

Trialling the use of controlled burning for exotic vegetation management in novel riparian ecosystems

Mabbott R¹ and Fryirs K¹

¹Department of Environmental Sciences, Macquarie University, North Ryde, NSW, 2109, Australia. Email: Rebecca.Mabbott@mq.edu.au

Key Points

- Rivers of southeastern Australia have undergone substantial geomorphic and vegetative change since European settlement.
- With improved land management practices, the areal cover of riparian vegetation has increased in recent decades. However, invasive species are often dominant and new methods for large-scale control are increasingly important.
- A trial controlled burn conducted to control *Arundo donax* within the riparian zone showed promising results for exotic species management and should be considered for future testing.

Abstract

Throughout Eastern Australia, and much of the New World, rivers have undergone dramatic geomorphic and vegetative change following European settlement. Recent research has documented a shift in the trajectory of river health towards recovery, including an increase in riparian woody vegetation and depositional landforms. However, there is limited information about the quality of the returning riparian vegetation, specifically the extent to which exotic plant species are contributing to the recovery and the geomorphic effectiveness of riparian vegetation. In response to these observations, this investigation sought to document and quantify the geomorphic and vegetative change that has occurred over the past century along the Paterson River in the Hunter Valley, New South Wales. Through combining studies of geomorphology and ecological restoration science, this project aimed to link the effects of land management, exotic plant species invasion and geomorphic change on river recovery, and couple this information with trials of large-scale invasive plant species management techniques in the riparian zone. Preliminary trials of field-based, large-scale riparian invasive plant species management were conducted using a combined process of aerial herbicide spraying and controlled burning. Overall, the initial riparian burn showed promising results for the management of invasive riparian plant species and should be considered for future testing.

Keywords

River recovery, riparian vegetation, exotic plant species, geomorphology

Introduction

Riparian vegetation plays a critical role in the physical and ecological function of river systems and the connectivity of the broader landscape through which rivers flow. Riparian vegetation is essential for providing habitat, moderating stream temperature, filtering sediment, retaining nutrients, and stabilising stream banks (Hood and Naiman, 2000; Naiman and Decamps, 1997). However, extensive anthropogenic disturbance to river systems and riparian vegetation has resulted from poor land management practices, such as those of agriculture, which has caused an increase of sediment and nutrient loads, water extraction, clearance of large woody debris and sand/gravel extraction (Brooks et al., 2003; Dyderski et al., 2015; Richardson et al., 2007). These anthropogenic disturbances exacerbate the natural characteristics of riparian systems that facilitate exotic species, such as frequent disturbance from flooding (Greet et al., 2013), transportation of propagules (Catford and Jansson, 2014), high nutrient levels (Richardson et al., 2007) and edge effects (Cumming, 2002). However, in recent decades there has been a shift towards better land management, allowing passive riparian vegetation recovery (Fryirs et al., 2013; Fryirs et al., 2018) in conjunction with an increase in riparian

Full Paper

Mabbott R. and Fryirs K.—Historical change and implications of eastern Australian riparian vegetation invasion

vegetation restoration projects (McDonald and Williams, 2009; Spink et al., 2010). Consequently, many river systems are physically recovering through channel contraction from river bed aggradation and the formation of bench and bar structures (Fryirs et al., 2009; Fryirs et al., 2018; Fujioka and Chappell, 2010; Mould and Fryirs, 2018). However, despite an increase in the cover of riparian vegetation, there is concern about whether the apparent recovery is owing to the establishment of invasive species in preference to native species (Cohen et al., unpublished; Fryirs et al., 2018; Webb and Erskine, 2003).

