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Should I plant or should I sow? Restoration outcomes compared across seven riparian revegetation projects

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Summary

To revegetate native plant communities, it is often cheaper to direct seed than to plant nursery grown stock. However, the outcomes of direct seeding can be quite variable, and it is unclear whether direct seeding or planting is more likely to facilitate the restoration of diverse plant communities. To address this question, we compared the outcomes of each method across several recent riparian revegetation projects where both direct seeding and tube-stock planting were used.

We surveyed riparian revegetation projects at seven sites within the greater Melbourne area that had been revegetated between 1 and 4 years previously. Sites were all on land previously used for agriculture or degraded public land and ranged in environmental and climatic conditions. Woody plant density, establishment of target species, species richness, species diversity (evenness) and plant heights were assessed.

Direct seeding tended to result in higher plant densities, similar species richness, but lower rates of species establishment and diversity compared with planting. A median of 67% of target species established via direct seeding compared with 100% for planting, with direct seeded areas often dominated by one or two species. In general, overall revegetation outcomes were often driven by climatic and site factors, rather than revegetation method. We suggest that to achieve good restoration outcomes from revegetation in riparian areas, a bet-hedging or combined approach using both sowing and planting may be the best strategy.

29

30 **Keywords (5-10 words)**

31 Biodiversity, direct seeding, ecological restoration, riparian revegetation, tube-stock planting,
32 vegetation diversity.

33

34 **Introduction**

35 “Ecological restoration is the process of assisting the recovery of an ecosystem that has been
36 degraded, damaged or destroyed”, with the goal to create a self-supporting ecosystem that is
37 resilient to perturbation (SER 2004). Restoration actions that enhance biodiversity should support
38 enhanced provision of ecosystem services and resilience (Benayas *et al.* 2009).

39 Revegetation is often desirable to accelerate ecosystem recovery and is the most common approach
40 to restoring plant communities (Palma and Laurance 2015; Ruiz-Jaen and Mitchell Aide 2005). Active
41 revegetation involves either direct seeding or planting of nursery-grown stock. While direct seeding
42 is typically cheaper than planting (Atondo-Bueno *et al.* 2018; Cole *et al.* 2011; Ede *et al.* 2017; Pérez
43 *et al.* 2019), direct seeding outcomes can be quite variable (Ammond *et al.* 2013; Ruthrof *et al.*
44 2010). Moreover, the comparative diversity outcomes of the two approaches are not well
45 understood.

46 Evaluation of revegetation effectiveness is often poorly done, if done at all, with poor record-
47 keeping often making it difficult to assess outcomes (Brooks and Lake 2007). Where revegetation
48 outcomes are assessed, success is often evaluated in terms of parameters reflecting vegetation
49 structure, which require less expert knowledge and are more readily measurable compared to
50 vegetation diversity or ecosystem processes (Ruiz-Jaen and Mitchell Aide 2005).

51 There is a key knowledge gap in understanding how vegetation communities develop after
52 revegetation and whether the method of revegetation influences vegetation diversity outcomes. We
53 surveyed several revegetated sites where the objective of the revegetation was to enhance the
54 riparian vegetation community by re-introducing appropriate native tree and shrub species. At each
55 site, direct seeding and tube-stock planting had been undertaken and we asked which revegetation
56 method resulted in better restoration outcomes.

57

Methods

Study sites

Revegetation outcomes at seven riparian sites were assessed for this study. All sites were within the Greater Melbourne area and in a rural or peri-urban setting (Figure 1). The Emu Creek site had been revegetated across two years and each year's revegetation was considered separately. All sites had been revegetated 1–4 years prior to survey and had been planted and sown with a mix of woody species selected to facilitate the establishment of the appropriate vegetation community for that site (Table 1).

