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Revegetation of post-mined land using directly planted native and local shrub species

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Abstract

Directly planting propagules from nearby undisturbed (pre-mined) land can decrease the time required to establish multiple layers of forest vegetation cover on post-mined land in the Canadian boreal forest. Typically, trees are planted, but the majority of native shrub species and forbs are left to regenerate unassisted, which may take decades. Hand collecting vegetative propagules from surrounding pre-mined land and directly planting these propagules on post-mined land may be the only method to successfully establish key shrub species and forbs. Directly planting propagules has several advantages over seeding or out-planting nursery grown stock: the vegetation will consist of species that are native and local to the area, there is no cost for the propagules, numerous species regenerate by vegetative reproduction and thus can be transplanted and new vegetative propagules are available for collection each year. The amount of labour required for transplanting can be reduced by using collection and direct planting techniques that result in a high percentage of survival but cause minimal impact on the surrounding vegetation at the collection sites. Greenhouse and field trials were conducted using both entire plants (above-ground plant and attached root) and root cuttings of Vaccinium myrtilloides *(common blueberry),* Viburnum edule *(low-bush cranberry),* Shepherdia canadensis *(Canada buffaloberry) and* Vaccinium membranaceum *(mountain huckleberry). The survival response of entire plants and root cuttings to season of collection (fall and spring) was species specific, and with the exception of Canada buffaloberry, root cuttings out-performed whole plants. The optimal root cutting length was between 10 and 15 cm when planted horizontally. In field trials at Coal Valley Mine, Alberta, Canada, preliminary results suggest that transplanting entire plants and root cuttings within soil plugs can increase the percentage of surviving propagules.*

1 Introduction

Rapidly establishing native and local shrub species on post-mined (disturbed) land is an important step in restoring a functional ecosystem; shrubs are important for decomposition, soil fertility and wildlife habitat (Nilsson and Wardle, 2005). In Alberta, Canada, common reclamation techniques for disturbed land in the boreal forest involves seeding grasses and legumes to stabilise the soil and planting trees to establish tree cover. Willow and alder cuttings are often planted, but most shrub species are left to regenerate unassisted. Unassisted, the establishment of shrubs on disturbed land can take decades (Mackenzie and Naeth, 2009). Rapidly restoring a functioning ecosystem on disturbed land is important in Alberta where more than 60,000 ha of land have been disturbed by oil sands mining in addition to land disturbed by 12 active coal mines, the largest of which comprises 5,000 ha (Government of Alberta, 2011).

Plant species in the boreal forest establish either by vegetative reproduction, from seed or a combination of both vegetative reproduction and by seed (Holloway and Zasada, 1979). Plants that establish vegetatively are initially supported by the tissue of the parent plant. The pool of resources (carbohydrates, nutrients, access to water) provided by parent plant tissue allows for the rapid development and growth of the plant. Conversely, establishment of plants by seed is typically slower and the germination and establishment success much lower (Young and Young, 1992). The extra resources provided by parent tissue in vegetative reproduction may be beneficial on disturbed land as resources needed for growth may be lacking.

Establishing shrub species on post-mined land using vegetative reproduction has many benefits. Propagules from pre-mined land can be collected and planted. Using local and native propagules preserves biodiversity, and the plants are adapted to the environmental conditions. At an operational scale, directly transplanting locally collected propagules on post-mined land decreases reliance on nursery grown stock and seed. Many boreal shrubs have low germination rates from seed (Young and Young, 1992), and both nursery grown stock and seed can be costly.

Several factors must be considered when attempting to re-vegetate post-mined land by directly planting vegetative propagules. Low soil moisture and competing vegetation i.e. weeds can cause rapid desiccation and prevent photosynthesis. Carbohydrate reserves of plants vary throughout the year (Landhausser and Lieffers, 1997), and propagules with low carbohydrates have a decreased capacity to survive without immediate inputs from photosynthesis. For example, a root cutting collected and transplanted during the summer has low carbohydrate reserves. It cannot photosynthesise immediately because it needs to produce shoots and leaves first, but due to its low carbohydrate reserves it is unable to produce new leaves, shoots or roots and thus exhaust its energy reserves. Propagules collected during the fall may have a greater carbohydrate reserve and be able to produce shoots, leaves and roots and survive. However, seasonal carbohydrate changes can vary by species (Landhausser and Lieffers, 1997). Similar to carbohydrates, hormone concentrations vary throughout the year (Frey et al., 2003) and a specific balance of hormones is needed for the production of new shoots and roots from vegetative propagules. Species specific collection and planting techniques that provide ideal environmental and physiological conditions need to be developed to ensure that the maximum establishment rate is achieved so that operational costs are kept low.