Current weed control techniques commonly include physical removal, herbicide application, biological controls, heat treatments and carbon application (Sheley et al., 2011). However, these weed control techniques are often unsuccessful, inefficient, not suited to the short time frames and/or small budgets of many environmental restoration contracts and applied in a patchy, site-by-site approach (McDonald and Williams, 2009). To address the limitations of current weed management techniques, and to address larger-scale invasion into riparian corridors, this research aims to trial the use of fire for invasive species control in riparian zones. There is much debate on whether fire should play a role in natural riparian systems (Dwire and Kauffman, 2003; Pettit and Naiman, 2007). However, in novel riparian systems that are heavily modified and disturbed by anthropogenic activity, or in ecosystems where fire has been part of the environmental and cultural history (e.g. Indigenous burning), fire could provide a means for controlling invasive species. Subsequent reintroduction of native species through passive regeneration or replanting can then occur (e.g. O'Donnell et al. (2014); O'Donnell et al. (2016)). This technique is intended to allow riparian vegetation restoration to occur more efficiently and on a larger scale by combining the use of aerial herbicide application with a controlled burn to remove invasive species biomass and create a window of opportunity in which conventional follow up weed control can take place. It is predicted that by using aerial herbicide application to create a dry, dead fuel load that a controlled burn will be able to reach a temperature sufficient to remove above ground biomass and kill or hinder below ground propagules. This will then provide a sufficient period of time with low vegetation cover in which any regenerating invasive species can be controlled before reinvading the site.

Regional setting

This study was conducted in the lower Hunter Valley Region of New South Wales, Australia, on the Paterson River (Figure 1). The Paterson River has a catchment area of approximately 1200 km² and flows from Barrington Tops National Park in its headwaters through to its confluence with the Hunter River at Hinton (WMA Water, 2016). Land use in the Paterson River catchment is dominated by agriculture with pockets of forest constrained to ridge tops and the headwaters within Barrington Tops National Park (McCauley, 2006). The prevalence of agriculture has resulted in widespread land and river degradation and the introduction of many agricultural and environmental pest species (McCauley, 2006).

The focus reach is located immediately downstream of the township of Paterson (Figure 1) and contains a large stand of *Arundo donax* (commonly known as giant reed or giant cane, hereafter *Arundo*) approximately 420 m long, spanning from the channel to the edge of the floodplain, with the widest section approximately 60 m wide. Previous control methods for *Arundo* on this site have included excavation and manual herbicide application but with limited success (pers. comm.). The study site is situated along a laterally unconfined, low sinuosity, fine-grained river with a sequence of up to three benches lining each bank (Figure 3). Flood history for the area is moderately well known (Morgan and Jones, 2016) and floods overtop the bank periodically, with the most recent major floods in 2015 (Figure 1).

