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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

## 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].

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 presence of livestock can significantly degrade riparian vegetation [10,11]. The direct effects 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 New South Wales (NSW) and the Australian Capital Territory (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].

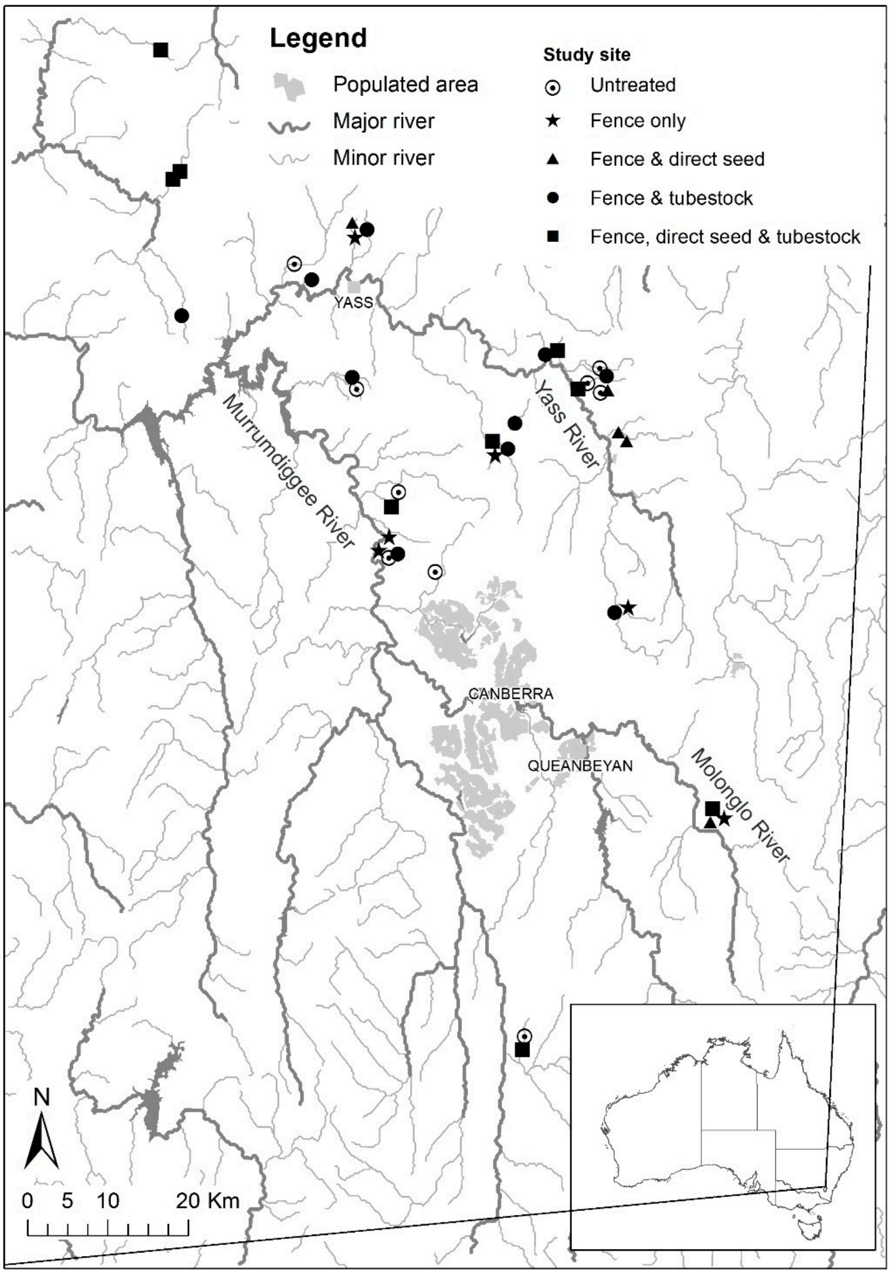


**Figure 1.** The location of the 29 restoration sites from the Bidgee Banks Restoration Program (BBRP) and nine untreated sites in the Upper Murrumbidgee River Catchment. Sites are classified by restoration method.