The objectives of the following study were to determine the environmental and physiological conditions needed to establish *Vaccinium myrtilloides* (common blueberry), *Viburnum edule* (low-bush cranberry), *Shepherdia canadensis* (Canada buffaloberry) and *Vaccinium membranaceum* (mountain huckleberry) on post-mined land in Alberta, Canada by transplanting vegetative material. Specifically, operationally feasible collection, handling and planting techniques were used to manipulate environmental and physiological conditions and the effects on plant establishment were determined.

2 Methods

2.1 Greenhouse trial

Vegetative propagules for common blueberry, low-bush cranberry and Canada buffaloberry were collected in May 2009 (spring) and October 2009 (fall) from 18 collection sites located on pre-mined land (undisturbed forest) within Syncrude Canada Limited's mine permit area. The permit area is located north of Fort McMurray in the central mixed-wood region of Alberta. Low-bush cranberry and Canada buffaloberry were collected from areas with trembling aspen (*Populus tremuloides*) canopy cover (9 sites), and common blueberry from areas with black spruce (*Picea mariana*) or jack pine (*Pinus banksiana*) canopy cover (9 sites). The same collection areas were used in the spring and fall. Simple and quick collection methods that could be applied at an operational scale were used. The desired species were identified and the above-ground portion of the plant was grasped with two hands, and the plant and attached root were pulled from the ground. Ten centimetres of root was left attached to the plant (whole plant), and the remaining root was trimmed. The trimmed-off portion of the root was cut into 5, 10 or 15 cm segments to be used as root cuttings. Whole plants were stored with the base of their stem in water and peat. Root cuttings were placed into sealed plastic bags containing moistened paper towels. The collected material was transported to a greenhouse. The spring collected material was planted immediately and the fall collected material was stored at -2°C from October 2009 until February 2010 when it was planted. The whole plants and root cuttings were planted in 0.25 gallon pots that were filled with a peat-perlite mix. Whole plants were planted with a minimum of 5 cm of soil covering the attached root. Root cuttings were planted horizontally at a depth of 5 cm. Five whole plants or root cuttings from the same collection site were planted in each pot. After transplanting, the pots were placed in a greenhouse with temperatures that ranged between 20 to 30°C for a 12 week growth period. Soil moisture was kept at 80% of its field capacity by weighing and watering the pots during the growth period.

2.1.1 Experimental design

The greenhouse trial was divided into two experiments for each of the three shrub species. The experiments examined the effects of vegetative material type, season of collection and root cutting length. Each collection site was considered a replicate and three pots (sub-replicates) were prepared from each collection site. The number of replicates was different for each of the experiments due to the availability of vegetative material (n = 9 for the first experiment, n = 6 for the second experiment).The effect of vegetative material type (whole plants and root cuttings) and season of collection (spring and fall) on establishment (production and maintenance of living leaves or shoots with leaves) was examined in the first experiment. Whole plants as opposed to root cuttings can produce auxins from its shoot buds to stimulate root growth. Whole plants can also immediately produce new leaves for photosynthesis. Unlike root cuttings or seeds, they do not need to produce both shoots and leaves. Initially, root cuttings do not have to support a large above-ground portion and thus demands for water and resources are reduced. Fall and spring collected propagules were used due to possible differences in hormone and carbohydrate content. All root cuttings were 10 cm long and planted horizontally. The second experiment examined the effect of root cutting length (5, 10 or 15 cm) and season of collection (spring and fall) on establishment. Longer root cuttings are thought to have a greater pool of resources for survival and establishment.

2.1.2 Data collection and analysis

At the end of the 12 week growing period, the number of established whole plants (plants that had living leaves) was counted for each pot. Root cuttings were dug up and the number of roots in each pot that had established (roots that had produced new shoots that were still living at 12 weeks) was counted. Data collected for each of the experiments were analysed as a two-way ANOVA using SYSTAT® Version 10. The data from the three pots that were planted from each collection site were combined (averaged), and each collection site was considered a replicate. For the first experiment the main treatments were season of collection (fall and spring) and vegetative material type (whole plants and root cuttings), including the interaction of these treatments. The response variable was establishment or the number of whole plants with living leaves or root cuttings with living shoots. For the second experiment the main treatments were season of collection (fall and spring) and root cutting length (5, 10 and 15 cm), including the interaction of these treatments. The response variable was establishment or root cuttings with living shoots. Least significant difference (LSD) tests were used to compare means. An alpha value of 0.05 was used to determine significance.