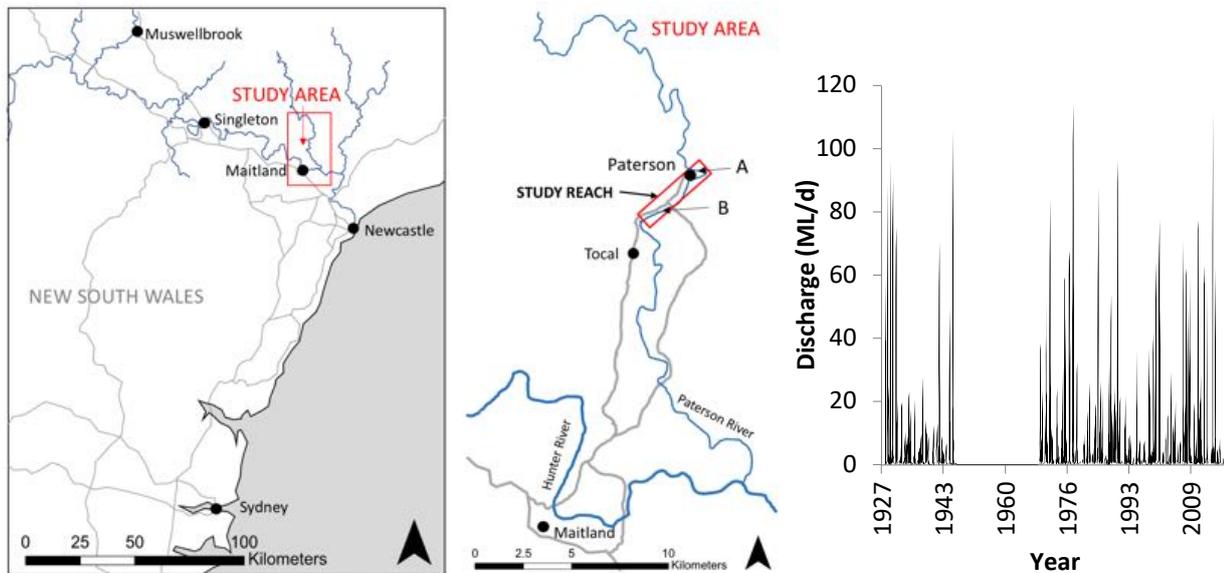


Figure 1: The study site was located between Tocal and Paterson on the Paterson River, approximately 150 km north of Sydney, New South Wales. The Gostwyck gauge (Bureau of Meteorology gauge number 210079) is located approximately 400 m upstream of Paterson. Data acquired from the NSW Office of Water PINNEENA database.

Methods

Vegetation mapping was conducted using desktop analysis of historical aerial imagery from 1938 and 1967 and satellite imagery from LANDSAT 2014. Aerial imagery was digitised and georeferenced using ArcMap v10.2 software, producing root mean square error values of 12.8-13.3 m and 12.7 m in 1938 and 1967, respectively. Vegetation mapping quantified the areal cover of woody riparian vegetation in km² and determined the percent woody riparian vegetation cover by determining the areal extent of the immediate riparian zone, assuming that the immediate riparian zone extended from the edge of the inset channel to the edge of the floodplain. Historical on-the-ground photographs were compared to contemporary photographs to demonstrate visual shifts in geomorphic and vegetative condition.

Aerial spraying (in collaboration with Tocal Agricultural College and Skyland Management) was conducted in spring 2016 and was applied using unmanned aerial vehicle (UAV) technology, which administered glyphosate (Roundup Ultramax 570) to approximately 5500 m² of riparian vegetation. Aerial spraying was constrained to large stands of *Arundo* not covered by native canopy and was not applied within 2 m of the river’s edge or to *Arundo* overhanging the adjacent agricultural land. The controlled burn was conducted in late winter 2017, nine months later, to allow sufficient drying of the standing sprayed material. The burn was initiated using drip torches applied to the perimeter. Light rain, cool temperatures and no wind was experienced during the controlled burn. Vegetation was surveyed before and after the controlled burn using randomized 2 m x 2 m quadrats, with 20 quadrats per variable (no pre-burn spray with no burn (control), pre-burn spray with burn, pre-burn spray with no burn). Each survey recorded species composition, growth type and percent cover.

Results

Geomorphic and vegetation change

Riparian vegetation cover analysis revealed an overall increase in woody riparian vegetation from 28% in 1938 to 48% and 54% in 1967 and 2014, respectively (Figure 2). However, despite an overall increase in vegetation cover it is evident that the shift in vegetation along the focus reach has been from evenly distributed low-

Full Paper

Mabbott R. and Fryirs K.—Historical change and implications of eastern Australian riparian vegetation invasion

density vegetation to vegetation that is more clustered, higher density and of increased coverage. Vegetation surveys conducted downstream of the Paterson Road bridge recorded a total of 49 species, composed of 45 exotic species and 4 native species. The site was dominated by *Arundo* with an understorey of exotic herbaceous and vine species. Geomorphic assessment of historical on-the-ground photographs demonstrated an increase in features such as bank-attached bars and benches with densely vegetated banks from early 1900 conditions of exposed banks and poor geomorphic heterogeneity (Figure 3).