### *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 [33]. An initial assessment identified 104 sites across the UMRC as potential sources of high sediment and nutrient loads due to 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 ('one-off') 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 the four restoration methods based on an initial site evaluation. Sites devoid of vegetation were fenced and planted and/or direct seeded while sites with remnant vegetation were often only fenced. Thus, the restoration methods (i.e., treatments) applied during the BBRP were not randomly applied. While initial assessments considered the BBRP to be successful, based on the strong community–government partnership and high seedling survival in spite of severe drought conditions during and following project implementation [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.

| Restoration Type | Restoration Action Undertaken | Number of Sites Examined | Number of Sites with Remnant Trees |
|---|---|---|---|
| 1. Fence Only | Fencing 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 in combination with fencing to exclude livestock. | 5 | 3 |
| 3. Fence and Tubestock | Seedlings of a range of native plants endemic to the region were planted in combination with fencing to exclude livestock. | 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** | **24** |

### *2.3. Evaluation 10 Years Post Restoration*

In April/May 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. Whilst this resulted in some clustering of sites, they were at least 1000 m apart. As the BBRP did not include baseline data, it was impossible to ensure the sites were representative of the range of initial conditions. 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/absence of remnant vegetation (Table 1). 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 analysis of aerial photographs. 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 is a field assessment which uses indicators: (1) longitudinal continuity of riparian canopy vegetation; (2) proximity to nearest patch of intact native vegetation; (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. These indicators 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. Aerial photographs have previously been used to assess changes in riparian vegetation before and after a management action within riparian areas [39]. We obtained two series of digital 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 these two sets of aerial site images (i.e. (1) prior (baseline 1996-2000) and (2) post restoration (2014)), two RARC indicators were recorded: (a) canopy cover for 26 sites encompassing the following 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 following restoration methods - 4 unrestored, 2 fence only, 3 fence and direct seed, 4 fence and tubestock, and 3 fence, direct seed and tubestock. The 16 sites outlined in (b) were a sub-set of the 26 sites in (a). 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. WinDIAS 3.2 is an image analysis software program which measures leaf area. Through this process, we could determine the visible vegetation changes that occurred at each site. Aerial imagery has been previously used to measure canopy cover and width of riparian canopy vegetation [40].

### *2.5. Assessing Geomorphological Condition*

Stream geomorphological condition was assessed using a modified version of the Ephemeral Stream Assessment method (ESA: Machiori et al. [41]), which is a field assessment method used to estimate 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. [41]. 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 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 ± 1.3SE 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 differences 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 (restoration) types for the other seven RARC indicators (Figure 3).

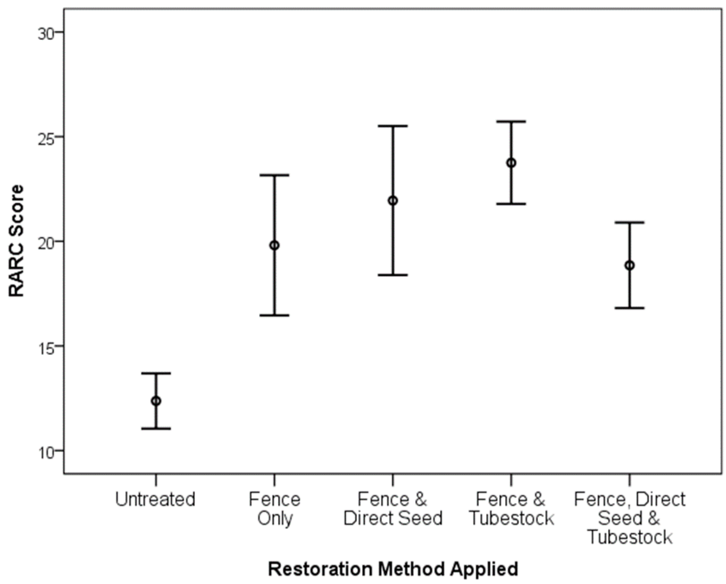


**Figure 2.** Mean riparian vegetation condition (RARC) scores 10 years after restoration for sites restored as part of the Bidgee Banks Restoration Project (BBRP) using four restoration methods (see Table 1). Untreated site scores are provided as a comparison. Error bars represent ± SE. A heathy site RARC score is 43.