2.2 Field trial

Vegetative material for mountain huckleberry was collected in May 2010 from a 3 ha undisturbed area within Coal Valley Resources mine permit area located south of Hinton in the upper foothills region of Alberta. The area had a tree canopy consisting of lodgepole pine (*Pinus contorta*) and black spruce (*Picea mariana*). Local Aboriginals were employed for collection and planting. The same collection methods used to collect vegetative material for the greenhouse trials were used. The collected material was placed in moist peat. Plugs of Litter, Fermented, Humus (LFH) (i.e. forest floor consisting of moss and decomposing vegetation) containing mountain huckleberry roots were also collected; 10 cm x 10 cm x 10 cm plugs of intact LFH and upper mineral soil were cut from the ground with a sharpened spade. The vegetative material and plugs were not stored but directly planted into soil that had been replaced after mining (reclaimed land). Planting involved cutting a 5 cm deep slit in the ground with a spade and inserting the root of the whole plant or root cutting into the ground. Ten cm long root cuttings were planted. The slit was then closed by stepping on the ground surface above the slit. LFH plugs were planted by cutting out a similar sized soil plug on the disturbed land and inserting the LFH plug into the resulting hole and then stepping around the plug to ensure it was in contact with the surrounding soil. The transplants were spaced approximately 1 m apart.

2.2.1 Experimental design

Planting treatments included age of reclaimed land, vegetative material type, and orientation of root cutting. Three ages of reclaimed land were chosen: reclaimed areas that had a closed tree canopy (approximately 20 years since soil replacement), recently tree planted areas that had mainly grass and legume cover (approximately 5 years since soil replacement) and areas where topsoil had been recently spread (less than one year since soil replacement). These areas were chosen for their differences in soil moisture and competing vegetation. Whole plants, root cuttings planted horizontal and root cuttings planted diagonally on a 45° angle i.e. one end of the root was just below the soil surface and the other end approximately 5 cm below the surface, were transplanted on the three ages of reclaimed land. Root cuttings were planted diagonally as the sucker has less soil to grow through before it emerges; however the chance of desiccation is greater as it is closer to the surface compared to horizontal planting. Three replicates for each age of reclaimed land were planted (n = 3). At each replicate, 5 rows of 20 plants (sub-replicates) were planted for whole plants, root cuttings planted horizontally and root cuttings planted diagonally. Two rows of 20 LFH plugs were also planted at each replicate site for areas with tree canopy cover and recently tree planted areas (LFH plugs were not transplanted on the areas where topsoil had been recently spread).

2.2.2 Data collection and analysis

Preliminary data were collected in September 2010. The number of whole plants or root cuttings that had established (plants that had living leaves or root cuttings that had produced new shoots that were still living) was counted for each row. The number of LFH plugs with living mountain huckleberry plants growing in them was counted per row and species richness per plug was recorded. Rows (sub-replicates) of similar treatment at each planting replicate were averaged (n = 3). The data were not analysed statistically as growth was minimal during the first year, but is presented to show preliminary trends.

3 Results

3.1 Greenhouse trial

3.1.1 Common blueberry

Common blueberry root cuttings had higher establishment rates than whole plants (p = 0.034). An average of 4.1 root cuttings per pot had newly produced living shoots (referred to as living) compared to 3.4 whole plants per pot with living leaves (referred to as living). Season of collection did not have a significant effect (p = 0.079) on establishment; fall collected material had 4.0 living whole plants or root cuttings per pot compared to 3.5 per pot for spring collected material (Figure 1).

