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Rehabilitation of former Snowy Scheme sites in Kosciuszko National Park

By Elizabeth MacPhee and Gabriel Wilks

Ten years of restoration work at 200 sites within Kosciuszko National Park – sites damaged during the construction of Australias most iconic hydroelectric scheme – is showing substantial progress and is contributing to the protection of the parks internationally significant ecosystems.

Key words: *alpine ecosystem restoration, conservation management, industrial site remediation, soil stabilisation.*

Figure 1. Summer view in Kosciuszko National Park looking from about 1750 m (subalpine zone) to Geehi Dam (at 1100 m). The Snowy Mountains Hydro-Electric Scheme left high historic value, but a legacy of environmental damage at about 400 sites in the park, of which about half have been rehabilitated to date through this ambitious restoration project (The Alpine zone, including Mt Kosciuszko is in the far distance.) (Photograph G. Little).

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Introduction

Kosciuszko National Park (Fig. 1), located in the south-eastern corner of New South Wales (NSW), contains alpine and subalpine flora and fauna communities (Box 1), the continents' highest mountains, unique glacial landscapes, and rich indigenous and historic cultural values. These features have contributed to the park being included on the Australian National Heritage List and recognised as an International Biosphere Reserve (UNESCO 2010).

The Snowy Mountains Hydro-Electric Authority (SMHEA) Scheme, Australia's largest industrial project, was carried out from 1949 to 1974 in the area now gazetted as national park. This scheme is listed on Australia's Register of the National Estate for its internationally recognised engineering achievements and its impact on

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Box 1. Kosciuszko National Park Ecosystems

Kosciuszko National Park is one of the largest conservation reserves in Australia, encompassing 673 542 ha of land. It straddles the Great Dividing Range in south-east corner of the Australian mainland and contains the continent's highest peak, Mt Kosciuszko, at 2228 m. The park contains the headwaters of the Murrumbidgee, Snowy and Murray Rivers; however, 60% of the stream flow in the Park is captured and diverted for the Snowy Scheme and irrigation purposes. Its valued features include exceptional diversity of plant communities and endemic species in alpine vegetation, soils of outstanding scientific value and a number of threatened fauna species.

Vegetation

Three zones, based on altitude, are recognised (Good 1992, McClucki 1927, Costin 1954, 1957): montane zone, subalpine zone and alpine zone.

1 *Montane zone* consists of steeply sloping land extending from the valley floors and plains (at about 300 m) up to about 1500 m in NSW. At this upper limit, the mean mid-winter temperature is about 0°C, and in mid-winter, snow continuously lies for a month or more. Summers are hot to warm (the latter at higher elevations), and at the lower elevation average rainfall is about 650 mm, increasing to 2200 mm at the higher elevation. Typically in this zone, the summers are warm and the winters are cold. In this zone, many species of eucalyptus and other trees can grow.

The zone supports eucalypts and other trees, with broad community types including

(i) Woodlands of peppermints, boxes and stringybarks (*Eucalyptus* spp.), on duplex soil with sharp increases in clay content at about 30 cm in depth. This leads to a hardsetting surface, with subsoils of low soil porosity.

(ii) Open forests of peppermints and gums on soils with a gradual increase in clay content with progressively more friable soil with more open structure and increasing acidity.

(iii) Tall open forests of Alpine Ash (*Eucalyptus delegatensis*) and Mountain Gum (*Eucalyptus dalrympleana*) on soils with uniform texture profiles on soils that are more friable and more acidic, as low as pH 5.0, becoming clay loams or loams at about 1200 m.

The steep terrain of the ridges and long upper slopes result in shallow soils, from which material is being removed by natural processes such as soil creep, and in deeper soils on the lower slopes sometimes on collegial gravels which have in filled deep former gullies.

2 *Subalpine zone* is characteristically high plains or rolling plateaus and occurs between 1350 and 1750 m and is characterised by very low winter temperatures with snow lying on the ground. Cold, wet and often windy conditions can occur at any time of the year, and summers can be warm and dry. The range of trees that can survive is restricted; however, more by the cold and wet low winter temperatures, Snow Gum (*Eucalyptus pauciflora*) is characteristic of this zone.