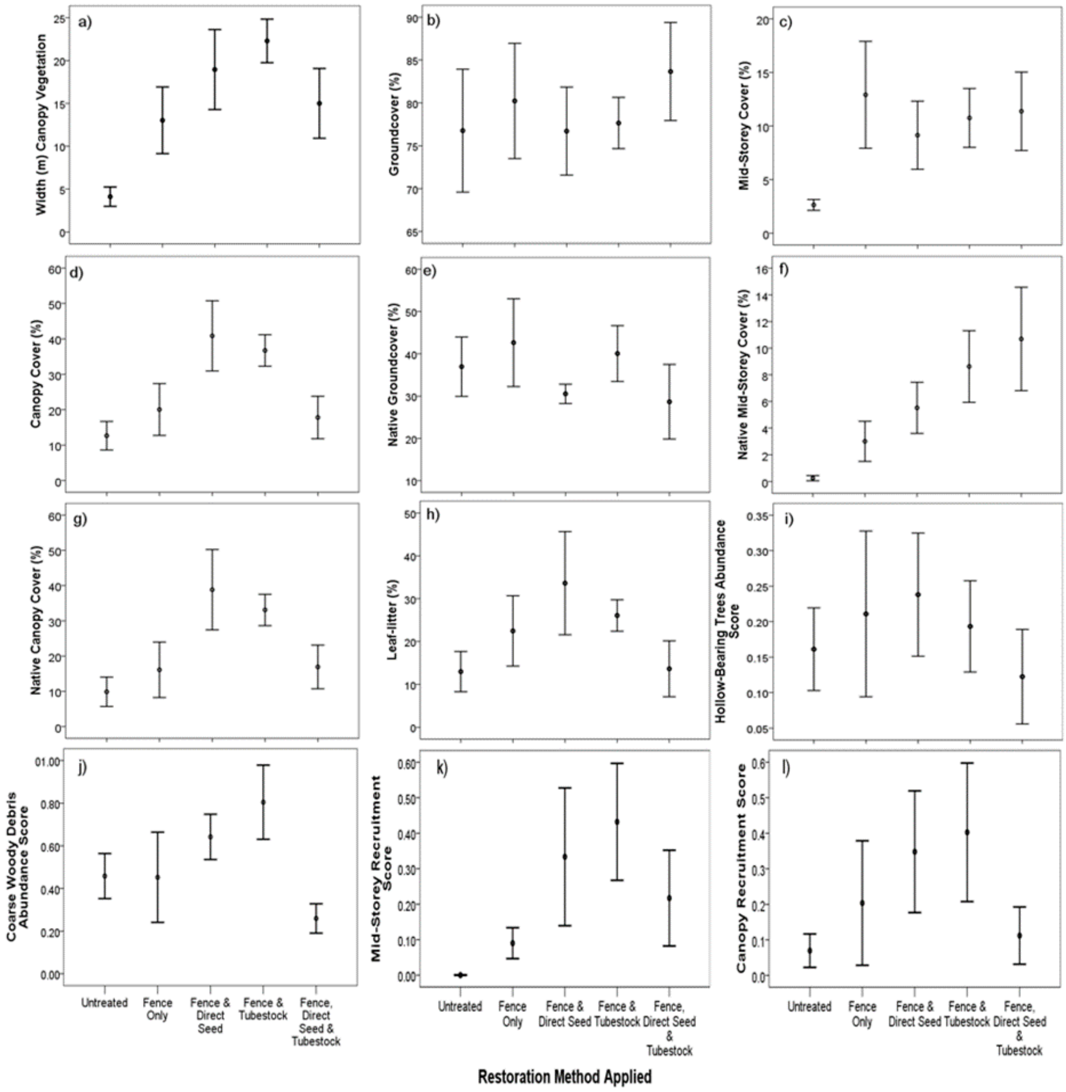


**Figure 3.** Mean scores for 12 indicators (**a**–**l**) within RARC 10 years after restoration for sites restored as part of the Bidgee Banks Restoration Project (BBRP) for each of four restoration methods. Untreated reference site scores are provided for comparison. Error bars represent ± SE. The y-axis varies between plots.