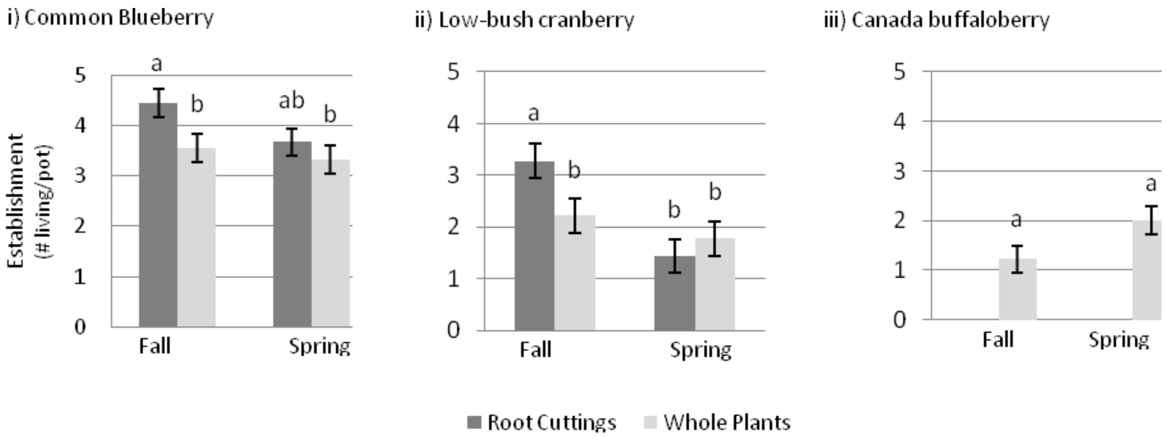

Figure 1 Effect of vegetative material type and season of collection on establishment of i) common blueberry (*Vaccinium myrtilloides*), ii) low-bush cranberry (*Viburnum edule*) and iii) Canada buffaloberry (*Shepherdia canadensis*) transplants. Bars represent the average number of transplanted whole plants with living leaves and root cuttings with living shoots per pot (5 whole plants or root cuttings were planted per pot) 12 weeks after transplanting. For each graph, different letters indicate significant differences based on LSD means comparison testing. Error bars represent standard error

Root cutting length affected establishment (p = 0.005) of common blueberry. Root cutting length had a larger impact on establishment for spring collected material than for fall collected material. Spring collected root cuttings 15 cm in length averaged 4.2 living per pot, 10 cm long root cuttings averaged 3.8 living per pot and 5 cm long root cuttings averaged 3.0 living per pot. For fall collected material the average number of living root cuttings ranged from 4.2 to 4.7; survival was slightly higher for longer root cuttings. Season of collection also affected establishment (p<0.001). Fall collected propagules averaged 4.5 living root cuttings per pot compared to 3.6 for spring collected (Figure 2). Examination of the root system of the transplants revealed that most of the propagules that were living after twelve weeks had produced new fine roots.

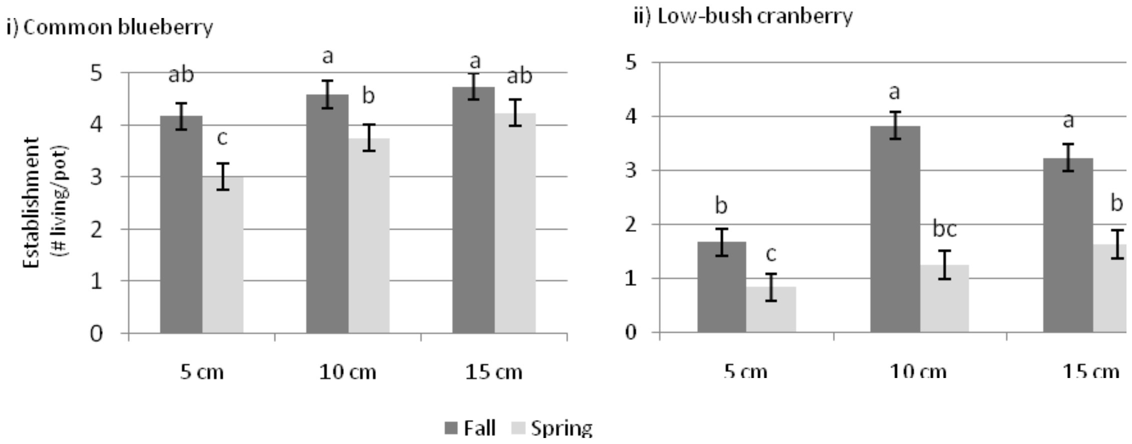

Figure 2 Effect of root cutting length and season of collection on establishment of i) common blueberry (*Vaccinium myrtilloides*) and ii) low-bush cranberry (*Viburnum edule*) transplants. Root cutting lengths of 5, 10 and 15 cm were transplanted. Bars represent the average number of transplanted root cuttings with living shoots per pot (5 root cuttings were planted per pot) after 12 weeks. For each graph, different letters indicate significant differences based an LSD means comparison testing. Error bars represent standard error