There are two distinctive landscapes with characteristic soils:

(i) Snow Gums and heaths on shallow, stony, uniform soils. The understorey species include snow grasses (*Poa* spp.) and sparse heath plants. The upper slopes also have similar soils, with heath species of *Prostanthera*, *Orites*, *Grevillea* and *Phebalium* occurring.

(ii) Grasslands on deep uniform soils (alpine humus soils or organic loams on the lower slopes of the rolling plateaus. These slopes are characterised by the absence of trees due to cold air drainage patterns, but support open heaths and grasslands.

3 *Alpine zone* occurs above the treeline where the mean summer temperature is approximately 10°C or less. In NSW, the alpine zone occurs at around 1800 m and supports a suite of significant vegetation communities, including heaths, herbfields, bogs, fens, feldmark and sod tussock grasslands. These communities also have significant biological and hydrological conservation values and support many rare and endemic flora and fauna species. Alpine soils are typically organic humus soils prone to wind and water erosion when exposed. They are typically low in nutrients, but cycle nutrients rapidly resulting in thick vegetation cover where undisturbed. Rocky outcrops are common.

Australian society from the influx of migrant workers and industrial workplace developments. The Scheme, which evolved into a hydroelectricity and irrigation complex, was a massive engineering feat with the construction of seven power stations, 16 major water storages and 220 km of tunnels and aqueducts.

In environmental terms, the construction of the 'Snowy Scheme' had significant negative impacts on the biota and landscapes of the park as well as on the catchments involved. This included impacts from activities such as water diversion from rivers and streams; the cutting and clearing of roads and construction sites through sensitive areas such as sphagnum bogs and steep unstable country; and the use of introduced plants to stabilise eroding soils (Costin 1958). One impact that has been perhaps less well documented is the dumping of large volumes of rock following underground blasting of tunnels and the cutting of benches for aqueduct pipelines in a range of locations across the park. This has resulted in the filling of a number of valleys with spoil rock (Fig. 2), some of which has destabilised and washed downstream in major flood event, causing turbidity and sedimentation of water which has severely impacted aquatic life below the site (Harris *et al.* 2006). The erosion events have also filled natural ponds, blocked or diverted streams, and buried riparian vegetation, creating moist areas open to weed invasion such as willows (*Salix* spp.) and Scotch Broom (*Cytisus scoparia*). Further slips have the potential to cause greater damage in the future unless the sites are fully stabilised.

Prior to corporatisation of the SMHEA in 2002, relevant agencies agreed that it was necessary to determine the extent of environmental liabilities on sites within Kosciuszko National Park that were no longer required as part of management of the Snowy Scheme. Between 1998 and 2000, approximately 400 former Snowy Scheme sites within the park (Fig. 3) were assessed by National Parks and Wildlife Service (NPWS), other natural resources state agencies (including the NSW Environmental Protection Authority), NSW Treasury, SMHEA and an independent consultant (CH2M Hill 2000) to determine the extent of risk of breaching NSW and Commonwealth environmental legislation. The sites were split into two categories: those with environmental issues but unlikely to breach legislation were classed as minor and those with greater potential for breaching legislation were classed as major. Of the 35 sites listed as major sites, 23 were spoil dumps with the remainder including quarries, former townships and landfill sites. Minor sites were generally snow courses, communications lines, storage depots, temporary camps and townships, power lines and stream gauging stations.

CH2M Hill was then engaged to further assess and develop a concept plan for each major site. Each plan identified the natural and cultural heritage values of the site and current issues at each site including site stability, flora and fauna, weed invasion, hydrology and water quality, solid waste, visual amenity, heritage values and management logistic issues. The

Box 1. Continued

Fauna

The park provides habitat for a diversity of mammals, birds, reptiles, frogs and invertebrate fauna. Among the mammals, there is only one species, the Mountain Pygmy Possum (*Burramys parvus*), which is today confined to the mountains of south-eastern Australia and only occurs above 1200 m. Another small mammal species, the Broad-toothed Rat (*Mastacomys fuscus*) is presently found in two widely separated areas in NSW (the Barrington Tops region and Snowy Mountains region).

