Revegetating farmlands in northern New South Wales: problems and solutions©

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INTRODUCTION

Why is revegetation important?

Since European settlement, land clearing for agriculture has led to the widespread destruction, modification, and fragmentation of Australia's native vegetation (Atyeo and Thackway, 2009; Bennett and Saunders, 2010; Yates and Hobbs, 2000). These changes have occurred so quickly that plant and animal communities have had little time to adapt, leaving them vulnerable to extinction (Bauer and Goldney, 2000). Consequently, Australia rates high on the extinct species list, particularly for mammal extinctions, which over the past 200 years has been higher than any other continent (Cardillo and Bromham, 2001; Hobbs and Mooney, 1998; McConnon, 2015). One way of addressing our declining biodiversity is by revegetating farmlands previously cleared for agriculture (England et al., 2013; Vesk and Dorrough, 2006). Studies have shown that revegetation, which is structurally and floristically diverse, is important for conserving biodiversity because it provides nesting, perching and shelter for birds, microhabitats for seedling establishment, and sources of food and shelter for fauna (Collard et al., 2013; Munro et al., 2009). Effective conservation in rural environments also requires interconnected networks of native vegetation that together, have the capacity to support large populations of native flora and fauna (Bennett and MacNally, 2004). In this respect, revegetation can function as stepping stones or continuous corridors to allow movement between subpopulations, thus maximising the persistence of a species and minimising inbreeding depression (Bennett and Saunders, 2010; Hilty et al., 2006).

However, the idea of integrating natural resource management with agriculture to achieve a more sustainable landscape has been met with some resistance. Specifically, landholders are concerned that the two are incompatible, particularly in terms of the constraints that native vegetation places upon agricultural productivity and land management flexibility (Schirmer and Bull, 2014). On the upside, traditional beliefs are waning amidst the increasing realisation that the agricultural industry is directly dependent on native vegetation for a range of vital ecosystem services (Fischer et al., 2006). These services include the provision of clean water, healthy soils and important crop pollinators, the regulation of pests and diseases, and the mitigation of salinity and soil erosion (Fischer et al., 2006; Wallace, 2007). In addition, native vegetation acts as a potential genetic storage for the future improvement of crop species (Altieri, 1999; Fischer et al., 2006).

Revegetation techniques

Revegetation techniques generally fall into three categories: (1) natural regeneration, (2) direct seeding, and (3) tubestock planting. Natural regeneration is often the preferred method of revegetation because it is cost effective, doesn't require planting or management input, and has the added advantage of retaining the character and native species of an area (Curtis, 1990; Whisenant, 1999). It is underpinned by the process of succession and is based on the premise that once disturbances impacting on the ecosystem are ameliorated, plants will naturally re-establish through vegetative means, or natural seed fall (Miller et al., 2013). The best way to encourage natural regeneration of native trees and shrubs is to exclude

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stock from the area for at least 5 years (Curtis, 1990). However, severely degraded farmlands that have been intensively managed for long periods of time are very slow to regenerate with little to no regeneration capacity (Cummings et al., 2007). Eucalypts in particular, are difficult to re-establish in rural landscapes because seed survival is low, even following a heavy seed fall (Curtis, 1990). The first step towards successful natural regeneration often involves identifying the restoration barriers (biotic and abiotic), which prevent the transition of the degraded landscape into a more desirable state (Cummings et al., 2007; Whisenant, 1999).

Direct seeding is a relatively inexpensive technique, which lends itself particularly well to broad-scale revegetation in agricultural settings (Dalton, 1993; Florentine et al., 2011). Various methods are used to introduce seeds into new sites, including broadcast seeding, aerial seeding, hydro-seeding and seeding using commercial agricultural seeders and drill seeders (Greipsson, 2011; Whisenant, 1999). Past studies have shown high variability in the success of direct seeding as a revegetation technique, particularly in parts of New South Wales (Carr et al., 2009; Van Andel and Aronson, 2012). This is most likely because of prolonged dry periods, lack of defined winter wet season and inadequate weed control (Geeves et al., 2008).