3.1.2 Low-bush cranberry

Fall collected low-bush cranberry root cuttings had higher establishment rates than spring collected root cuttings, spring collected whole plants and fall collected whole plants. The interaction of season and vegetative material type was significant ($p = 0.039$). For fall collected root cuttings, there was an average of 3.3 living root cuttings per pot (Figure 1). The effect of root cutting length and season of collection on establishment was more evident in fall collected cuttings than spring collected cuttings ($p = 0.006$ for the interaction of season and cutting length). Fall collected root cuttings 15 cm in length had 3.2 living root cuttings per pot, 10 cm long root cuttings had 3.8 living per pot and 5 cm long cuttings had 1.7 living per pot. Spring collected root cuttings had between 0.8 to 1.6 living root cuttings per pot; establishment was slightly higher for longer root cuttings (Figure 2). Examination of the root system of the transplants revealed that most of the propagules that were living after twelve weeks had produced new fine roots.

3.1.3 Canada buffaloberry

Fall and spring collected Canada buffaloberry root cuttings did not produce any shoots. The establishment rate for fall and spring collected whole plants was not significantly different ($p = 0.065$). There was an average of 2 living plants per pot for the spring collection and 1.2 living plants per pot for the fall collection (Figure 1).

3.2 Field trial

Preliminary results suggest that the age of reclaimed land affects the establishment rate of mountain huckleberry whole plants and root cuttings. An average of 1 whole plant or root cutting per row (20 whole plants or root cuttings were planted per row) was living on reclaimed areas with tree canopy cover, 0.8 were living per row on areas that had been recently tree planted and 3.9 were living per row on areas where topsoil had been recently placed. Whole plants, root cuttings planted horizontally and root cuttings planted diagonally had similar establishment rates. There was an average of 2.1 living whole plants per row, 1.9 living root cuttings planted horizontally per row, and 1.8 living root cuttings planted diagonally per row (Figure 3).

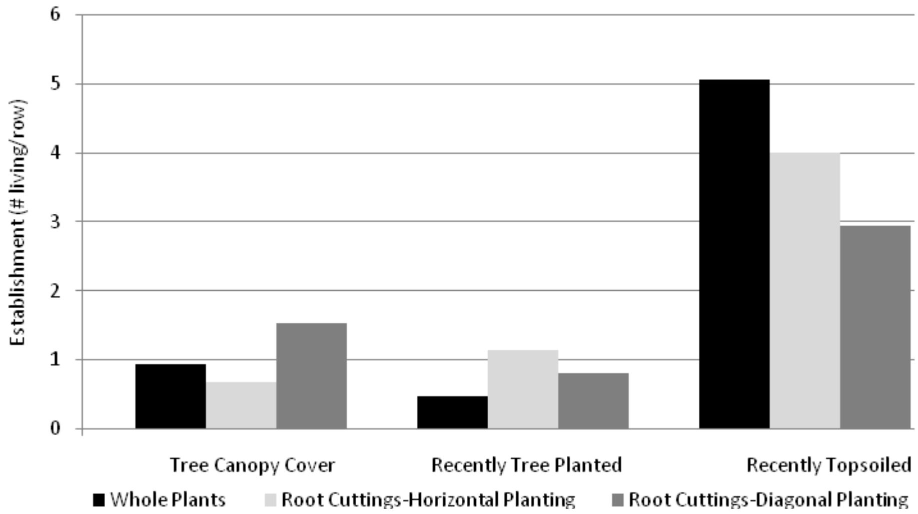

Figure 3 Preliminary effect of age of reclaimed land and vegetative material type on establishment of mountain huckleberry (*Vaccinium membranaceum*) transplants. Transplants were planted under a closed tree canopy, on areas with that had been recently tree planted and areas that had topsoil placed recently. Root cuttings were planted both horizontally and diagonally at a 45° angle. Bars represent the average number of transplanted whole plants with living leaves and root cuttings with living shoots per row of 20 transplants after approximately 12 weeks