Figure 2. Aerial photo sequence demonstrating changes in riparian vegetation cover from 1938 (38%), to 1967 (48%) and 2014 (54%).

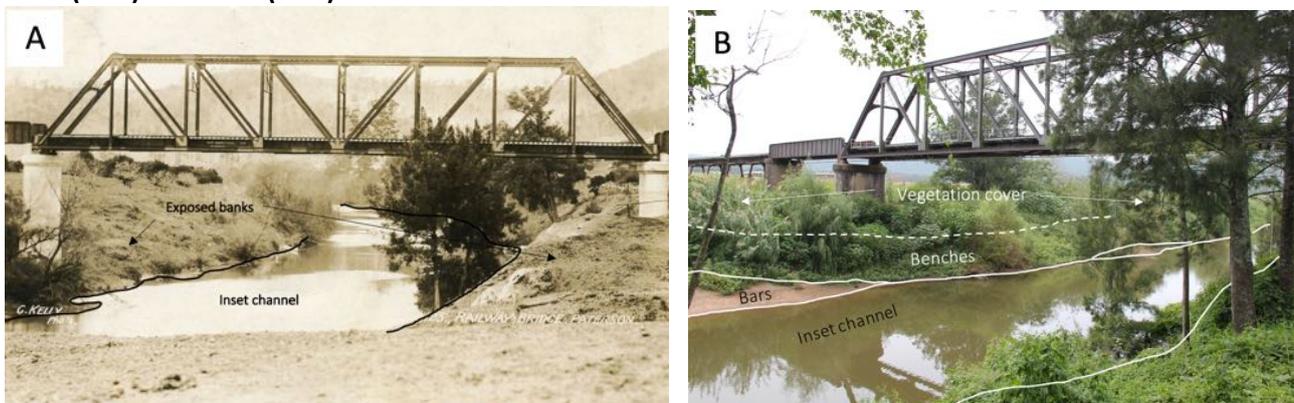


Figure 3. Historical on-the-ground photographs of the Paterson railway bridge demonstrating shifts in geomorphic and vegetative condition. Image A, circa 1905-1915 (G. Kelly). Image B, 2015 (Dossier 48).

Controlled burn trial

The total area covered by the controlled burn was approximately 2500 m², which covered approximately 36% of the vegetation treated with herbicide. Owing to unfavourable weather conditions, the controlled burn had difficulty travelling through the target area and resulted in patchy burn coverage. However, burnt areas had almost complete combustion of biomass and appeared to have reached moderate temperatures. Overall, species composition analysis revealed several species only germinated after aerial spraying, including Native Grape (*Cayratia clematidea*), Inkweed (*Phytolacca octandra*) and Castor Oil (*Ricinus communis*), presumably due to the increase in sunlight reaching the understorey below the *Arundo*. Several species did not reappear after the controlled burn, including Cobbler's Peg (*Bidens pilosa*), Lantana (*Lantana camara*) and Wild Tobacco (*Solanum mauritianum*), with Trad (*Tradescantia fluminensis*) also substantially reduced after the controlled burn. The target species, *Arundo*, appeared to have been considerably stunted by the controlled

burn, with limited or no regrowth in burnt areas 12 weeks after the burn, regardless of the pre-burn effectiveness of the aerial spraying (Figure 4A-4B). Total vegetation cover was an average of 17% at 12 weeks after the controlled burn. Across some burnt areas there was a substantial flush of Castor Oil germination which is assumed to be a consequence of accumulation of bird dropped propagules previously suppressed by the *Arundo* monoculture (Figure 4C). The only species to show a significant increase in cover after the burn when compared to pre-burn conditions was *R. raphanistrum*.