In unpredictable and inhospitable environments where direct seeding operations seldom succeed, transplanting whole plants is the most viable alternative (Whisenant, 1999). Although the cost of tubestock plantings is high, the technique is often preferred because trees can be established in the landscape in a relatively short timeframe and the results are immediate (Rawlings et al., 2010). Seedlings can be planted using a mechanical planter consisting of a ripper tyne, furrow opener, plant delivery system and a press wheel. Alternatively, seedlings are planted by hand using either a Hamilton planter or a Pottiputki planter (Namoi Catchment Management Authority, 2013). Choosing healthy, disease-free seedlings with good root development is critical to short-term and long-term survival (Rawlings et al., 2010), along with good site preparation and weed control (England et al., 2013).

PROBLEMS AND SOLUTIONS

Revegetation is one of the most expensive natural resource conservation activities (Florentine et al., 2011). Since the mid-1990s the Australian government has invested millions of dollars in revegetation programs largely for vegetation re-establishment (England et al., 2013). For example, in 2000-2001 alone AU$36.4 million dollars was spent to re-establish native vegetation and to provide appropriate habitat for wildlife (Florentine et al., 2011). Despite this investment, little to no follow-up monitoring has been done to assess the effectiveness and success of revegetation projects (Atyeo and Thackway, 2009; England et al., 2013; Florentine et al., 2011). Of those projects monitored from the 1970s to the present, many have been unsuccessful in terms of survival (Freudenberger and Harvey, 2003). Factors affecting survival include climate, soil type, previous land use, and poor establishment techniques (Andrews, 2000; Close and Davidson, 2003; England et al., 2013).

My research is based on the Northern Tablelands of New South Wales, Australia. The primary aims of my research are: (1) to evaluate the success of past and present revegetation projects in terms of tree performance, (2) to investigate different planting and management techniques to increase the germination and survival rates of direct seeding and tubestock planting, and (3) to provide scientifically based guidelines for landholders, revegetation practitioners and NRM organisations. I discuss below some of the primary problems impeding the success of direct seeding and tubestock planting on the Northern Tablelands.

Poor species/provenance selection

Revegetating altered landscapes to achieve diverse, functional systems rich in native species requires vast quantities of seed (McKay et al., 2005). The decision as to where to source this seed has caused conflict among revegetation practitioners and organisations over past decades (Hancock and Hughes, 2012). Traditionally, the paradigm of “local is best” has been widely advocated, and using local seed still remains a goal for much of the revegetation work undertaken in Australia (Broadhurst et al., 2008; McKay et al., 2005; Williams, 2007). It is based on the premise that local provenance seed delivers better revegetation outcomes because it is adapted to local conditions and, therefore, it reduces the risk of genetic pollution and outbreeding depression (Broadhurst et al., 2008; Hancock and Hughes, 2012; Williams, 2007). However, as revegetation targets increase and research into the effectiveness of current strategies intensifies, the appropriateness of the local provenance paradigm has come under review (McKay et al., 2005).

A fundamental problem underpinning the "local is best" paradigm is that there is no universal definition for "local" (Carr, 2008; Hancock and Hughes, 2012). Although local provenance is almost always determined by spatially explicit guidelines, these vary among revegetation practitioners and organisations (Hancock and Hughes, 2012). A second is that seed harvesting to meet growing revegetation targets is likely to impact on remnant populations by reducing seed availability for natural population turnover, or reducing plant vigour through collateral collection damage (Broadhurst et al., 2008). Moreover, as our understanding of the demographic and genetic effects associated with landscape fragmentation broadens, there is growing evidence that using locally adapted seed may be consigning the progeny to a genetic dead-end (Williams, 2007). Such evidence identifies the need for a less restrictive approach to seed collection, with a view towards composite provenancing or mixing seed from sources from within the species' natural range to minimise the risk of inbreeding and to promote genetic diversity within newly planted areas (Carr, 2008; Williams, 2007). The latter is critically important given that genetic variation is an essential prerequisite for evolutionary change and the persistence of species in changing environments, particularly in relation to current climate change predictions (Hancock and Hughes, 2014).