Among the birds, there are no species confined to the mountains. However, of the 60 species recorded living above 500 m, there are only 12 species that are year-round residents in the Snowy Mountains. These include owls, kingfishers, warblers and wood swallows.

Terrestrial vertebrate wildlife is usually scarce in alpine regions. However, the wildlife of the Snowy Mountains and Victorian Alps is comparatively rich with eight frogs, two snakes and 12 lizards, all but one of which are skinks. Endemic skink species include the Alpine Water Skink (*Eulamprus kosciuskoi*), the Guthega Skink (*Liopholus guthega*) and the Alpine Oak Skink (*Cyclodomorphus praealtus*). Three frog species, the Southern Corroboree Frog (*Pseudophryne corroboree*), Northern Corroboree Frog (*Pseudophryne pengilleyi*) and the Baw Baw Frog (*Philoria frosti*) and two subspecies, the Alpine Tree Frog (*Litoria verreauxii alpina*) and the Snowy Mountains Banjo Frog (*Limnodynastes dumerili fryi*), are found only in snow-country areas.

The majority of endemic species occur in the invertebrate group: swift moths, stoneflies, cockroaches and particularly the grasshoppers of the genus *Kosciuscola* are specific to the Australian Alps.

[Fauna information for this box was drawn from Green and Osborne (2012) and DEC (2006).]

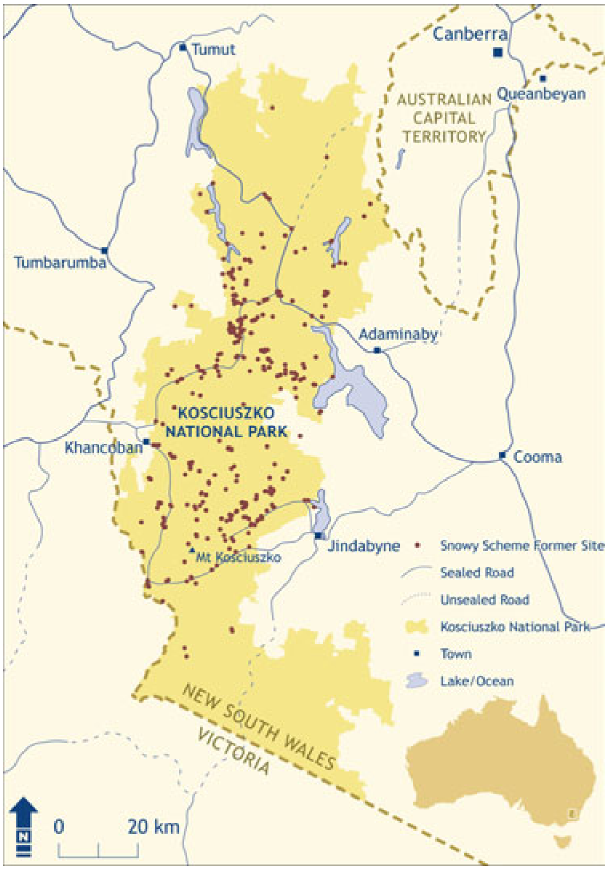

Figure 2. Distribution of the Former Snowy Scheme Sites within Kosciuszko National Park as surveyed by CH2M Hill. The survey informed the agreement between NPWS and SHL to fund and implement the Former Snowy Scheme Rehabilitation programme (Map courtesy NPWS Tumut).

plan also provided conceptual restoration measures to treat the causes and addresses these impacts, including an estimate of cost. A total of $78 million was estimated to implement the agreed restoration objectives at these major sites.