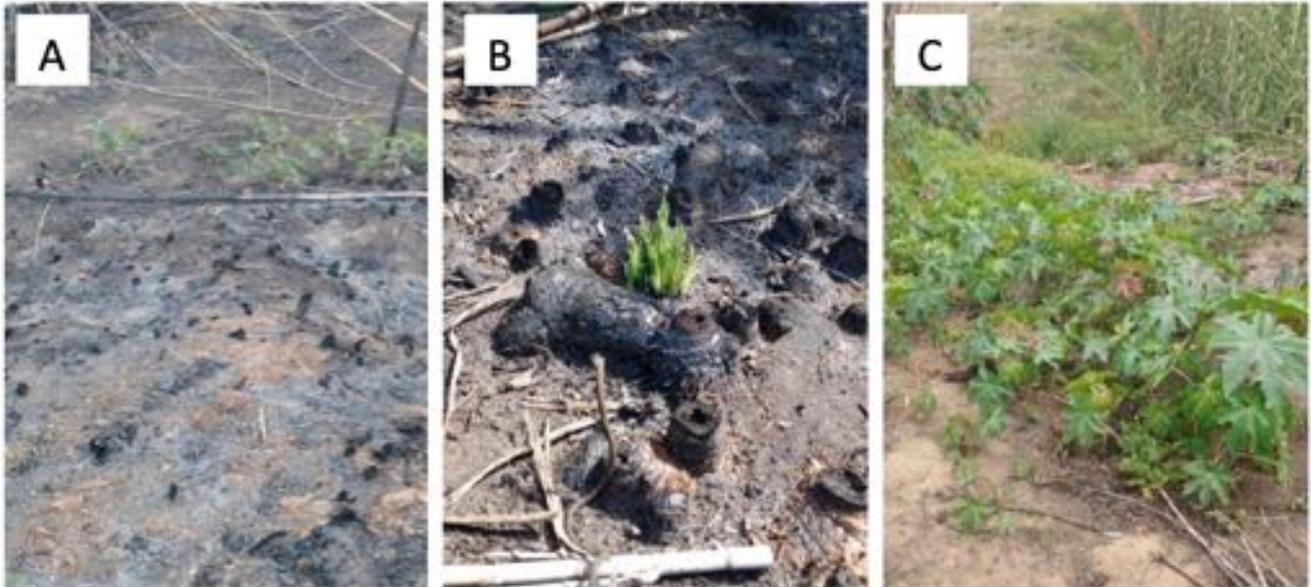


Figure 4. A-B) Remains of *Arundo* rhizomes 12 weeks post burn with limited evidence of stunted growth C) Patch of Castor Oil germination in areas of seed bank accumulation.

Discussion

Through this investigation it was revealed that over the past century the Paterson River has undergone geomorphic and vegetative change that has resulted in an increase in riparian vegetation largely composed of exotic species. Despite poor burning conditions and burn extent, the trial controlled burn was sufficient for the purposes of reducing invasive species biomass, particularly that of *Arundo*. The significant decline in total vegetation cover, to an average of 17%, three months after the controlled burn, suggests that sufficient time for follow up invasive species control was made possible by the controlled burn. In addition, it was shown that there was no significant increase in any particular growth type or any particular species, other than the annual *R. raphanistrum*, and that there was no continued dominance by a single species. This suggests that the controlled burn did not trigger a widespread recruitment of any particular species and did not leave the site prone to the immediate introduction of a new species to the site. The removal of species that create monocultures, such as *Arundo* and *T. fluminensis*, was of particular importance as it has been shown that many ecosystem processes and functions decline as species diversity declines to very low levels (Hooper et al., 2005). Furthermore, as the species that regenerated post-burn were those already present prior to the burn, it can be suggested that all regrowth/regeneration was from propagules present before the controlled burn. This suggests that through implementing the controlled burn to control above ground biomass it also provides disturbance to stimulate and deplete existing invasive seed bank supplies (Cole et al., 2016), which can then be followed up with post-burn control measures. This is beneficial for creating a single pulse of invasive regrowth that can be treated effectively with post-burn control measures such as secondary herbicide application, manual removal or crash grazing (Cole et al., 2016; Sebastian et al., 2017). This method prevents the exotic seed bank from being replenished by immediate propagule sources and allows for more effective ongoing site maintenance.