Inadequate ground preparation

Inadequate ground preparation is often the downfall of revegetation efforts in northern New South Wales (Andrews, 2000). This is probably because existing protocols are not being adhered to, or corners are being cut due to time constraints, poor planning, or unsuitable machinery and equipment. Characteristics of a well prepared site include friable, aerated soil, good moisture availability throughout the soil profile, and soil that is free from competing weeds and weed seed burdens at the time of planting (Andrews et al., 2004). Furthermore, the longer a site is prepared prior to planting the better the performance of the trees subsequently planted there (Andrews, 2000). Andrews et al. (2004) recommends the following protocols for establishing trees on the Northern Tablelands:

- Slash or crash graze the site to remove heavy accumulations of herbage.
- Commence fallow using a knock-down herbicide or by cultivation 10-12 months prior to planting. Maintain fallow.
- Deep rip (500-600 mm) planting beds soon after commencement of fallow. Soil should be dry to ensure a good shatter at depth.
- Mound and/or cultivate 6 months before planting once good root release is achieved from the first herbicide application.
- One month before planting apply a residual herbicide along with another application of knock down herbicide if needed.

Bad timing

Planting at the right time is essential for successful revegetation. Site conditions such as rainfall, temperature and soil moisture all play crucial roles, whether direct seeding of planting tubestock (Namoi Catchment Management Authority, 2013). When planting tubestock, past research has shown that adequate water availability at seedling establishment phase, along with good soil moisture stores prior to planting, enhance seedling survival (Andrews et al., 2004; McGinness et al., 2007). Therefore, taking advantage of windows of opportunity that maximise the likelihood of follow-up rain and minimise evaporation rates is an important strategy (McGinness et al., 2007). For the Northern

Tablelands and Northwest Slopes and Plains, spring planting is recommended, however when planting in free-draining soils, where soils dry out faster than seedlings can extend their roots, autumn planting is an option (Andrews et al., 2004).

The timing of direct seeding is complicated as germination is cued by a complex combination of soil moisture, temperature, light, day length, and chemical signals, often in a specific order (Carr et al., 2009). Most NRM organisations and revegetation practitioners recommend sewing at a time when there is the highest probability of these optimal conditions occurring. If germination is delayed by planting out of season, dormant seeds are more at risk of desiccation, predation and disease (Carr et al., 2007). Generally, direct seeding should occur in winter and early spring in winter-dominant rainfall zones, while in summer-dominant rainfall zones mid-spring or autumn plantings are recommended. However, sowing times will vary according to the species planted, and conditions at the time of planting. For example, often a compromise between sowing early to maximise soil moisture availability and sowing later when temperatures are high enough to stimulate germination, will need to be made (Carr et al., 2007).

Overall, bad timing may not only be attributed to a lack of local knowledge, but also the need to push revegetation projects through in order to meet annual revegetation deadlines. In addition, plantings often occur out of season to relieve pressures from nurseries needing to offload seedlings pre-ordered for different NRM organisations. Succumbing to these pressures should be avoided, as the success of all planned revegetation is fully dependent on the survival and establishment of germinants and seedlings.

Inhospitable climates

Low temperatures represent one of the most harmful biotic stressors affecting temperate plants (Janská et al., 2010). In areas of northern NSW, cold temperatures and severe frosts limit the survival and growth of native trees, particularly in parts of the landscape where cold air drainage occurs (Reid et al., 2012). We assessed the impact of the physical environment on the survival and growth of three eucalypt species: *Eucalyptus nitens, E. pauciflora*, and *E. viminalis* on the Northern Tablelands (Figure 1). Using multimodel inferencing we identified minimum temperature to be one of the main abiotic stressors affecting tree performance. Other studies have reported similar findings in relation to cold stress in eucalypts (Ball et al., 1991; Green, 1969; Harwood, 1980; Leslie et al., 2013; Paton et al., 1979). Extreme cold may restrict plant survival directly, through mechanical injury, or indirectly by shortening the growing season. Further, a reduction in the growing season does not allow adequate time for photosynthetic-driven carbon gain or for recovery from grazing or frost damage (Reid and Palazzo, 1990).