As a result of the assessment process, in 2002, the newly corporatised Snowy Hydro Limited (SHL) and NSW NPWS signed a deed whereby SHL agreed to contribute a total of $25 M to fund the restoration, managed by NPWS, of the major Former Snowy Scheme Sites – and $7 M to fund the minor former sites. The difference in funding was agreed to be addressed by further risk assessment, and accepting sites would not be fully restored to their pre-existing landforms, but stabilised with functional locally native vegetation communities, achieving restoration standards to the highest standard feasible.

This article focuses on reporting results of site reshaping and revegetation works that have been conducted on reshaped rock spoil and dump sites within the last 10 years – comprising a major part of the Former Snowy Scheme Sites Restoration Project. The objectives of the works have been to address a range of issues at the sites to achieve the twofold aim of reducing environmental risks (including further erosion) and reinstating self-perpetuating indigenous plant communities on the sites.

Former Snowy Scheme Sites Restoration Project

The 'Restoration of Former Snowy Scheme Sites Project' (the Project) commenced in 2003. One of the major challenges facing the team at the start of the project was the absence of procedures and techniques for ecological restoration works on very steep, high-altitude sites virtually devoid of soil and organic matter – the conditions found at spoil dumps (Box 2, Fig. 2).

Box 2. Issues at Most of the Sites Requiring Major Works

- **Unconsolidated** rock dumped in steep valleys and hill slopes, with rock sitting at the material angle of repose (1–1.5) presenting instability factors (i.e. only marginally stable) (Sinclair Knight Merz 2013).
- Continual movement of outer slope faces due to steepness, lack of a soil cover and organic matter, and vegetation, to the extent that, over 50 years, little vegetation has been able to establish itself on these unstable surfaces.
- A requirement for the final landform to be safely traversable by personnel for revegetation work.
- Many of the sites, particularly the large spoil dumps, were located in steep valleys where creeks were either located adjacent to the sites or ran through the sites. This posed a serious problem to the overall stability of the sites.

Previous efforts at soil stabilisation and revegetation after the removal of grazing and/or wildfire at high-altitude sites in the park by the NSW Soil Conservation Service involved sites with considerable amounts of topsoil and some natural vegetation present (Clothier & Condon 1968; Good 1976, 1992, 1999). In these areas, cultivation, sowing with an exotic stabilising 'crop', mulching and subsequent oversowing or planting of native species was the basic approach. Much was learnt from this extended programme, particularly in terms of mulching rates, soil temperature regimes, native seed germination and application rates, and the restoration of peat swamp ecosystems (Good 1999). Some erosion control works had also been undertaken in similar high country in the Victorian Alps after disturbances associated with ski slopes, roads and the hydroelectric scheme (McDougall 2001). Good natural recovery has been noted in sites on relatively gentle slopes, although this has been slow (McDougall 2005).

The SMHEA soil conservation branch also undertook some revegetation works on roadside batters and some steep sites in the early years of construction of the Snowy Scheme. The techniques for these sites included the installation of batter berms and planting with advanced willows, poplars (*Populus* spp.) and Scotch Broom that are now environmental weeds within the park (Good 1999). Unfortunately, this work provided limited guidelines to the restoration of the former Snowy Scheme construction sites, although work by Carr *et al.* (1980), Johnson (1987) and MacPhee (1998) recognised the use of native shrub species in subalpine area restoration works.

Figure 3. Happy Jacks Spoil Dump 1, in which over 970 000 m^3 rock spoil was dumped both sides of the Tumut River, is another of the 35 major sites that has now been subject to rehabilitation earthworks and planting. Its condition prior to treatment, pictured here, illustrates the environmental risk associated with the filling of valleys with spoil rock, which can be further washed down by streams or even block or divert the streams themselves (Photograph Regina Roach).

At the commencement of the current project, therefore, no successful examples existed of revegetation of a former Snowy site that was predominantly rock spoil, devoid of topsoil and bare for over 50 years. The restoration team was faced with the challenge of developing new techniques and procedures, drawing on some specialist advice and a limited soil conservation and ecological restoration literature for exposed sites (e.g. Houghton & Charman 1986; Allen 1988; Berger 1990; Tongway & Ludwig 1990.) The specific methods developed were continually updated and refined as more was learned about the ecological requirements of local ecosystems and specific sites, largely through the monitoring of success and/or failure on each of the sites.

