, it is acknowledged that the condition of these sites may differ from the original condition of the treated sites prior to restoration.

2.4 Assessing vegetation condition

The condition of the riparian vegetation was evaluated using a combination of field assessments and aerial imagery. The **riparian vegetation condition** was assessed using the Rapid Appraisal of

Riparian Condition method (RARC: Jansen et al. [36]), which was initially developed as a tool to determine the impacts of grazing management practices on riparian condition in NSW [37] and has been used since to determine riparian vegetation condition [9, 38]. The RARC method uses indicators: (1) longitudinal continuity of riparian canopy vegetation, (2) proximity, (3) width of riparian canopy vegetation; (4) groundcover; (5) mid-storey cover; (6) canopy cover; (7) native groundcover; (8) native mid-storey cover; (9) native canopy cover; (10) leaf litter; (11) native leaf litter, (12) standing dead trees, (13) hollow-bearing trees; (14) coarse woody debris; (15) mid-storey species recruitment (i.e. seedling <1 m tall), (16) canopy species recruitment (i.e. seedling <1 m tall), and; (17) abundance of native tussock grasses and reeds, to provide an overall appraisal of the vegetation condition at a site, which collectively provides a RARC score (out of 50); with a heathy site having a score of 43 [37]. Data for RARC indicators longitudinal continuity and proximity were given single values for the whole site, while all other indicators were assessed along four transects positioned perpendicular to the channel and evenly spaced across the site following the methods established by Jansen et al. [36].

We used historical **aerial imagery** to retrospectively assess the sites to determine the baseline condition. We obtained two series of digital images of aerial photographs from the NSW Land and Property Information Department (2014) for each site (derived from GPS coordinates of the sites). The first series of images were taken prior to restoration (between 1996 and 2000), and the second corresponded to the 2014 field evaluations. Each site was located on the aerial photographs using distinguishing features like streamlines, trees and fence lines supported by field observations.

On each of the two sets of aerial site images (i) prior (baseline) and (ii) post restoration, the following two RARC indicators were recorded: (a) canopy cover for 26 sites encompassing the restoration methods (6 untreated, 4 fence only, 5 fence and direct seed, 5 fence and tubestock, and 6 fence, direct seed and tubestock), and (b) width of canopy vegetation for 16 sites encompassing the restoration methods (4 unrestored, 2 fence only, 3 fence and direct seed, 4 fence and tubestock, and 3 fence, direct seed and tubestock). Measurements for only these two RARC indicators could be readily extracted from the aerial images. Unfortunately, some sites could not be assessed because of the quality of the images or missing site coverage. Width of canopy vegetation was calculated using a digital ruler to calculate transect lengths. Canopy cover was calculated from the total projective foliage cover (using defined site boundaries) based on the tones of woody vegetation in each image using the image recognition software WinDIAS 3.2. Through this process we could determine the visible vegetation changes that occurred at each site.

2.5 Assessing geomorphological condition

Stream **geomorphological condition** was assessed using a modified version of the Ephemeral Stream Assessment method (ESA: Machiori et al. [39]), which estimates bank stability and attributes of erosion. Seven indicators were used: (1) vegetation on the drainage-line floor; (2) vegetation on the drainage-line walls; (3) particle size of materials available for erosion; (4) longitudinal morphology of the drainage-line; (5) nature of drainage-line materials; (6) shape and aspect ratio of the drainage-line cross-section, and; (7) lateral flow regulation, to provide an overall geomorphological condition assessment. The original ESA method incorporates an eighth indicator (the shape of the stream bordering flat land and/or slopes) which was not used here as restoration actions do not affect this indicator. Data for each of the seven indicators were collected every 25 m along the drainage line of each site using transects and following the methods established by Machiori et al. [39]. The maximum achievable ESA score is 1. The image quality of the aerial photos was not of sufficient resolution to assess the geomorphological condition, and thus comparisons between 2004 and 2014 could not be undertaken.

2.6 Data analysis

Normally distributed data were tested using a factorial analysis of variance (ANOVA). Where possible, non-normally distributed data were transformed to meet the assumptions of an ANOVA. Significant results were tested with a Tukey-Kramer multiple comparison test, to identify the source of significance at <0.05. A non-parametric Kruskel-Wallis analysis of variance was performed on

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RARC indicators: hollow bearing trees, coarse woody debris, mid-storey recruitment, and canopy species recruitment and the seven ESA indicators as these metrics have ordinal data. Error estimates represent one standard error (SE) from the mean.

3. Results

3.1 Riparian vegetation assessment

The mean riparian vegetation condition (RARC) score across all restored sites and restoration methods was significantly greater at 21.3 ± 1.3 10 years after restoration, compared to 12.4 ± 1.3 for untreated sites (F=4.24; *df*=4,33; p=<0.01: Figure 2). The different restoration methods led to different vegetation condition (Figure 2), with difference between the 12 individual indicators (Figure 3). While the combination of fence and tubestock planting resulted in (i) a higher overall vegetation condition, (ii) the two highest individual site scores (33.1 and 30.6), and (iii) the highest minimum site score (16.7) (Figure 2), no restoration method resulted in the highest scores across all 12 indicators (Figure 3). Five of the 12 individual RARC indicator scores were significantly higher in treated than untreated sites (Figure 3), being: width of riparian canopy vegetation (F=5.60; *df*=4,33; P=<0.01), canopy cover (F=4.40; *df*=4,33; P=<0.01), native mid-storey cover (F=3.00; *df*=4,33; P=0.03), native canopy cover (F=3.76; *df*=4,33; P=0.01) and mid-storey species recruitment ($\chi 2$=10.22; P=<0.04). RARC indicators canopy cover and width of riparian vegetation contributed strongly to the changes in the RARC condition score observed, with the width of riparian vegetation scores being the most correlated with the overall RARC score (R^2=0.629, *F* (1,36)=61.099, *P*=<0.001) and canopy cover the third most (R^2=0.586, *F* (1,36)=51.04, *P* =<0.001). There was no discernable difference between treated and untreated sites or between treatment types for the other seven RARC indicators (Figure 3).