The sites vary in their environmental characteristics such as soils and climate—e.g. four of the monitored sites are located within the fertile Yarra River valley, while two sites are located on the less fertile basalt plains west of Melbourne and experience a drier climate (Table 1). The adjacent land use also varied between sites, from the Yarra River site at McMahons Creek which is situated on the edge of the Yarra Ranges National Park to the Emu Creek site which is adjacent to a quarry (Table 1). At all sites, the original riparian vegetation had been cleared and at the time of revegetation, the vegetation at all sites was dominated by exotic species, primarily pasture grasses. Five sites were previously used for agricultural purposes, and two sites (Hoddles Creek and Cardinia Creek) were on degraded public lands. The extent to which factors such as fertiliser application, ploughing and compaction had compromised soil quality is unknown for most sites, and is not considered in our study.

Revegetation activities

Weed control was undertaken at all sites prior to revegetation and typically included at least two applications of a broad-spectrum herbicide to control herbaceous species (Table 1). In addition, mechanical slashing of tall herbaceous weeds such as grasses and thistles was undertaken prior to spraying at the Launching Place and Emu Creek sites. Woody weed control was also undertaken at these two sites with willows (*Salix* spp.) and African Boxthorn (*Lycium ferocissimum*) removed respectively.

Rabbit (*Oryctolagus cuniculus*) control measures were implemented at the Emu Creek and Deep Creek sites, but no other active herbivore control measures were employed at sites. At the McMahons Creek site, herbivore-exclusion fences were erected around all plots. All other sites were unfenced (Table 1).

While five sites were sown mechanically, two sites were sown by hand broadcasting (Table 1). Tube-stock plants were planted by hand, into holes created by a mechanised augur, Hamilton planter or spade. Tree guards (plastic or wire mesh guards) were used at all unfenced sites except Hoddles Creek, and jute mats were placed at the base of plants at the time of planting at some sites (Table 1).

The seeding and planting rates, and the species mixes used at each site were based on the relevant vegetation community being restored. Some species were common to several sites, but no species was present at all sites. Within sites, similar species mixes were sown and planted, but different numbers of species were often present in the sowing and planting mixes, with more species generally sown than planted (Table 1).

Site maintenance after revegetation varied between sites (Table 1). Standard industry practice for post-establishment weed control was applied at most sites, with herbicide spraying around the base of tube-stock plants carried out up to three times per year after planting. For lines of direct seeding, spraying occurred between lines as close to the edge of the sown line as possible without risking damage to emerging seedlings. All site preparation, fencing, revegetation and site maintenance was carried out by contractors, following industry best practice.

Data collection and synthesis

Sampling protocols used at each site were flexible to account for differences in site size and characteristics. At the Cardinia Creek, Emu Creek sites and Hoddles Creek sites, all plants within sown and planted lines/plots were assessed. At the Deep Creek, Launching Place and Sheepstation Creek sites, randomly selected belt transects were used to sub-sample direct seeding lines. Transects encompassed sown lines and were either 20 m long (Sheepstation Creek) or 50 m long (remaining sites). The number of transects assessed per site varied with site size (minimum $n = 6$). Low numbers of tube-stock were planted at the Deep Creek and Sheepstation Creek sites, and 50 plants were randomly sampled at these sites. At Launching Place, three randomly placed quadrats (50 m x 20 m) were used to assess tube-stock plants. Similarly, at McMahon's Creek, tube-stock were assessed in six 5 m x 5 m quadrats, while twelve 1 m x 1 m quadrats were used to assess the direct seeding at this site, with quadrats randomly placed. At all sites, the sampling intensity was sufficient to represent outcomes. In all cases, plant numbers and plant heights of all identified target species were recorded.

For each site and revegetation approach (direct seeding or planting) we calculated: the resulting woody plant density (plants per hectare); the proportion of species that were either sown or planted which established (i.e. were represented by live individuals at the time of survey); species

richness, including those species that recruited naturally – species not sown/planted; species diversity, based on Pielou’s evenness index (a measure of how evenly individuals are distributed across species; Pielou 1966); and mean plant heights.