To achieve success, it was clear that a multidisciplinary team was needed that contained engineering, environmental assessment, high-altitude plant establishment and administrative expertise. A Rehabilitation Officer, an Environmental Officer and an Engineer formed the team – along with administrative support and field staff with specialist skills in remote area nursery and irrigation establishment and site-specific compost production. Skilled contractors are also engaged for geotechnical design, earthworks, large-scale/steep planting, fauna surveys, weed control in difficult terrain and seed collection.

Without pre-existing models, it was necessary to develop ecological restoration techniques by undertaking trials on the sites themselves. In 2005, earthworks and revegetation trials were conducted at the T2 Dogleg site (Fig. 4), a former rock crushing site used for concrete making for the Tumut 2 Power Station Dam wall. This site was selected as it presented a number of stability, weed and pest animal problems that were common to many of the former Snowy Scheme sites – with a view to developing a suite of techniques and protocols that could be applied at other sites.

Figure 4. T2 Dogleg site was used to trial approaches to site remediation. In 2005–2006, the site was reshaped, metal removed and earthworks undertaken. A range of trial techniques including use of sediment mats, straw and compost were applied prior to planting 85 000 plants. (a) T2 dogleg just after earthworks and prior to soil preparation and planting and (b) same site 5 years after planting. The site is starting to integrate with the surrounding environment and is demonstrating ecosystem function with natural recruitment of species (Photographs NPWS Tumut).

Initial Trial Site

T2 Dogleg techniques pilot project

The rock spoil dump at T2 Dogleg site, located on the Elliott Way adjacent to the Tumut 2 Power station on the Tumut River, has an altitude of about 750 m, an area of about 12 ha and an average slope of about 35 degrees. The range of issues presented included issues of stability, access, weed control, pest animal control, lack of topsoil, protection of remaining native vegetation and artificial bat habitat. The site was heavily burnt in 2003, which exposed much of the waste and site instability. The objectives were to achieve site stability and then reinstate a framework of native plant species selected from those occurring in the surrounding vegetation. The aim was for a vegetation community that could integrate visually into the surrounding natural landscape and be colonised by additional species over time.

Works commenced with reshaping of the site using standard bench/batter techniques (Fig. 4a). Machinery completing the earthworks was also used to bury relatively benign waste such as steel and to remove large treated Blackberry (*Rubus fruticosus*) bushes. Willows were cut down, poisoned and chipped, and the remnant patches of native vegetation were methodically checked by volunteers. Each blackberry cane was cut and painted. This resulted in a neat and accessible site, but with a rock spoil and subsoil surface with a north-westerly aspect.

After lengthy planning and consultation with all stakeholders, the site was revegetated using a range of different techniques including a range of planting densities and hole sizes for a diverse plant species, along with the use of slow-release fertilisers, prewet water crystals and straw mulch (Appendix S1). Over 85 000 tubestock were planted. Direct seeding of native plants was also trialled, along with seeding with a sterile Rye Corn cover crop. 'Log ladders' were installed to create terraces (to slow water and accumulate soil and any dispersing seed, Tongway & Ludwig 2006) and to assist with access for the planters working on very steep slopes (Fig. 5).

Vegetation survival rates and establishment rates were subsequently assessed for each differently treated area. The limitations and successes for each treatment are tabulated in Appendix S1. Greater than 95% survival of seedlings occurred when using small planting holes, while large planting holes resulted in <50% survival, largely due to the holes collapsing in over time and crushing the seedlings. Planting centres of 1–2 m proved most successful, while direct seeding failed in the inhospitable environment. The log ladders and cover crop improved soil stability and biological activity.