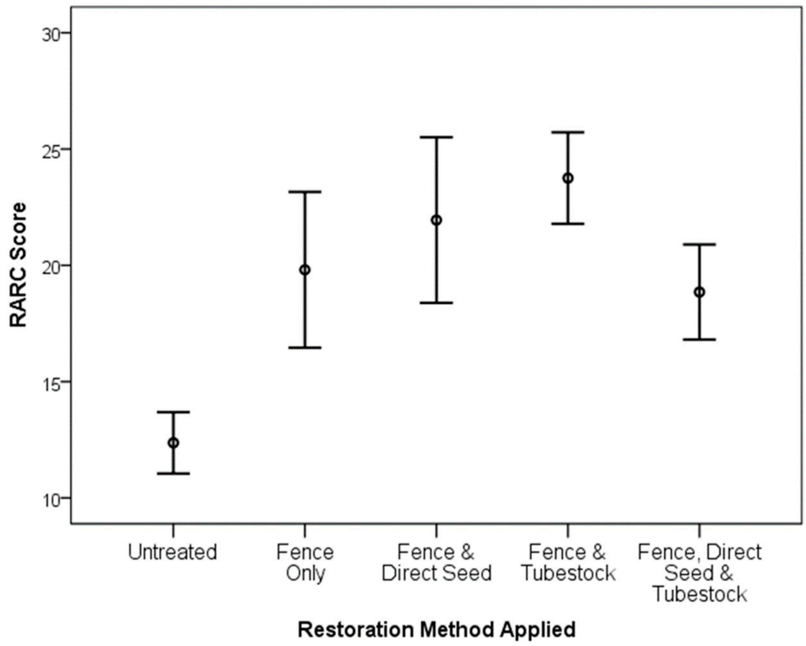

Figure 2. Mean riparian vegetation condition (RARC) scores for sites restored as part of the Bidgee Banks Restoration Project (BBRP) using four restoration methods (see Table 1). Untreated site scores are provided as a comparison. Error bars represent ± SE.

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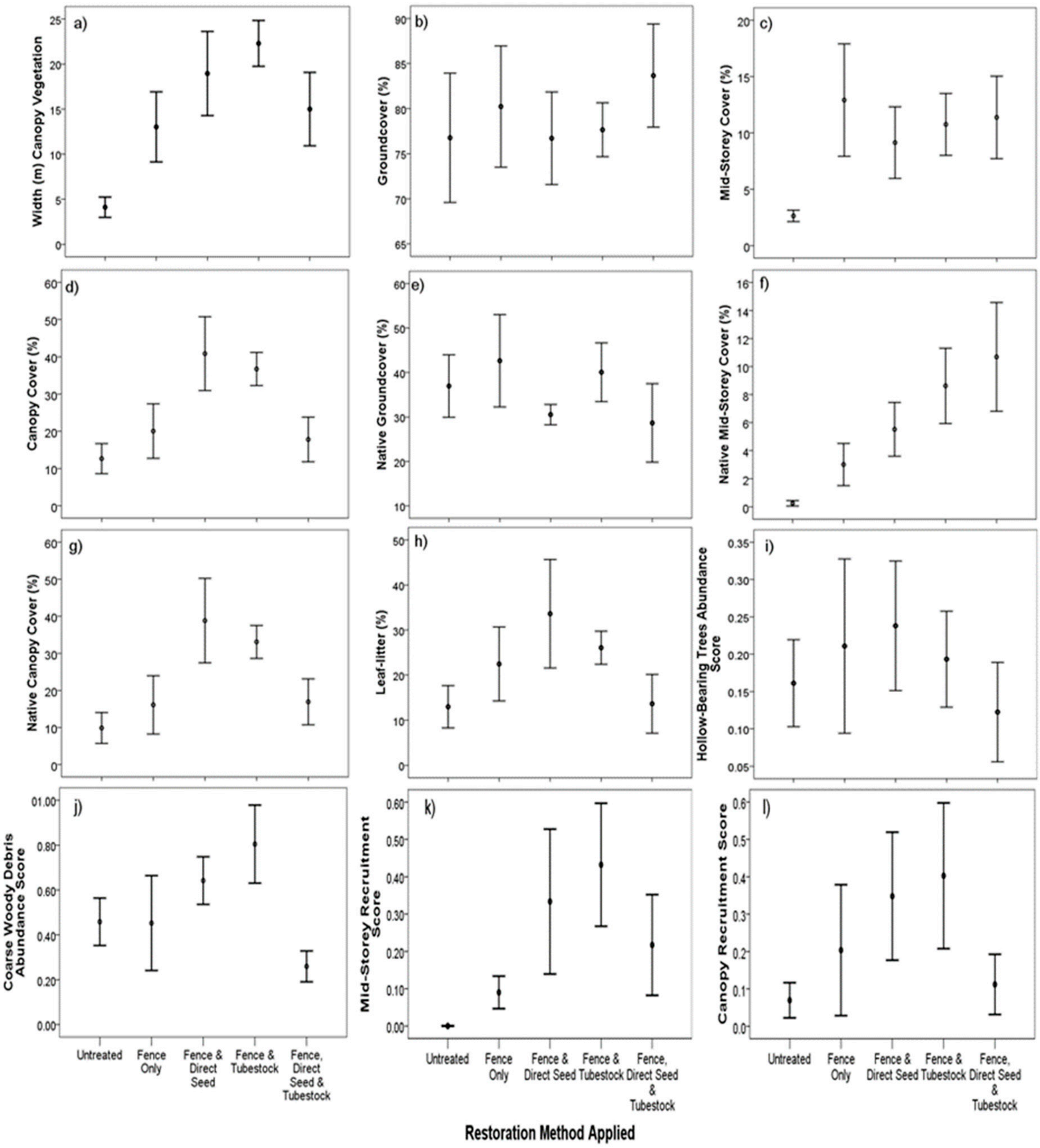