Figure 1. Failed revegetation as a result of extreme cold temperatures, Armidale, NSW, August 2013 (photograph by S.L. Brown).

Frost damage generally causes injury to plant cells, either through the mechanical rupture of the cell membrane and cell wall, or through an imbalance in electrolytes as freezing removes water from solution (Reid and Palazzo, 1990). However, there is an abundance of research, which has shown that cold temperatures also interact with light stress to damage plants (Ball et al., 1991; Blennow and Lindkvist, 2000; Godde et al., 1992; Hayden et al., 1986; Osmond et al., 1987). This phenomenon is known as cold-induced photoinhibition. Photoinhibition occurs in all photosynthetic organisms because light is the driving force for photosynthesis (Murata et al., 2007). Light induces the production of reactive oxygen species (ROS), which inactivate the photochemical reaction centre of photosystem II (PSII) (Murata et al., 2007). Under normal circumstances, the PSII is able to repair itself quickly and efficiently through the synthesis of proteins (Ball et al., 1991; Murata et al., 2007). However, exposure to low temperatures increases a plant's sensitivity to light and inhibits protein synthesis, so that the damage to PSII occurs more rapidly than it can be repaired (Ball et al., 1991; Blennow and Lindkvist, 2000; Murata et al., 2007).

Water availability

Water is an essential requirement for all living organisms. In herbaceous plants, the water content ranges from 70-95%; however, it is continually lost from a plant through the processes of transpiration and photosynthesis (Passioura, 1982). The importance of managing soil moisture conservation in all revegetation (before and after planting) cannot be overstated. This requires effective planning and management, including adequate ground preparation and weed control, mulching, and follow up watering (McGinness et al., 2007), although in reality, this rarely occurs. Knowing the site and the soil water holding capacity, along with choosing drought tolerant species are also important factors. Surprisingly, the benefits of artificial irrigation to seedling survival have not been widely studied. One Australian study undertaken at Gungahlin, ACT, demonstrated a high survival rate (84-96%) of eucalypt seedlings planted into a soil profile that was artificially filled with water (McGinness et al., 2007). An earlier study (Yantabulla, NSW) reported that summer irrigation maintained the survival of *Dodonaea viscosa* subsp. *angustissima* (syn. *Dodonaea attenuate*) seedlings (>80%) planted in a natural grassland compared to zero survivorship in the unirrigated control (Harrington, 1991).

We investigated the effect of deep watering on the survival of *E. populnea* and *Casuarina cristata* seedlings in Narrabri, NSW. A total of 120 seedlings of each species were planted along with an equal number of control seedlings. The planting took place in the summer of 2014 so we were able to affectively assess the impacts of heat stress and water availability on seedling establishment. Treatment seedlings were planted within paper pulp cocoons, a Dutch designed watering system that held 25 L of water made available to the seedlings through a nylon wick (Figure 2) (Land Life Company, 2015). Controls were planted using a Hamilton planter, with each seedling receiving 5 L of water through a ground spike before planting and an additional 5 L after planting. Five months post planting 95% of the treated seedlings had survived, compared to 0% survival in the controls. We concluded that watering protocols need to be established and the associated costs factored in at the initial planning stages of revegetation to ensure seedling survival. Seedlings should receive at 5-10 L of water at the time of planting to avoid transplant shock and further follow up irrigation at 4 week intervals (during summer) and 8 week intervals (during winter) if reasonable rain is not forecast (Namoi Catchment Management Authority).

Figure 2. Land life box trials, Narrabri, NSW, October 2014 (photograph by S.L. Brown).