At the two sites where seed was broadcast by hand (Hoddles Creek and McMahon’s Creek), plant density was calculated on a per m² basis and then scaled up to a per hectare basis. For the remaining sites, plant density in sown lines was calculated on a plants per lineal metre basis and then scaled up assuming 3 linear kilometres of sowing lines per hectare. All plant nomenclature conforms to that of Walsh and Stajsic (2007).

Results

Plant density

Direct seeding typically resulted in higher plant densities than planting (5 out of 6 cases; Table 2)—the latter being largely determined by initial planting density. In some cases, resulting plant densities were an order of magnitude greater in sown than planted areas, e.g. 21,866 plants/ha in broadcast sown plots compared to 2,000 plants/ha in planted plots at Hoddles Creek (Table 2).

Low plant densities resulting from direct seeding at some sites were attributable to environmental factors. For example, dry conditions prevailed following the 2015 direct seeding at Deep Creek. Frosts and low rainfall befell the 2017 sowing at Emu Creek, while at the Sheepstation Creek site waterlogging is likely to have limited plant recruitment from direct seeding. Such conditions also typically hampered the survival or condition of plantings, but to a lesser extent.

Species establishment

The number of species that established compared to the number sown/planted was generally lower for direct seeding than planting, with a median of 67% of target species establishing in direct seeded areas compared to 100% in planted areas (Table 2). Direct seeding did not result in all sown species establishing at any site (maximum = 90%). In contrast, in all but one of the eight revegetation projects assessed, 100% of the planted species established. Notably, that site (Hoddles Creek) was the only one in which the tube-stock plantings were not guarded or fenced.

Species richness

Even though more species were often included in the sowing mix than were planted at each site (Table 1), the native woody species richness recorded in sown and planted areas were generally similar (Table 2). The two exceptions were: Hoddles Creek, where plantings were unguarded and damaged by browser and human impacts; and McMahon's Creek, where despite the very high plant densities resulting from direct seeding (100,000+ plants/ha), only 9 of the 17 sown species established (an additional two species Silver Wattle, *Acacia dealbata*, and Yarra Burgan, *Kunzea leptospermoides*, naturally recruited within sown areas). Species introductions resulting from natural recruitment were not common and limited (Table 2).

Species diversity (evenness)

The species diversity (evenness) of plants resulting from direct seeding was consistently lower, and in some cases much lower, than that for plantings (Table 2), with direct seeded areas commonly dominated by one or two (often *Acacia*) species (Figure 2). For example, at Launching Place, Silver Wattle accounted for 272 out of the 397 plants surveyed (69% of all plants). In contrast, the dominant species in the planted areas, Swamp Gum (*Eucalyptus ovata*) and Prickly Moses (*A. verticillata*), accounted for 13% and 11% of plants, respectively. Similarly, at Cardinia Creek, Hedge Wattle (*A. paradoxa*) and Prickly Moses accounted for 80% of all plants resulting from direct seeding, and at Emu Creek, four *Acacia* spp. accounted for 84% of all plants resulting from the 2017 sowing (13 species sown) (Figure 2).

Plant heights

Mean plant heights (ignoring some large between-species differences) largely reflected the age of the revegetation, with plants unsurprisingly taller with increased age. There was also a tendency for plants to be taller at sites with wetter climates than at sites with drier climates at a similar age. At the youngest sites, planted plants tended to be taller than direct seeded plants, reflecting the different ages of the plants. However, direct seeded plants were taller than their planted counterparts at the two oldest sites surveyed, Hoddles Creek (4 years) and Launching Place (2.5 years) (Table 2).

Some sites with relatively low plant densities resulting from direct seeding also had relatively low plant heights, often as a result of herbivory. High levels of browsing of both direct seeded plants and plantings was apparent at the Cardinia, Emu, Sheepstation and Deep Creek sites.

Discussion

Our assessments of seven revegetation projects in the first years after establishment suggest that direct seeding tends to result in greater plant density, similar species richness, but lower rates of species establishment and species diversity than planting.