Figure 3. Mean scores for 12 indicators (a-l) within RARC for sites restored as part of the Bidgee Banks Restoration Project (BBRP) for each of four restoration methods (see text for details). Untreated reference site scores are provided for comparison. Error bars represent ± SE.

3.2 Before and after restoration from aerial imagery

There was an overall increase in the width of the riparian vegetation 10 years after restoration across all restoration methods (Figure 4); which on average doubled following restoration (Figure 4a). The greatest increase in the width of the riparian vegetation occurred at sites where fencing and direct seeding were used, and the lowest increase was for fence, direct seed and tubestock (Figure 4b). The untreated sites showed no apparent change in the width of riparian vegetation over the same 10-year period (Figure 4).

The mean projected foliage cover increased by almost 2-fold following restoration (Figure 5a). The increase was only observed where active restoration (tubestock planting and direct seeding) methods were used (Figure 5b). Projected foliage cover did not change in untreated sites over the

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same timeframe (Figure 5). With the exception of the fence only sites, the projected foliage cover prior to restoration was similar to that of the untreated sites (Figure 5b).

There was a strong positive correlation between the width of canopy vegetation measurement taken from the aerial photographs and field assessments (R^2=0.73, $F(1,10)$=27.66, P<0.001). There was also a positive correlation between the projective foliage cover measurement taken from aerial imagery and field assessment of the canopy cover measurement (R^2=0.45, $F(1,17)$=13.85, P=0.002), which was strengthened once field assessments of canopy cover and mid-story cover were combined (R^2=0.49, $F(1,17)$=15.99, P<0.001).

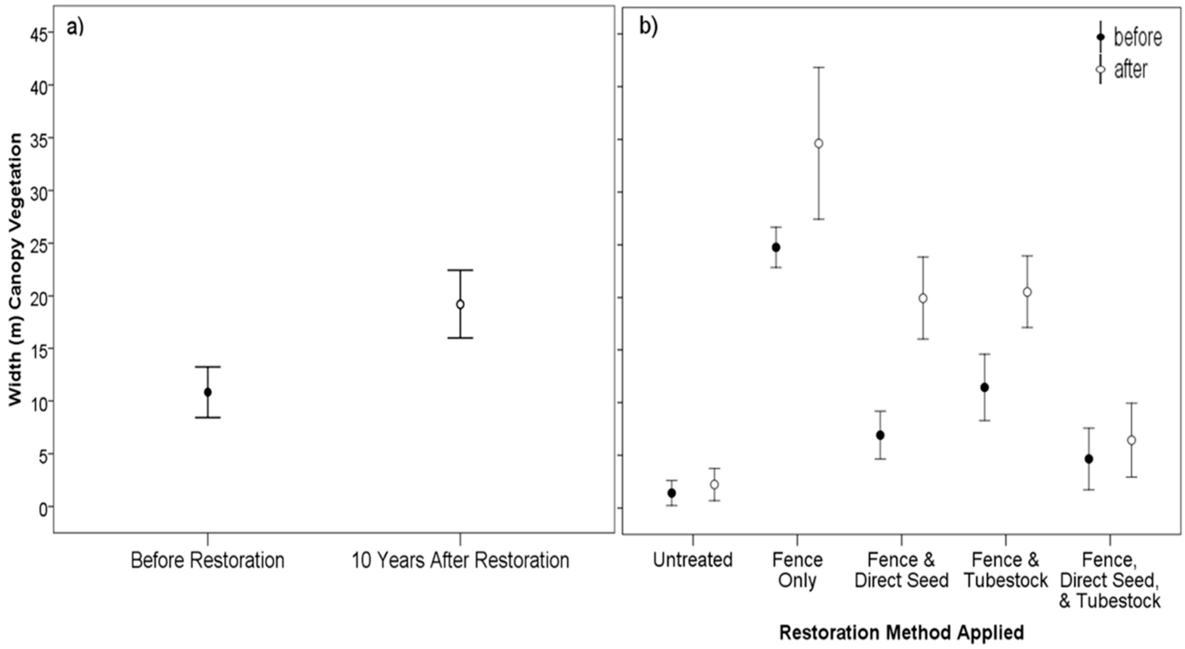

Figure 4. Change in width of canopy vegetation from aerial photographs of sites before restoration occurred and 10 years after. Width of canopy vegetation (a) across all treated sites and, (b) for untreated sites and sites restored using each of the four restoration methods (see text for details). Closed circles (●) = before restoration, and open circles (○) = approximately 10 years after restoration. Error bars represent ± SE.