The survival of mountain huckleberry propagules when transplanted within LFH plugs was affected by age of reclaimed land. On reclaimed areas with tree canopy cover an average of 17.6 plugs per row of 20 plugs had living mountain huckleberry plants compared to 15.4 for areas that had been recently tree planted. A total of 14 different species were observed growing in the plugs. Common species observed, in addition to mountain huckleberry, included bunchberry (*Cornus canadensis*), bog cranberry (*Vaccinium vitis-idaea*), Labrador tea (*Ledum groenlandicum*) and trembling aspen (*Populus tremuloides*). Plugs planted under a tree canopy had an average of 2.4 different living native forb, shrub and tree species per plug compared to 2.0 different species per plug for plugs transplanted into reclaimed areas that had been recently tree planted.

4 Discussion and conclusions

Establishing native shrub species on disturbed land in the boreal forest is possible by directly transplanting local and native vegetative material. Greenhouse trials with common blueberry and low-bush cranberry suggest that establishment rates of >80% for common blueberry vegetative propagules and 60–80% for low-bush cranberry can be achieved from root cuttings. These establishment rates are significantly higher than seed germination rates for these species (Young and Young, 1992). The highest establishment rates were from fall cut root cuttings 10 to 15 cm in length. Unlike whole plants, root cuttings do not have to support an above-ground portion of a plant when they are under the greatest environmental stress just after transplanting and longer root cuttings provide a greater pool of resources. Fall collected root cuttings also benefit from higher carbohydrate reserves than spring collected cuttings (Landhausser and Lieffers, 1997). The greater carbohydrate reserves allow for the rapid production of leaves, shoots, and fine roots which are necessary for survival. For Canada buffaloberry, root cuttings did not produce shoots (suckers) but establishment rates for whole plants were approximately 40%. For some species, transplanting whole plants can be beneficial due to the presence of apical buds which are capable of producing auxin needed for root development. Establishment rates for Canada buffaloberry were lower than common blueberry and low-bush cranberry, but it may require very specific environmental or physiological conditions (Noste and Bushey, 1987) that were not replicated by the collection and planting techniques or growing conditions.

Preliminary results from the field trials with mountain huckleberry showed establishment rates of <20%; however, of the root cuttings that were dug up and observed, approximately 80–90% had suckers that had not yet emerged from the surface of the soil and may emerge in the upcoming growing season. Coal Valley Mine is located in the upper foothills where below freezing temperatures can persist from September until June and the average summer temperature is 13°C (National Climate Data and Information Archive, 2010). The cold temperature may have slowed the growth of these suckers. The age of reclaimed land and the presence of tree canopy cover did not appear to initially benefit establishment rates; higher rates were observed on areas where topsoil had been recently placed. However, there was greater than average precipitation during the 2010 growing season and under drier conditions establishment may be more dependent on soil moisture which is typically greater beneath a tree canopy. Whole plants and root cuttings planted horizontally and diagonally had similar survival rates. Long-term survival may be higher for the root cuttings due to the observation of shoots that had not yet emerged.

Greater than 80% of mountain huckleberry propagules transplanted within LFH plugs were living after 12 weeks. Planting the plugs under a tree canopy increased mountain huckleberry survival and allowed for the survival of other native species compared to planting on more recently reclaimed land. The increased soil moisture and lack of competition from grasses under the tree canopy likely allowed for a higher survival rate. Establishment is likely greater when vegetative propagules are transplanted within the LFH plugs because collection does not disturb the fine root system, and the LFH provides nutrients and other beneficial organisms such as myccorrhizal fungi which may be lacking in reclaimed soil (Mummey et al., 2002). Transplanting plugs allowed for the introduction of several shrub, forbs and moss species which were absent on most reclaimed land at Coal Valley Mine (Strong, 2000).

Rapidly establishing local and native vegetation on post-mined lands is essential for restoring ecosystem function, meeting government requirements and industry goals. High and rapid establishment rates are possible by transplanting vegetative propagules of local and native shrub species which are adapted to the area. Developing on-site stooling beds can increase the efficiency of propagule collection allowing for revegetation by directly planting vegetative propagules to be operationally feasible. Utilising alternative revegetation methods to establish local native shrub species creates opportunities for end land users, local aboriginal and community members, to participate in the revegetation of forested land and wildlife habitat. Working together and applying knowledge gained through research will allow industry to reduce their long-term impact on the environment.

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