### 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 4b).

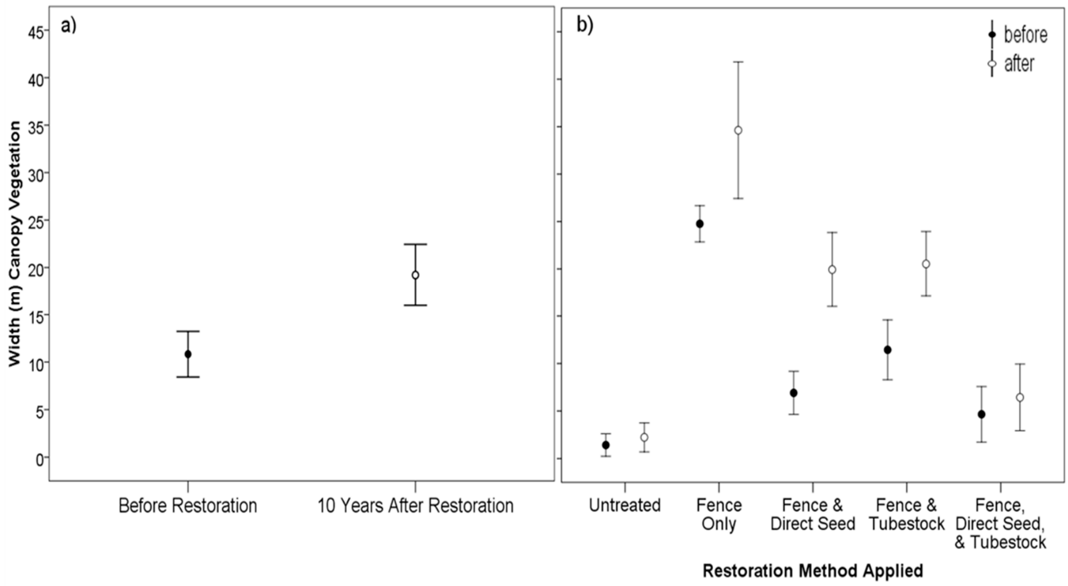


**Figure 4.** Change in width of canopy vegetation from aerial photographs of sites before restoration occurred and 10 years after. Width of canopy vegetation (**a**) across all treated sites and, (**b**) for untreated sites and sites restored using each of the four restoration methods. Closed circles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

The mean projected foliage cover almost doubled following restoration (Figure 5a). The increase was observed to a greater extent where active restoration (tubestock planting and direct seeding) methods were used (Figure 5b). Projected foliage cover did not change in untreated sites over the same timeframe (Figure 5b).