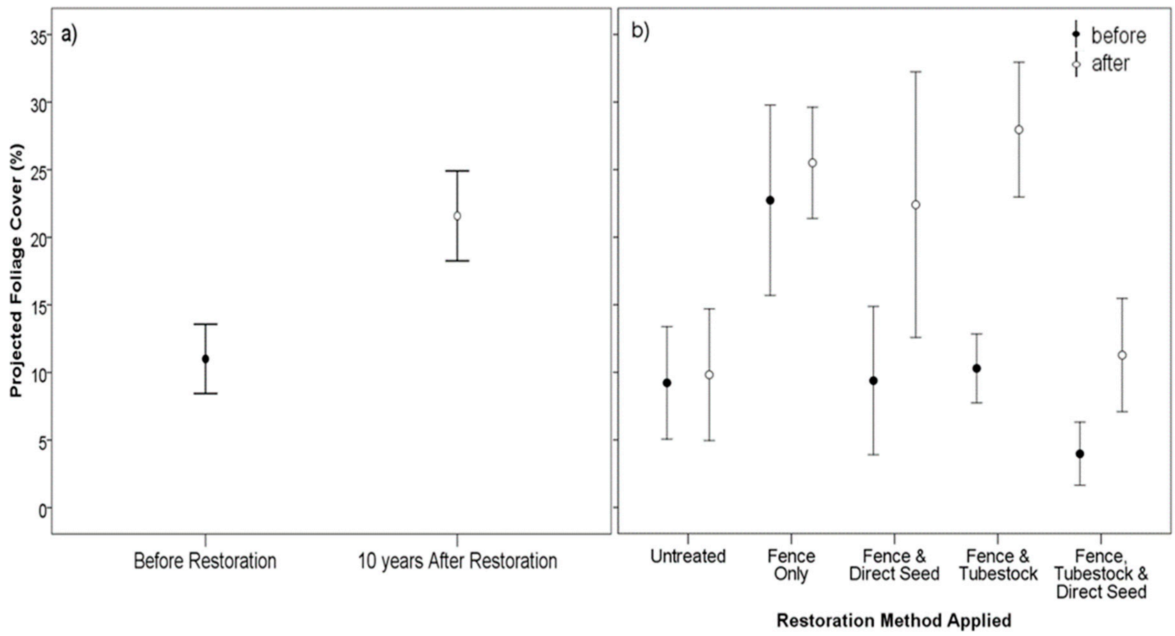

Figure 5. Changes in projective foliage cover from aerial photographs of sites before restoration occurred and 10 years after. Mean projected foliage cover (a) across all treated sites and, (b) for untreated sites and sites restored using each of the four different restoration methods (see text for details). Closed circles (●) = before restoration, and open circles (○) = approximately 10 years after restoration. Error bars represent ± SE.

3.3 Geomorphological Assessment

The mean ephemeral stream assessment (ESA) scores across all restoration methods were significantly higher at 0.69 ± 0.01, compared to 0.52 ± 0.03 for untreated sites (F = 8.45, *df* = 4,33, P = <0.00: Figure 6). While there was no significant difference between restoration methods (Figure 6), differences were observed between the seven individual ESA indicators (Figure 7). Five of which were significantly higher for the treated sites than for untreated sites: vegetation on the drainage-line floor ($\chi 2$=6.18; P= 0.012: Figure 7a), vegetation on the drainage-line wall ($\chi 2$=8.46; P= 0.004: Figure 7b), nature of drainage-line material score ($\chi 2$=9.15; P= 0.002: Figure 7e), the shape of cross section ($\chi 2$=13.27; P=<0.001: Figure 7f), and lateral flow regulation ($\chi 2$=18.46; P=<0.001: Figure 7g).

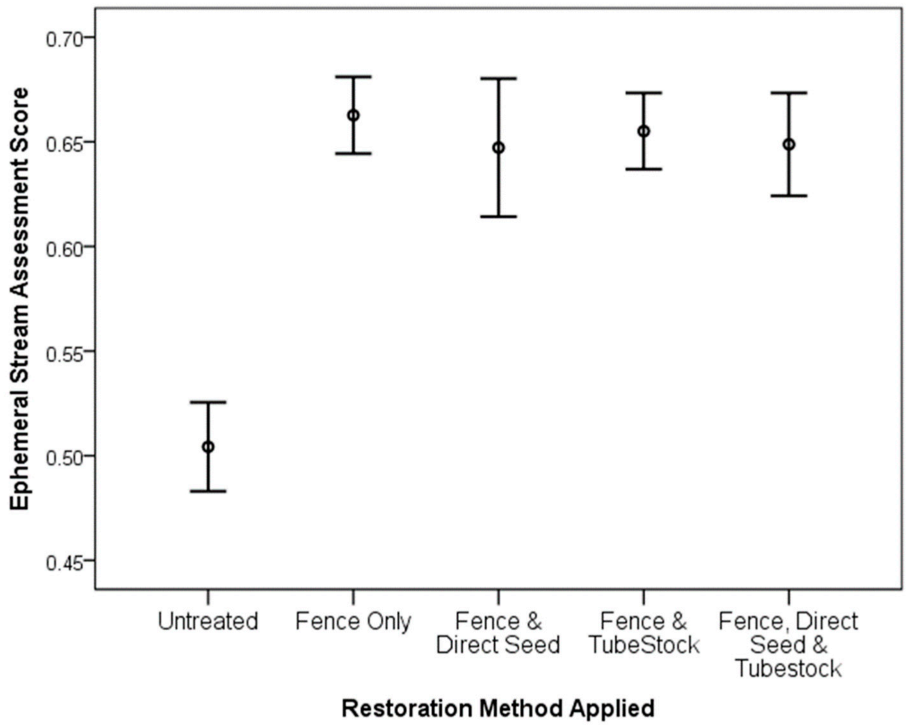

Figure 6. The mean ephemeral stream assessment (ESA) condition scores for sites restored as part of the Bidgee Banks Restoration Project (BBRP) using four restoration methods (see text for details). Untreated site scores are provided as a comparison. Error bars represent ± SE. The maximum achievable ESA score is 1.