Plant density outcomes

Our findings are consistent with previous studies that have found that direct seedling typically results in higher plant densities than planting tube-stock (England *et al.* 2013; Freitas *et al.* 2019). Also consistent with previous studies, direct seeding outcomes were quite variable between our study sites. Such variability has been highlighted by other reviews of direct seeding outcomes, e.g. 150–8460 plants/ha for 50 sites in northern Victoria (Pryde and Duncan 2015) and 860–20,000 plants/ha for three sites in Tasmania (Close and Davidson 2003). In contrast, densities resulting from planting can be expected to be more predictable (based on initial planting densities).

Stem densities at two of our sites (Hoddles Creek and McMahon's Creek) were particularly high (20,000+ stems/ha), but were similar to densities found at 1.5 year old direct seeded sites in the Southern Tablelands of NSW (~17,000 stems/ha; Schneemann and McElhinny 2012). Indeed, plant densities resulting from direct seeding are often much higher than those of the vegetation communities that the revegetation is attempting to restore (Pryde and Duncan 2015; Schneemann and McElhinny 2012). This is potentially of concern given that high stem densities resulting from revegetation can delay the provision of habitat features such as tree hollows and fallen logs by decades (Vesk *et al.* 2008). However, plant densities resulting from direct seeding can be expected to decline with age (Schneemann and McElhinny 2012), as is commonly seen in natural recruitment events after a disturbance such as a flood or fire.

Species establishment, species richness and diversity outcomes

Direct seeding typically resulted in much lower proportions of species establishment (compared to the number introduced) than planting. In all projects where plants were guarded, all planted species were represented. In contrast, approximately two-thirds of the sown species established via direct seeding. These proportions of species establishment from direct seeding are comparable to those found in a study in southern Western Australia at similarly aged sites: 15–70% across eight direct seeding projects (Heydenrych and Ten Seldam 2011).

Nonetheless, because more species were often sown than were planted, the species richness of direct seeded and planted areas were similar, at most sites. However, the diversity (evenness of spread of individuals across species) was typically much lower for direct seeded areas. This lower

diversity (evenness) of species in the early stages of establishment following direct seeding is of concern given that sown sites are likely to decline in species richness with age (Schneemann and McElhinny 2012). Such declines have been attributed to a few dominant overstorey species (e.g. *Acacia* species) monopolising site resources (Close and Davidson 2003). Similarly, in our study, one or a few *Acacia* species often dominated sown areas; these may become more dominant over time, further depressing diversity. Notably, relatively unpalatable *Acacia* species (e.g. Hedge Wattle at Deep Creek) tended to be particularly dominant at sites where browsing impacts were common and direct seeding resulted in low–moderate stem densities.

It should be noted, however, that our study only assessed relatively young revegetation sites, and analyses of revegetation outcomes over longer time periods may also reveal declining species richness in tube-stock plantings over time, as has been observed at some sites (D. Robertson, personal observation). It is also worth noting that survival of planted specimens does not necessarily mean that progeny of that species will germinate on the site in the future—one of the long-term goals of restoration. In contrast, the potential for germination has already been demonstrated in the case of those species that successfully germinated and established on site from direct seeding.

Plant growth and overall revegetation outcomes

Direct seeded plants were taller than tube-stock plants at the older (>2 years-old) sites we assessed. This suggests that initial differences in plant heights between tube-stock plants and seedlings resulting from direct seeding may be readily overcome. Moreover, given the higher stem densities in direct sown areas, stand development is likely to be faster for direct seeded than planted areas (England *et al.* 2013; Freitas *et al.* 2019).

Nonetheless, at our sites, overall revegetation outcomes were often driven by environmental factors, regardless of revegetation method. Sites that experienced conditions that were particularly dry (e.g. Deep Creek) or wet (Sheepstation Creek) generally had poorer outcomes. Herbivory was another impediment to plant establishment and growth at many of our sites. It is likely that weed competition also limited plant establishment at some sites. These results reflect the findings that climatic factors (e.g. droughts, flooding) and biotic interactions (herbivory and competition) are often major constraints to revegetation efforts globally (Palma and Laurance 2015).