It must be noted that this approach is not intended as a 'set and forget' technique for riparian vegetation restoration. As shown by the large diversity of invasive species present post-burn and the limited presence of native species, due to historical clearance and disturbance of the site, there is a need for ongoing post-burn invasive species management. Furthermore, due to current restrictions on the initiation of fires in riparian zones (NSW RFS, 2006), it will be integral to implement this technique accompanied by a change in current policy and regulations. Several considerations will also need to be incorporated into restoration plans which weigh up the risks associated with controlled burns, particularly in the riparian zone. The acceptable associated level of risk should be determined for events such as high intensity weather events that could promote detrimental erosion (Pettit and Naiman, 2007), risk to downstream water quality (Smith et al., 2010) or the risk of native canopy mortality (Radford et al., 2008). The determined risk of these events needs to be considered in light of specific site characteristics such as the vegetation community, soil type, minimum and maximum fire frequency, fuel load, burn pattern and burn seasonality (Knapp et al., 2006; Smith et al., 2010).

In addition, the resilience, history and landscape setting of vegetation should be taken into consideration when prioritising areas for restoration projects (Holl and Aide, 2011). Recent studies have demonstrated that riparian structures such as benches and bars can contain a substantial native seed bank at moderately disturbed sites, which could be activated using a prescribed burn and aid in the strategic focus of target reaches (Goodson et al., 2001; O'Donnell et al., 2014; O'Donnell et al., 2016). In less disturbed settings where a native species seed bank response could occur, it could be possible to combine efforts of follow-up invasive species management with more passive efforts such as the protection of native species naturally regenerating post-fire (Holl and Aide, 2011). However, sites that are more severely disturbed by biotic and/or abiotic disturbances, to a stage where natural regeneration is not possible, should be approached as novel ecosystems when considering restoration (Hobbs et al., 2009). Novel ecosystems are systems that have surpassed thresholds of abiotic and/or biotic disturbances to a stage that prevents them from being restored to their original condition with a reasonable amount of intervention (Hobbs et al., 2006). The consideration of degraded riparian systems as novel ecosystems could allow the implementation of unconventional restoration techniques, such as controlled burning, that would not be traditionally considered within an intact system.

Currently, restoration at a catchment scale is considered near impossible with conventional restoration techniques and that the scope and outcomes of restoration in the riparian zone is constrained by the condition of the catchment (Richardson et al., 2007). This is where it is often beneficial to work on a reach-scale approach for restoration in order to formulate achievable outcomes (Moerke and Lamberti, 2004). The key benefit provided by large-scale restoration techniques, such as controlled burning, is that the rapid removal of above ground biomass allows restoration efforts focused at a reach scale to progress more rapidly and allow for a shift towards a more catchment scale approach. This shift towards restoration at a larger scale will be essential to addressing the large-scale invasion of riparian zones that is being witnessed throughout river systems.

Conclusions

Overall, this investigation demonstrated that the Paterson River has undergone geomorphic and vegetative change that has results in an increase in overall riparian vegetation, but a substantial increase in exotic species composition. It was shown that a combined use of aerial spraying and controlled burning can be used for the primary removal of above ground invasive species biomass to allow for efficient subsequent riparian vegetation restoration. The trial of unconventional techniques such as controlled burning in riparian zones will be essential for addressing the large scale invasive species infestations in riparian vegetation and it will be essential to acknowledge that many riparian systems that are currently recovering from past river degradation are novel ecosystems and that their management may differ substantially from conventional views of how remnant vegetation should be treated. This change in approach to riparian vegetation restoration will be essential for developing techniques at a large, landscape scale.