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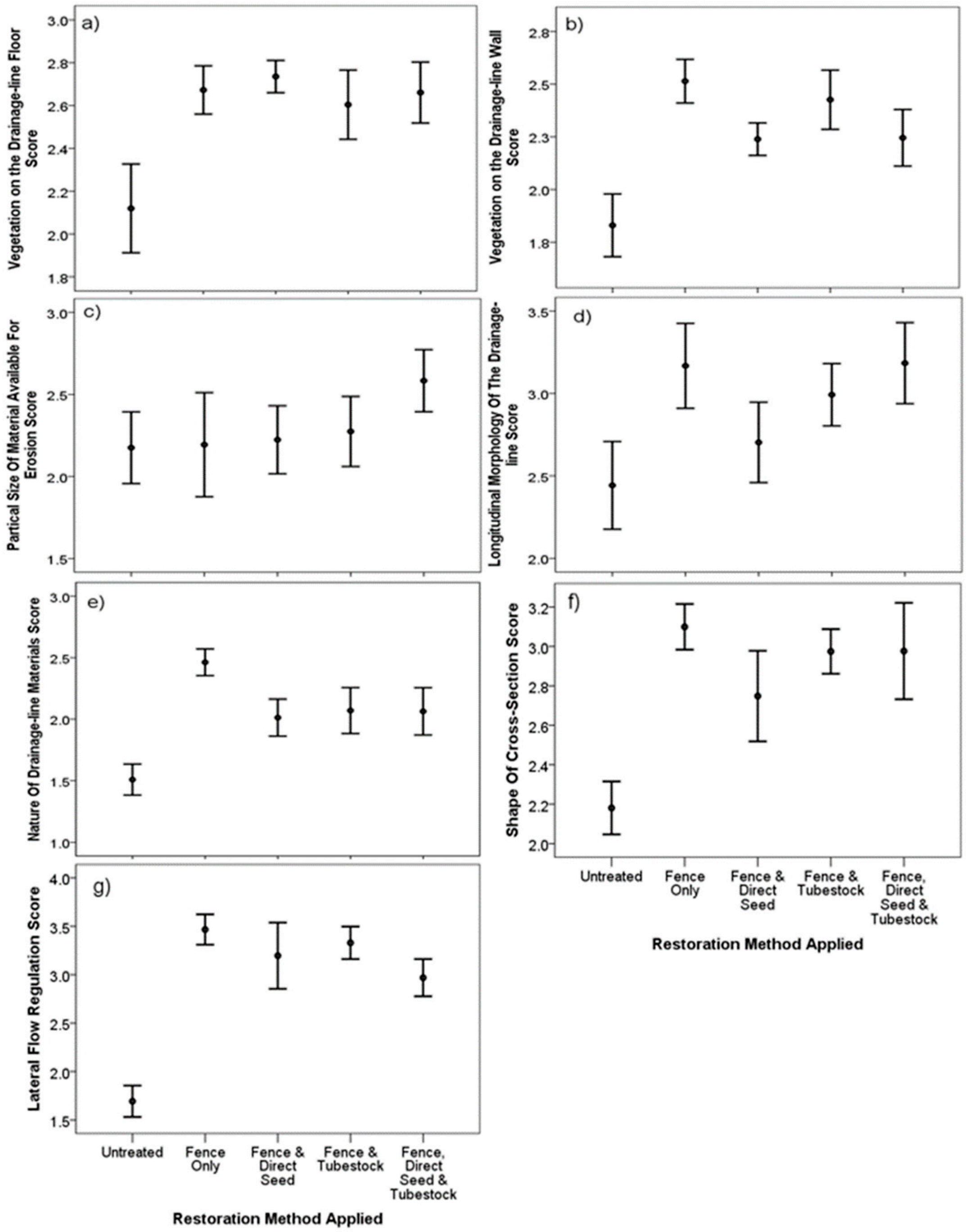

Figure 7. Mean scores for the seven indicators within ESA for sites restored as part of the Bidgee Banks Restoration Project (BBRP) for each of four restoration methods (see text for details). Untreated site scores are provided as a comparison. Error bars represent ± SE.

4. Discussion

Despite the restoration of riparian zones being a major component of river management [21], there has been limited long-term evaluations of the outcomes of such actions, especially involving multiple sites and comparisons across restoration methods [40]. While implementing appropriate monitoring for current restoration programs can address these issues in the future, understanding the legacy of past restoration programs is needed. The retrospective assessments of the BBRP we undertook using rapid appraisal methods, successfully illustrated the changes that occurred at these sites, especially when combined with (a) assessments from untreated sites, and (b) reconstruction and assessment of the baseline from aerial imagery of the restored sites prior to restoration. This study

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shows that these approaches can successfully be used to retrospectively assess prior restoration programs.