Poor weed control

Revegetation practitioners identify poor weed control as one of the primary factors affecting the successful establishment of trees in rural landscapes (Andrews et al., 2004; Hall, 1985). Weeds can reduce early growth rates by up to 70% and decrease survival to as little as 10% (Greening Australia, 2003). It is the very nature of weeds that makes them a such problem, for example, weeds are usually early colonisers, exhibit rapid growth, reproduce prolifically and can withstand an array of environmental challenges. Consequently, weeds compete very effectively against planted seedlings for light, nutrients, and water (Figure 3). Effective weed control may encompass various techniques, including the use of mulches and weed mats, scalping, cultivation, flaming, hand removal, and chemical control (Greening Australia, 2003; Namoi Catchment Management Authority, 2013; Taylor, 2013). Weed control for direct seeded sites is particularly challenging, as it is difficult to avoid spraying the germinated seedlings. Traditionally, weeds have been managed by long-term weed control before sowing, or by applying a knockdown herbicide in the months preceding, followed by a residual just before sowing. However, this practice is not always effective (Semple and Koen, 2006; Taylor, 2013). This raises the question as to whether herbicide oversprays could be used as an effective method of weed control if some native species exhibit tolerance to them (Semple and Koen, 2006). Moore (1999) used this technique to demonstrate the tolerance of 21 of 26 native species to chlorthal and napropamide, while approximately half of the species tested were tolerant to chlorsulfuron and imazethapyr.

We investigated the tolerance of 12 native tree and shrub species to nine residual (broadleaf and grasses) herbicides oversprays. These trials took place in a temperature controlled glasshouse at the University of New England between December 2014 and February 2015. Our results were variable in that different species exhibited tolerances to different herbicides. Survival rate for seedlings treated with Jaguar® (diflufenican) was zero for all species. *Eucalyptus*, *Acacia*, and *Dodonea* species exhibited tolerance to Goal® (oxyfluorfen). *Casuarina*, *Senna* and *Acacia* species exhibited tolerance to Spinnaker® (Imazethapyr), while all species exhibited tolerance to Amitrole T (amitrole) and Balance™ (Isoxaflutole). We are currently investigating the effectiveness of herbicides against weeds and testing the tolerance of the same suite of species in situ. Clearly there is scope for continued research on herbicide tolerance of a broad range of species.

Figure 3. Infestation of thornapple (*Datura* sp.) at a direct seeded site 5 months post-planting Bingara, NSW, March 2015 (Photograph by S.L. Brown).

Planting against the contour

Although one would expect that planting along the contour would be a fundamental principle of successful revegetation, sometimes it is not practiced. The main problem associated with planting against the contour is the increased risk and severity of erosion, especially in the event of a rainstorm (Figure 4). Figure 4 shows a site that encompasses 10 km of direct seeding and tubestock in undulating basalt country near Ben Lomond, NSW. Two months after planting the area received heavy rains over a short period of time, resulting in widespread damage to the planting.

Figure 4. Erosion along direct seeded ripline after heavy rain Ben Lomond, NSW, April 2015 (photograph by S.L. Brown).

Survival and growth rates also differ in trees planted against the contour due to environmental gradients, which correspond to the natural topography of the landscape (Ferrero et al., 2013). Topography substantially modifies local environmental conditions by altering the regional climate and its interactions with soil properties (Ferrero et al., 2013). Consequently, trees planted along environmental gradients often display variations in their response to local environmental conditions, particularly in relation to frosts and waterlogging (Davidson and Reid, 1985; Gilfedder, 1988). Inverted tree lines are very good visual representation of how patterns in tree height vary along an environmental gradient.

Planting along the contour not only rectifies these problems, but affords many other benefits. For example, contour plantings allow runoff to be collected along the prepared bed, which in turn allows water to soak in and directly benefit the survival of direct seeded germinants and tube stock (Namoi Catchment Management Authority, 2013). It also facilitates the retention of leaf litter, thus reducing the loss of natural resources from the site, improving the foundations for ecological functioning (Mullan, 2000).

CONCLUSIONS

The purpose of this paper is to provide practical solutions to problems that my research has identified as being detrimental to revegetation success. However, these problems are not new. The last 40 years of revegetation efforts have liberated an abundance of planting protocols and recommendations, which have been made available to a wide range of NRM audiences. The challenge, therefore, is to establish clear communication pathways between revegetation organisations, revegetation practitioners and landholders, so that advice can be freely available at all stages of the project, monitoring procedures can be established and implemented before and after planting, expectations can be clarified, and the risk of failure can be managed so that successful revegetation can be achieved.

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