Acknowledgments

We thank the Tocal Agricultural College for field access and Phil Milling from Skyland Management for including us in the trial. This project was supported by an Australian Research Council Linkage grant [LP130100120]. Rebecca Mabbott is supported by a Macquarie University Master of Research stipend and Macquarie University Faculty of Science and Engineering (Higher Degree Research funding).

References

- Brooks, A.P., Brierley, G.J., Millar, R.G., 2003. The long-term control of vegetation and woody debris on channel and flood-plain evolution: insights from a paired catchment study in southeastern Australia. *Geomorphology*, 51(1–3), 7-29.
- Catford, J.A., Jansson, R., 2014. Drowned, buried and carried away: effects of plant traits on the distribution of native and alien species in riparian ecosystems. *New Phytologist*, 204(1), 19-36.
- Cohen, T.J., Suesse, T., Skorulis, A., Reinfelds, I., Fryirs, K., Carrigan, A., Chisholm, L., Belcher, A., unpublished. The re-greening of eastern Australian rivers: Unprecedented riparian transformation.
- Cole, I.A., Prober, S., Lunt, I., Koen, T.B., 2016. Nutrient versus seed bank depletion approaches to controlling exotic annuals in threatened Box Gum woodlands. *Austral ecology*, 41(1), 40-52.
- Cumming, G., 2002. Habitat shape, species invasions, and reserve design: insights from simple models. *Conservation Ecology*, 6(1).
- Dwire, K.A., Kauffman, J.B., 2003. Fire and riparian ecosystems in landscapes of the western USA. *Forest Ecology and Management*, 178(1), 61-74.
- Dyderski, M.K., Gdula, A.K., Jagodziński, A.M., 2015. “The rich get richer” concept in riparian woody species—A case study of the Warta River Valley (Poznań, Poland). *Urban Forestry & Urban Greening*, 14(1), 107-114.
- Fryirs, K., Chessman, B., Rutherford, I., 2013. Progress, problems and prospects in Australian river repair. *Marine and Freshwater Research*, 64(7), 642-654.
- Fryirs, K., Spink, A., Brierley, G., 2009. Post-European settlement response gradients of river sensitivity and recovery across the upper Hunter catchment, Australia. *Earth Surface Processes and Landforms*, 34(7), 897-918.
- Fryirs, K.A., Brierley, G.J., Hancock, F., Cohen, T.J., Brooks, A.P., Reinfelds, I., Cook, N., Raine, A., 2018. Tracking geomorphic recovery in process-based river management. *Land Degradation & Development*.
- Fujioka, T., Chappell, J., 2010. History of Australia aridity: chronology in the evolution of arid landscapes. *Geological Society, London*, 346, 121-139.
- Goodson, J., Gurnell, A., Angold, P., Morrissey, I., 2001. Riparian seed banks: structure, process and implications for riparian management. *Progress in Physical Geography*, 25(3), 301-325.
- Greet, J., Cousens, R., Webb, J., 2013. More exotic and fewer native plant species: riverine vegetation patterns associated with altered seasonal flow patterns. *River Research and Applications*, 29(6), 686-706.
- Hobbs, R.J., Arico, S., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., Epstein, P.R., Ewel, J.J., Klink, C.A., Lugo, A.E., 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global ecology and biogeography*, 15(1), 1-7.
- Hobbs, R.J., Higgs, E., Harris, J.A., 2009. Novel ecosystems: implications for conservation and restoration. *Trends in ecology & evolution*, 24(11), 599-605.
- Holl, K.D., Aide, T.M., 2011. When and where to actively restore ecosystems? *Forest Ecology and Management*, 261(10), 1558-1563.
- Hood, W.G., Naiman, R.J., 2000. Vulnerability of riparian zones to invasion by exotic vascular plants. *Plant ecology*, 148(1), 105-114.