Sites restored as part of the BBRP have better riparian vegetation and geomorphological condition compared to the untreated sites. Analysis of aerial imagery before and 10 years after restoration demonstrated improvements in projective foliage cover and an increase in the width of riparian vegetation at treated sites while no change has occurred at untreated sites. The BBRP appears to be tracking towards meeting its objectives of reversing vegetation loss. We were unable to evaluate the outcomes of the restoration for instream sediment and nutrient loads because site scale water quality data were not available, but it is likely that the removal of livestock and the observed improvements in riparian vegetation condition have increased the ability of the riparian zone to filter and process nutrients [see 25, 26]. The site scale improvements in riparian vegetation and geomorphological condition observed in this study are likely to reduce sediment and nutrient loads in the rivers of the UMRC. Thus, the assumption that improvements in riparian vegetation and geomorphological condition would lead to reduced sediment and nutrient loads in the rivers of the UMRC [34] was well founded.

The presence of livestock can significantly degrade riparian vegetation [10, 11]. The removal of livestock from the riparian zone in the BBRP was observed to improve vegetation condition, a result observed elsewhere; for example Spooner and Briggs [41] found significantly more seedlings and shrub cover in fenced than unfenced areas and attributed this to an absence of herbivores. Seedling recruitment and mid-storey cover were much higher in treated sites (including fence only sites) compared to the untreated sites in this study. Given the degraded nature of many riparian zones, the planting of native seedlings is commonly used in restoration [20, 40] to restore seed reserves and accelerate recovery [42], and is often combined with passive restoration [29]. The combination of passive (i.e. livestock exclusion using fencing) and active restoration (planting of native plants) led to greater improvements in riparian and geomorphological conditions after 10 years compared to passive restoration (fence only).

Given the restoration methods applied at each BBRP site were determined by a prior site assessment (see Starr 2000), it is not surprising that our results showed that passive restoration alone was a successful restoration method as these sites had the highest projected foliage cover and width of canopy vegetation prior to restoration of all restoration methods. Variability in outcomes of active restoration may be attributed to the level of site degradation prior to restoration, as active restoration was applied to more degraded sites. The outcomes observed from combining active and passive restoration at degraded sites illustrates how targeting the method to the site can accelerate recovery. The outcomes of direct seeding of natives was more variable than planting seedlings, and in many instances the combination of these two approaches resulted in a worse outcome than either approach individually. One possible explanation is that sites in very poor condition received the combined restoration method (i.e. both tubestock planting and direct seeding) based on prior evaluation (Starr 2000), and despite such efforts these highly degraded sites may require additional restoration in both time (i.e. more than a ‘one-off’ event) and resources (i.e. additional plantings).

While we showed that treated sites had a better riparian vegetation condition score 10 years after restoration compared to untreated sites, the scores recorded were still less than half that of healthy sites (i.e. a RARC score of 43 [37]). The 10 year timeframe appears sufficient for changes in indicators such as width of riparian canopy vegetation and canopy cover to occur, [similar to that found by 25, after a similar timeframe]. The timeframe however maybe insufficient to result in measurable changes in leaf litter, hollow bearing trees and coarse woody debris which reflect the presence of mature vegetation [43]. Mature trees contribute litter, hollows and woody debris to riparian zones and their replacement is important for ecological restoration and it has been suggested that indicators for litter, hollows and woody debris could take between 50 and 100 years to reach ‘healthy levels’ [10, 44].

There was a significant difference in geomorphological condition between treated and untreated sites. The exclusion of livestock through fencing appears to be a major contributor to geomorphological condition [as observed elsewhere 6, 26, 45] as sites in all restoration treatments demonstrated a better geomorphological condition (regardless of the inclusion of tubestock or direct

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seed) than untreated sites. This was especially evident for the shape of cross-section of the bank (i.e. a measure of bank stability).

Groundcover species are needed to reduce erosion and improve downstream water quality [46] and the ESA metrics vegetation on the drainage-line floor and wall scores were much higher at treated than untreated sites. The presence of mature vegetation also contributes to the geomorphological condition of the riparian zone by maintaining bank stability [47] and increasing inputs of organic matter and debris. Many of the BBRP sites restored with passive restoration (i.e. fence only) contained higher levels of remnant vegetation before restoration occurred (i.e. higher canopy cover and width of riparian canopy vegetation). This different starting point was still evident 10 years after restoration with higher scores for vegetation on the drainage-line wall, nature of drainage-line materials, and shape of cross section of the bank at sites treated with fence only compared to sites treated with active restoration. As discussed above the absence of mature remnant vegetation may limit future improvements in restoration outcomes in the short- to medium-term (i.e. until they can be re-established on site). Thus, highly degraded sites (i.e. with no or limited remnant vegetation) may experience substantial lags in achieving a healthy site assessment following restoration.

The results from our untreated sites illustrated the current poor condition of both the riparian vegetation and geomorphology in the presence of livestock, similar to elsewhere [10, 37]. Given the RARC and ESA scores observed, these untreated sites are unlikely to provide the 'normal' riparian ecosystem functions of sediment trapping, nutrient cycling and flood mitigation [2, 8]. Moreover, the presence of such sites across the Catchment shows that despite restoration actions and some successes as outlined here after 10 years, improvements to the riparian zones of the Murrumbidgee River and Catchment requires additional resources and effort.

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

One of the common challenges for evaluating long term outcomes from restoration programs is a lack of pre-assessment data [40]. While such challenges can lead to inaction associated with undertaking long-term evaluations, our results show that alternatives can be found. Successful retrospective evaluations for vegetation using historical aerial imagery (especially when combined with image analysis software) can overcome such data shortfalls (including a lack of control sites). The changes in canopy cover and width of riparian vegetation we observed were sufficient to aid management decisions and provide evaluations of programs in the absence of other assessments. Theoretically, aerial imagery could also be used to assess channel bank erosion using orthophotos and the increasing quality and availability of satellite imagery will provide better options for future evaluations.