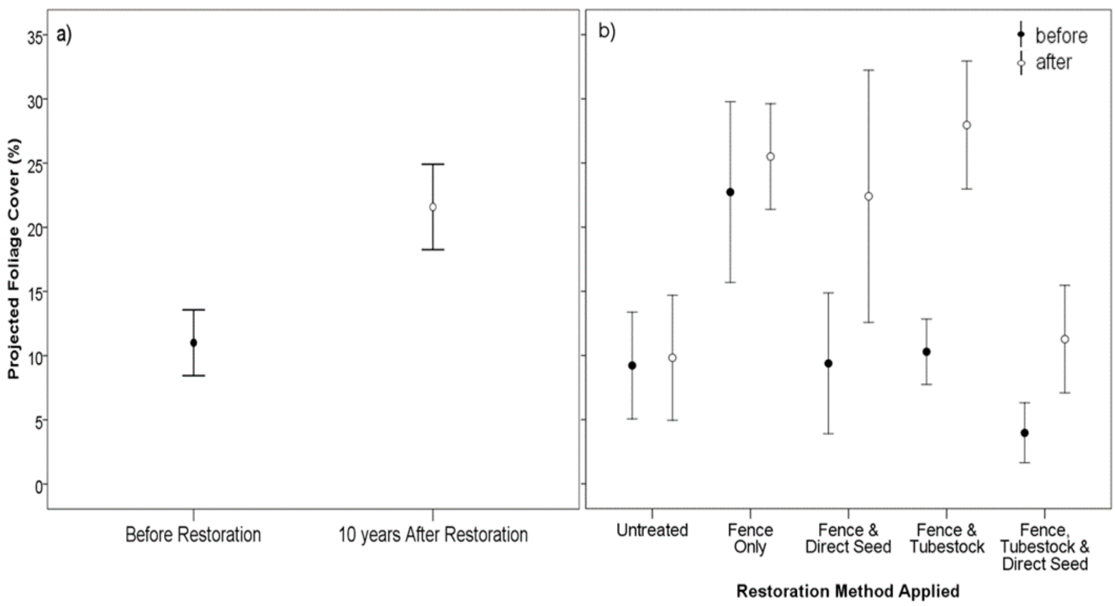


**Figure 5.** Changes in projective foliage cover from aerial photographs of sites before restoration occurred and 10 years after. Mean projected foliage cover (**a**) across all treated sites and, (**b**) for untreated sites and sites restored using each of the four different restoration methods. Closed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

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).

*3.3. Geomorphological Assessment*

The mean ephemeral stream assessment (ESA) scores across all restoration methods were significantly higher at 0.69 ± 0.01SE, compared to 0.52 ± 0.03 for untreated sites (F = 8.45, *df* = 4,33, $p$ < 0.001: 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).

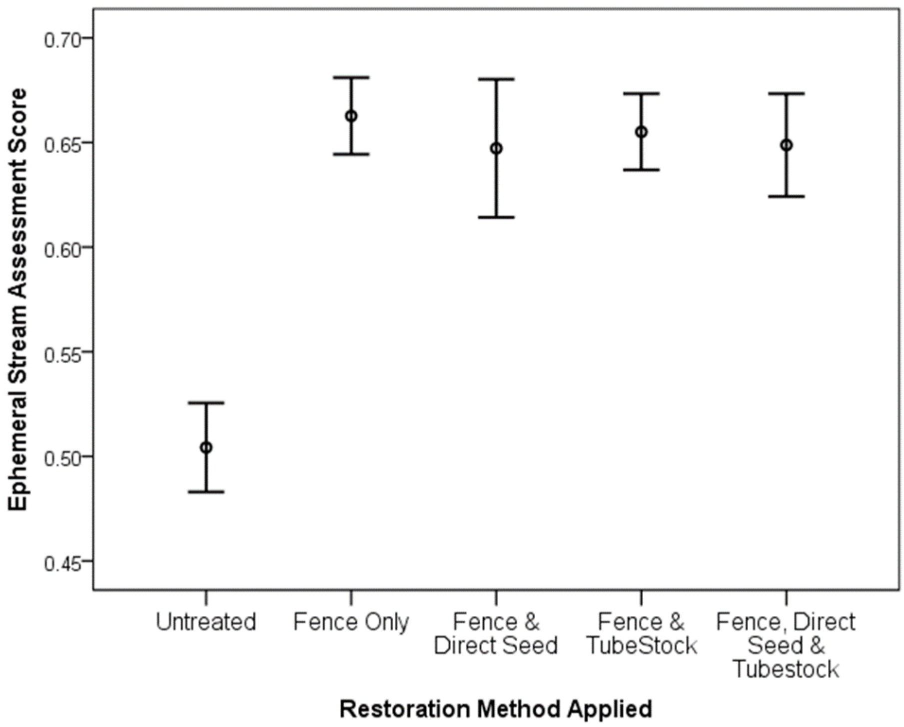


**Figure 6.** The mean ephemeral stream assessment (ESA) condition scores 10 years after restoration for sites restored as part of the Bidgee Banks Restoration Project (BBRP) using four restoration methods. Untreated site scores are provided as a comparison. Error bars represent ± SE. The maximum achievable ESA score is 1.