Full Paper

- Mabbott R. and Fryirs K.—*Historical change and implications of eastern Australian riparian vegetation invasion*
- Hooper, D.U., Chapin, F., Ewel, J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J., Lodge, D., Loreau, M., Naeem, S., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological monographs*, 75(1), 3-35.
- Knapp, E.E., Schwilk, D.W., Kane, J.M., Keeley, J.E., 2006. Role of burning season on initial understory vegetation response to prescribed fire in a mixed conifer forest. *Canadian Journal of Forest Research*, 37(1), 11-22.
- McCauley, A., 2006. Vegetation survey and mapping of the Hunter, Central and Lower North Coast Region of NSW. Report to the Hunter-Central Rivers Catchment Management Authority.(Environment Division of Hunter Councils: Newcastle.).
- McDonald, T., Williams, J., 2009. A perspective on the evolving science and practice of ecological restoration in Australia. *Ecological Management & Restoration*, 10(2), 113-125.
- Moerke, A.H., Lamberti, G.A., 2004. Restoring stream ecosystems: lessons from a midwestern state. *Restoration Ecology*, 12(3), 327-334.
- Morgan, D., Jones, R.H., 2016. Paterson River Flood Study - Vacy to Hinton, Maitland City Council, Port Stephens Council and Dungog Council.
- Mould, S., Fryirs, K., 2018. Contextualising the trajectory of geomorphic river recovery with environmental history to support river management. *Applied Geography*, 94, 130-146.
- Naiman and, R.J., Decamps, H., 1997. The ecology of interfaces: riparian zones. *Annual review of Ecology and Systematics*, 28(1), 621-658.
- NSW RFS, 2006. Bush Fire Environmental Assessment Code, NSW Rural Fire Service, New South Wales, Australia.
- O'Donnell, J., Fryirs, K., Leishman, M.R., 2014. Digging deep for diversity: riparian seed bank abundance and species richness in relation to burial depth. *Freshwater Biology*, 59(1), 100-113.
- O'Donnell, J., Fryirs, K.A., Leishman, M.R., 2016. Seed banks as a source of vegetation regeneration to support the recovery of degraded rivers: a comparison of river reaches of varying condition. *Science of the Total Environment*, 542, 591-602.
- Pettit, N.E., Naiman, R.J., 2007. Fire in the riparian zone: characteristics and ecological consequences. *Ecosystems*, 10(5), 673-687.
- Radford, I.J., Grice, A.C., Abbott, B.N., Nicholas, D.M., Whiteman, L., 2008. Impacts of changed fire regimes on tropical riparian vegetation invaded by an exotic vine. *Austral Ecology*, 33(2), 151-167.
- Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pyšek, P., Hobbs, R.J., 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and distributions*, 13(1), 126-139.
- Sebastian, D.J., Nissen, S.J., Sebastian, J.R., Beck, K.G., 2017. Seed bank depletion: the key to long-term downy brome (*Bromus tectorum* L.) management. *Rangeland Ecology & Management*, 70(4), 477-483.
- Sheley, R., James, J., Rinella, M., Blumenthal, D., DiTomaso, J., Briske, D., 2011. Invasive plant management on anticipated conservation benefits: a scientific assessment. *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps*. United States Department of Agriculture, Natural Resources Conservation Service, 291-336.
- Smith, H.G., Sheridan, G.J., Lane, P.N., Sherwin, C.B., 2010. Paired Eucalyptus forest catchment study of prescribed fire effects on suspended sediment and nutrient exports in south-eastern Australia. *International Journal of Wildland Fire*, 19(5), 624-636.
- Spink, A., Hillman, M., Fryirs, K., Brierley, G., Lloyd, K., 2010. Has river rehabilitation begun? Social perspectives from the Upper Hunter catchment, New South Wales, Australia. *Geoforum*, 41(3), 399-409.
- Webb, A.A., Erskine, W.D., 2003. A practical scientific approach to riparian vegetation rehabilitation in Australia. *Journal of Environmental Management*, 68(4), 329-341. WMA Water, 2016. Paterson River Flood Study, Maitland City Council.