The improvements in riparian and geomorphological condition at sites restored as part of the BBRP is encouraging and is testament to the hard work and planning undertaken by the project managers and on-going maintenance by the landholders, as well as the investment of public funds. A 'healthy' riparian site may be an unrealistic 10-year target when restoring degraded sites depending on the starting condition. However, our results show that 10 years after restoration, the restoration sites are on an improving trajectory, and that successful riparian restoration is being achieved using a range of approaches tailored to site conditions.

Author Contributions: For research articles with several authors, a short paragraph specifying their the individual contributions of each author are as follows: conceptualization of the project (William Higgisson, Paul Downey and Fiona Dyer).; methodology (William Higgisson).; software (William Higgisson).; validation (William Higgisson, Paul Downey and Fiona Dyer).; formal analysis (William Higgisson); investigation (William Higgisson); resources (William Higgisson, Paul Downey and Fiona Dyer); data curation (William Higgisson).;

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References

1. Naiman, R. J.; Decamps, H., The ecology of interfaces: riparian zones. *Annual review of Ecology and Systematics* **1997,** *28*, 621-658.
2. Ewel, K. C.; Cressa, C.; Kneib, R. T.; Lake, P.; Levin, L. A.; Palmer, M. A.; Snelgrove, P.; Wall, D. H., Managing critical transition zones. *Ecosystems* **2001,** *4* (5), 452-460.
3. Tabacchi, E.; Lambs, L.; Guilloy, H.; Planty-Tabacchi, A.-M.; Muller, E.; Decamps, H., Impacts of riparian vegetation on hydrological processes. *Hydrological processes* **2000,** *14* (16-17), 2959-2976.
4. Hickin, E. J., Vegetation and river channel dynamics. *The Canadian Geographer/Le Géographe canadien* **1984,** *28* (2), 111-126.
5. Brinson, M. M.; Malvárez, A. I., Temperate freshwater wetlands: types, status, and threats. *Environmental Conservation* **2002,** *29* (02), 115-133.
6. Burger, B.; Reich, P.; Cavagnaro, T., Trajectories of change: riparian vegetation and soil conditions following livestock removal and replanting. *Austral Ecology* **2010,** *35* (8), 980-987.
7. Buckley, C.; Hynes, S.; Mechan, S., Supply of an ecosystem service—Farmers' willingness to adopt riparian buffer zones in agricultural catchments. *Environmental Science and Policy* **2012,** *24*, 101-109.
8. Likens, G. E.; Bormann, F. H.; Johnson, N. M.; Fisher, D.; Pierce, R. S., Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological monographs* **1970,** *40* (1), 23-47.
9. Jansen, A.; Askey-Doran, M.; Pettit, N.; Price, P., Impacts of land management practices on riparian land. *Chapter* **2007,** *9*, 159-174.
10. Robertson, A.; Rowling, R., Effects of livestock on riparian zone vegetation in an Australian dryland river. *Regulated Rivers: Research and Management* **2000,** *16* (5), 527-541.
11. Trimble, S. W.; Mendel, A. C., The cow as a geomorphic agent—a critical review. *Geomorphology* **1995,** *13* (1), 233-253.
12. Crosslé, K.; Brock, M. A., How do water regime and clipping influence wetland plant establishment from seed banks and subsequent reproduction? *Aquatic Botany* **2002,** *74* (1), 43-56.
13. Armour, C.; Duff, D.; Elmore, W., The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* **1991,** *16* (1), 7-11.
14. Sovell, L. A.; Vondracek, B.; Frost, J. A.; Mumford, K. G., Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristicsof southeastern Minnesota, USA, streams. *Environmental Management* **2000,** *26* (6), 629-641.
15. Belsky, A. J.; Matzke, A.; Uselman, S., Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation* **1999,** *54* (1), 419-431.
16. Brooks, S. S.; Lake, P. S., River restoration in Victoria, Australia: change is in the wind, and none too soon. *Restoration Ecology* **2007,** *15* (3), 584-591.

17. Goodwin, C. N.; Hawkins, C. P.; Kershner, J. L., Riparian restoration in the western United States: overview and perspective. *Restoration Ecology* **1997,** *5* (4S), 4-14.

18. Hobbs, R. J.; Norton, D. A., Towards a conceptual framework for restoration ecology. *Restoration ecology* **1996,** *4* (2), 93-110.

19. Williams, L.; Hale, R.; Cavagnaro, T.; Reich, P.; Lake, P. S., Developing a vision for improved monitoring and reporting of riparian restoration projects. *Ecological Management & Restoration* **2011,** *12* (1), 11-16.

20. González, E.; Sher, A. A.; Tabacchi, E.; Masip, A.; Poulin, M., Restoration of riparian vegetation: a global review of implementation and evaluation approaches in the international, peer-reviewed literature. *Journal of Environmental Management* **2015,** *158*, 85-94.

21. Bernhardt, E. S.; Palmer, M.; Allan, J.; Alexander, G.; Barnas, K.; Brooks, S.; Carr, J.; Clayton, S.; Dahm, C.; Follstad-Shah, J., Synthesizing US river restoration efforts. *Science* **2005,** *308* (5722), 636-637.

22. Kondolf, G. M., Lessons learned from river restoration projects in California. *Aquatic Conservation: marine and freshwater ecosystems* **1998,** *8* (1), 39-52.