Such constraints are likely to be more deleterious to seedlings that arise from direct seeding than planted tube-stock due the limited ability of young seedlings to compete for resources. It is likely that this greater vulnerability of small seedlings to the vagaries of weather, herbivores and competition make direct seeding outcomes so variable (Close and Davidson 2003; Pryde and Duncan

2015). While direct seeding is cheaper than planting, planting seedlings can yield better results in terms of increased survivorship, potentially accelerating recovery of vegetation structure and diversity (Palma and Laurance 2015).

Potential strategies for enhancing revegetation outcomes

Revegetation is undertaken for many reasons, in riparian areas these tend to be for biodiversity, erosion control or water quality purposes. If high species diversity is not a primary objective, direct seeding is likely to be the most cost-effective approach, given appropriate management of weeds, browsing threats and abiotic limitations, where possible. Where higher species richness is needed, supplementary planting may be beneficial.

Regardless of revegetation approach (direct seeding or planting), in drier environments contingencies should be made for the potential need to water young plants (Close and Davidson 2003). A good understanding of browsing pressures at a site is necessary to guide appropriate browser protection measures, while appropriate pre- and post-revegetation weed control is also critical (Close and Davidson 2003).

Where biodiversity gains are the primary aim of the revegetation, it is possible that a combined approach including both sowing and planting may prove most fruitful. Hardier or more reliable species may be sown, combined with planting and guarding of more palatable or keystone or rare species (Jusaitis and Polomka 2008). Alternatively, Schneemann and McElhinny (2012) suggest tubestock planting of overstorey species and direct seeding of mid- and understorey species to minimise competition, achieve appropriate stem densities and maximise species diversity. Some authors and practitioners suggest a successional approach, with sowing and planting occurring in stages to facilitate appropriate structural development and enhance diversity (Close and Davidson 2003; Cole *et al.* 2011).

There is good evidence to suggest using a greater number of species in sowing mixes increases the species richness of direct seeding outcomes (Kirmer *et al.* 2012; Pryde and Duncan 2015; Schneemann and McElhinny 2012). Although using species-rich species mixes is more expensive, resultant diversity gains are likely to improve vegetation community development (Kirmer *et al.* 2012; Palma and Laurance 2015). Species selection for revegetation is often constrained by availability (Palma and Laurance 2015), and in Australia, there is a need to better develop our seed production industries (Cuneo *et al.* 2018). Importantly, species selection for direct seeding is often less constrained than for planting (Palma and Laurance 2015)—as was found in our study with greater numbers of species used in direct seeding than planting.

We suggest that when diverse native vegetation communities are the goal, optimal revegetation outcomes are likely to be achieved when direct seeding and planting are used in tandem.

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359 **Table 1: Study site and revegetation details, including weed control and other site preparation/maintenance details, and age at assessment.** MAR = Mean annual rainfall, taken from
 360 nearest Bureau of Meteorology station.

Site	Description	Sowing/Planting (no. species sown/planted)	Site maintenance	Plant protection	Age at assessment (~years)
Hoddles Creek	Riparian crown land 60 x 1200 m Some remnant vegetation nearby MAR: 884 mm	5 plots each 100 m ² , containing 40 – 50 niches Niches either hand sown (3 plots) or planted with 1 plant per niche (2 plots) (20/7 trees and shrubs)	Weed control at 1 and 3 months after establishment	Unfenced Tube-stock unguarded, jute mats installed	4
Launching Place (Yarra River)	Ex-pasture 4 km stream frontage, varying width Limited remnant vegetation nearby MAR: 884 mm	6.2km lines direct seeded (mechanical) 6,000 tube-stock plants (18/13 trees and shrubs)	Seeding line edges sprayed 1 and 2 months after sowing	Unfenced Tube-stock guarded with plastic guards, jute mats installed	2.5
Cardinia Creek	Retarding basin Approximately 1 ha	104 m lines direct seeded (mechanical)	Seeding line edges sprayed 1, 2 and 3	Unfenced Tube-stock guarded	2