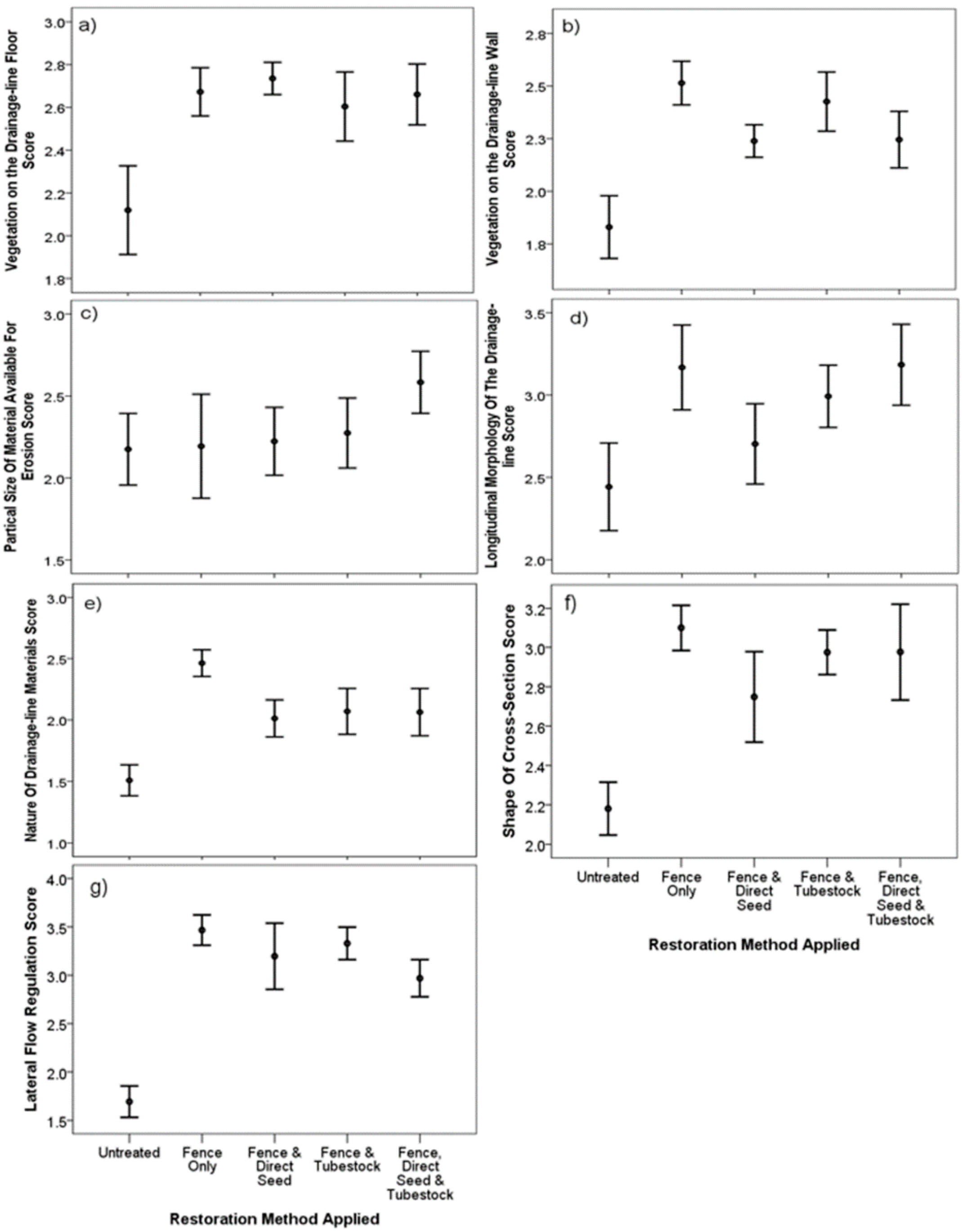


**Figure 7.** Mean scores for the seven indicators (**a**–**g**) within ESA 10 years after restoration for sites restored as part of the Bidgee Banks Restoration Project (BBRP) for each of four restoration methods. Untreated site scores are provided as a comparison. Error bars represent ± SE. The y-axis varies between plots.