23. Morandi, B.; Piégay, H.; Lamouroux, N.; Vaudor, L., How is success or failure in river restoration projects evaluated? Feedback from French restoration projects. *Journal of Environmental Management* **2014,** *137*, 178-188.

24. Wohl, E.; Angermeier, P. L.; Bledsoe, B.; Kondolf, G. M.; MacDonnell, L.; Merritt, D. M.; Palmer, M. A.; Poff, N. L.; Tarboton, D., River restoration. *Water Resources Research* **2005,** *41* (10).

25. Hale, R.; Reich, P.; Daniel, T.; Lake, P. S.; Cavagnaro, T. R., Assessing changes in structural vegetation and soil properties following riparian restoration. *Agriculture, ecosystems & environment* **2018,** *252*, 22-29.

26. Cavagnaro, T., Life at the interface: above-and below-ground responses of a grazed pasture soil to reforestation. *Applied soil ecology* **2016,** *100*, 27-37.

27. Williams, J.; Hook, R. A.; Gascoigne, H. L., *Farming action: Catchment reaction The effect of dryland farming on the natural environment*. CSIRO Publishing: Melbourne, 1998.

28. Breckwoldt, A. R., Wildlife in the home paddock: nature conservation for Australian farmers. *Robertson; Sydney, Australia* **1983**.

29. Gould, L. In *Key ingredients for the successful implementation of riparian rehabilitation programs*, 5th Australian Stream Management Conference, Charles Sturt University, Thurgoona, New South Wales., Charles Sturt University, Thurgoona, New South Wales., 2007.

30. Starr, B.; Caitcheon, G. G.; Wasson, R. J., *Soil Erosion, Phosphorus and dryland salinity in the Upper Murrumbidgee: past change & current findings*. Murrumbidgee Catchment Management Committee: Canberra, 1999.

31. Olley, J. M.; Wasson, R. J., Changes in the flux of sediment in the Upper Murrumbidgee catchment, Southeastern Australia, since European settlement. *Hydrological processes* **2003,** *17* (16), 3307-3320.

32. Wallbrink, P.; Olley, J.; Murray, A.; Olive, L., The contribution of subsoil to sediment yield in the Murrumbidgee River basin, New South Wales, Australia. *Hydrological Sciences* **1996,** *236*, 347-356.

33. Bidgee Banks Project Steering Committee, Charting a Course for River Restoration. A Summary of Achievements, Problems, Solutions and Lessons Learnt from a Landmark Devolved Grant Project, Bidgee Banks, Canberra. **2003**.

34. Starr, B. *Budgeting for Bidgee Banks: A report prepared for and on behalf of Greening Australia*; Canberra, 2000.

35. Patmore, S.; Davey, A., Bidgee Banks Monitoring and Evaluation in the Upper Catchment. Report to Greening Australia ACT & SE NSW and the Bidgee Banks Project Steering Committee. University of Canberra: Canberra, 2004.

Peer-reviewed version available at *Water* **2019**, *11*, 1252; doi:10.3390/w11061252

36. Jansen, A.; Robertson, A.; Thompson, L.; Wilson, A., Development and application of a method for the rapid appraisal of riparian condition. *Riparian Land Management Technical Guideline* **2004,** *4*, 1-14.
37. Jansen, A.; Robertson, A. I., Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of applied ecology* **2001,** *38* (1), 63-75.
38. Johnston, L.; Skinner, S.; Ishiyama, L.; Sharp, S., Survey of vegetation and habitat in key riparian zones: Murrumbidgee River, ACT. *Department of Territory and Municipal Services, Canberra* **2009**.
39. Machiori, K.; Tongway, D.; Loch, R., A Geomorphic System for Gully Assessment. . *Landloch Pty Ltd, Darling Heights and CSIRO Sustainable Ecosystems, Canberra.* **2003**.
40. Bernhardt, E. S.; Sudduth, E. B.; Palmer, M. A.; Allan, J. D.; Meyer, J. L.; Alexander, G.; Follastad-Shah, J.; Hassett, B.; Jenkinson, R.; Lave, R., Restoring rivers one reach at a time: results from a survey of US river restoration practitioners. *Restoration Ecology* **2007,** *15* (3), 482-493.
41. Spooner, P. G.; Briggs, S. V., Woodlands on farms in southern New South Wales: A longer-term assessment of vegetation changes after fencing. *Ecological Management and Restoration* **2008,** *9* (1), 33-41.
42. Holl, K. D.; Aide, T. M., When and where to actively restore ecosystems? *Forest Ecology and Management* **2011,** *261* (10), 1558-1563.
43. Gibbons, P.; Lindenmayer, D., *Tree hollows and wildlife conservation in Australia*. CSIRO publishing: 2002.
44. Manning, A. D.; Cunningham, R. B.; Lindenmayer, D. B., Bringing forward the benefits of coarse woody debris in ecosystem recovery under different levels of grazing and vegetation density. *Biological conservation* **2013,** *157*, 204-214.
45. Anbumozhi, V.; Radhakrishnan, J.; Yamaji, E., Impact of riparian buffer zones on water quality and associated management considerations. *Ecological Engineering* **2005,** *24* (5), 517-523.
46. Muñoz-Robles, C.; Reid, N.; Frazier, P.; Tighe, M.; Briggs, S. V.; Wilson, B., Factors related to gully erosion in woody encroachment in south-eastern Australia. *Catena* **2010,** *83* (2), 148-157.
47. Abernethy, B.; Rutherfurd, I. D., The effect of riparian tree roots on the mass-stability of riverbanks. *Earth Surface Processes and Landforms* **2000,** *25* (9), 921-937.