	Limited remnant vegetation nearby MAR: 936 mm	288 tube-stock plants (6/6 shrubs)	months after sowing, then 3x/year Tube-stock sprayed 3x/year	with plastic guards, jute mats installed	
McMahons Creek (Yarra River)	Ex-pasture 70 x 800 m National Park adjacent MAR: 1380 mm	13 plots each 225 m ² Plots either hand sown (4 plots) or planted with 350 tube-stock (9 plots) (17/23 trees and shrubs)	Sprayed at 1, 4 and 5 months after sowing	Fenced with deer and rabbit proof fences Tube-stock had jute mats installed	2
Emu Creek	Ex-agriculture, quarry adjacent Approximately 1.5 ha Very limited remnant vegetation nearby MAR: 587 mm	800 m lines direct seeded (mechanical), both years 2016: 400 plants; 2017: 264 plants (2016: 17/14 trees and shrubs; 2017: 13/8 trees and shrubs)	Slashing/spraying between lines 2x yearly Watering (2–3x/summer) On-going rabbit control	Unfenced Tube-stock guarded with wire guards	2, 1 (revegetation across two years)
Sheepstation Creek	Ex-pasture 0.5 ha	Site direct seeded (mechanical) in lines	Seeding line edges sprayed	Unfenced Tube-stock guarded	1.5

	Some remnant vegetation nearby	Tube-stock haphazardly planted between lines		with plastic guards	
	MAR: 1296 mm	(20/10 trees and shrubs)			
Deep Creek	Ex-pasture	Site direct seeded	Nil	Unfenced	1
	Approximately 2 ha	(mechanical) in lines		Tube-stock guarded	
	Limited remnant vegetation nearby	Tube-stock haphazardly planted across site		with wire guards	
	MAR: 535 mm	(7/4 trees and shrubs)			

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Table 2. Plant densities, species establishment, species richness, species diversity (evenness) and heights of plants established by either direct seeding or planting at seven sites between one and four years after revegetation (see Table 1 for details). *n* = total number of plants sampled; NA – not applicable.

Site	<i>n</i>		Plant density (plants/ha)		Species establishment		Species richness*		Species diversity (evenness)		Plant heights (cm ± SE)	
	<i>Sown</i>	<i>Planted</i>	<i>Sown</i>	<i>Planted</i>	<i>Sown</i>	<i>Planted</i>	<i>Sown</i>	<i>Planted</i>	<i>Sown</i>	<i>Planted</i>	<i>Sown</i>	<i>Planted</i>
Hoddles Creek	719	40	21,866	2,000	90%	57%	18	7(3)	0.65	0.88	200 ± 5	143 ± 15
Launching Place	397	373	1,985	1,193	61%	100%	12(1)	17(4)	0.48	0.93	406 ± 16	387 ± 16
Cardinia Creek	69	226	2,019	6,519	83%	100%	5	6	0.66	0.93	73 ± 5	138 ± 4
McMahons Creek	366	236	103,300	14,067	53%	100%	11(2)	23	0.73	0.94	153 ± 4	257 ± 11
Emu Creek												

2016	661	332	2,486	1,252	71%	100%	13(1)	14	0.73	0.96	29 ± 1	90 ± 3
2017	436	221	1,654	829	62%	100%	8	8	0.81	0.96	13 ± 1	40 ± 1
Sheepstation Creek	243	50	806	NA	50%	100%	10	10	0.90	0.92	18 ± 1	32 ± 2
Deep Creek	70	50	700	NA	71%	100%	5	5(1)	0.67	0.85	9 ± 1	31 ± 2
Median	382	224	2,002	1,626	67%	100%	10.5	9	0.70	0.93	51	90

364 *Numbers of species recorded that were not sown/planted, i.e. natural recruits, shown in parentheses.



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