## 4. Discussion

Despite the restoration of riparian zones being a major component of river management [21], there have been limited long-term evaluations of the outcomes of such actions, especially involving multiple sites and comparisons across restoration methods [42]. 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 that 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 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 restored (treated) sites while no change occurred at untreated sites. The BBRP appears to be tracking towards meeting its objective of reversing vegetation loss.

The width of the riparian area 10 years after restoration was largely defined by the width of the fenced area, with riparian vegetation truncated to the fence line. Naiman, et al. [43] suggested that a seven metre riparian vegetation buffer strip is adequate to provide bank stability, and Wenger [44] showed that a 30 metre wide riparian zone is sufficient to trap sediment. The average riparian vegetation width observed in the BBRP was 19.2 metres which is nearly double that prior to restoration, but just short of the initial aim to achieve a minimum 20 metre wide riparian buffer. While it should be noted that the width of the fenced area was, in part, determined by the amount of land the landholder was prepared to fence off, it highlights the value of establishing clear goals for riparian buffer width as part of the broader program.

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. It is likely, however, 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]) and thus, reduce sediment and nutrient loads in the rivers of the UMRC.

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 [45] 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 restored (treated) sites (including fence only sites) compared to the untreated sites in this study.

The outcomes observed from combining active and passive restoration at degraded sites illustrates how targeting the method to the site can accelerate recovery [46]. The variability in outcomes of active restoration observed, however, may be attributed to the level of site degradation prior to restoration, as active restoration was applied to more degraded sites. The outcomes of direct seeding of natives were more variable than those of 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 [34], and despite such efforts these highly degraded sites may require additional investment in both time (i.e., more than a 'one-off' event) and resources (i.e., additional plantings). The variability in outcomes between sites highlights the need for monitoring. Funding for restoration activities in Australia is frequently in the form of 'one-off' investments enabling a single treatment. This study clearly shows the value of a 'one-off' restoration treatment, but it is possible that greater benefit may be achieved if multiple restoration works were undertaken. However, it is not clear if the marginal benefit would be worth the investment and the expense of an untreated site. This would be an area for future research.

While we showed that restored (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 Hale et al. [25], after a similar timeframe. The timeframe, however, may be insufficient to result in measurable changes in leaf litter, hollow bearing trees and coarse woody debris which reflect the presence of mature vegetation [47]. 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' [10,48].

There was a significant difference in geomorphological condition between restored (treated) and untreated sites. The exclusion of livestock through fencing appears to be a major contributor to geomorphological condition (as observed elsewhere [6,26,49]) as sites in all restoration treatments demonstrated a better geomorphological condition (regardless of the inclusion of tubestock or direct seed) than untreated sites. This was especially evident for the index representing the shape of cross-section of the bank (i.e., a measure of bank stability). The reduced stock movement in accessing the stream has reduced the direct effects of livestock on the geomorphological condition (such as trampling and loosening soil) [11] and the geomorphological condition appears to be improving.

The presence of mature vegetation contributes to the geomorphological condition of the riparian zone by maintaining bank stability [50] 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 ESA metrics: 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, a finding reported 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, improvement to the riparian zones of the Murrumbidgee River and Catchment requires additional resources and effort.

## 5. Conclusions

One of the common challenges for evaluating long-term outcomes from restoration programs is a lack of pre-assessment data [42]. 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 that 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 availability of satellite imagery will provide better options for future evaluations, particularly as image and spectral data resolution improves.

The improvements in riparian and geomorphological condition at sites restored as part of the BBRP are encouraging and are testament to the hard work and planning undertaken by the project managers and ongoing maintenance by the landholders, as well as the investment of public funds. This study demonstrates the value of 'one off' restoration actions, but also highlights the need for monitoring and project evaluation to identify sites where further work may be required. 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.

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