Standard Techniques and Procedures Applied to Other Sites

Adaptive management and monitoring

The results of the Dogleg T2 trial were used to inform a set of techniques then applied to other sites – with refinements then made on an ongoing basis. Further lessons were

Figure 5. Planting into compost-filled holes at Bourkes Gorge #2 site. Site preparation involving surface shaping and creating permeable and fertile microniches is a key to successful plant establishment. Engaging local contractors is also important. Over 200 000 work days for local contractors has been generated by the project, which has created substantial benefits to local communities (Photo NPWS Tumut).

to be derived from both informal and formal monitoring including the following.

1 Informal photomonitoring and inspection of each site by the restoration team is carried out throughout the year to monitor for weeds, planting success and site stability;

2 Formal monitoring is carried out by personnel from Greening Australia Capital Region at eight key planting sites against a benchmark of remnant vegetation at each site. Site recordings were not undertaken prior to works; however, site photography attests to the fact that all the sites were basically rubble prior to treatment, with some natural regeneration and various levels of weed infestation occurring on the smaller sites.

   The formal postrehabilitation monitoring uses an adapted BioMetric (DECCW 2011) methodology, recording data along permanent 50-m transects and in a 20 × 20 m quadrat at each site. On small sites, shorter transects are used. All plant species are counted, regardless of height, to ensure that recently planted tree and shrub tubestock are included. Woody debris are measured in a smaller area within the 20 × 20 m quadrat, and the results are extrapolated to the 20 × 20 m quadrat. At each site, a photograph is taken along the transect from each end (Greening Australia 2012).

Site assessment

At major sites, the concept plan prepared by CH2M Hill provides a basis for undertaking further assessment and developing the rehabilitation design. Prior to scheduling specific works, the Environmental Officer undertakes a review of environmental factors, drawing on specialist expertise for fauna surveys. These surveys are based on structured transect observations, surveys using Elliot traps and harp nets, playback, and audio and camera recordings. Soil and water samples are taken where required to identify whether any contamination occurs on the site and to assist with managing plant health at planting time. If significant earthworks are required, the Project Engineer manages the surveying work and development of geotechnical design, detailing and catering for anticipated water flows across site, and installing run-off control structures if required. The Rehabilitation Officer then undertakes detailed assessments of the weeds and natives on site to develop planting lists and substrate preparation specifications to ensure the works are specifically tailored to conditions at each site.

Erosion and sediment control

Where possible, sites are reshaped to achieve the standard of 2:1 (H:V) slope ratios, with access benches and log ladders constructed as required. The three main erosion and sediment control methods for surface stabilisation are as follows: covering the site with organic matter (chip mulch and straw), the construction of cross drains and covering with jute matting. Standard geotextile sediment fencing is temporarily installed to catch any soil, small rocks or soil fines disturbed during earthworks and is removed once seedlings are established and the site is stable. Supported by stakes, the base of the sediment fencing is dug in and secured with rocks, pins and straw bales. Cross drains, manually constructed or by a small excavator, act as small collection areas for water, soil, seed and any other biota and promote the movement of water through the rock slope rather than over the top of it. Jute matting is used on larger areas such as spoil dump slopes or sloping batters to prevent erosion and soil loss. However, rice straw is the most commonly used material to prevent erosion of the spoil and any remnant soil where soil exists.

Selection of species for planting

A formal flora survey of 25 selected former Snowy Scheme sites listed the most common indigenous colonisers across the sites as candidates for the revegetation works (Duncan & Gillies 2000). These species included Burgan (*Kunzea ericoides*), Smallfruit Hakea (*Hakea microcarpa*), Silver Wattle (*Acacia dealbata*), Blackwood (*Acacia melanoxylon*), Common Cassinia (*Cassinia longifolia*) and Native Raspberry (*Rubus parvifolius*). Standard procedure during the planning phase for restoration works at each site, however, includes a site inspection and preparation list of species only occurring at that particular site – from which a much wider planting list is complied. This considers the need to include species from each stratum; the dominant species in the surrounding vegetation; colonisers occurring locally; the feasibility of commercial propagule collection and propagation; and tolerance to exposure and relative vulnerability to herbivory.

The use of colonising shrubs is a now standard approach in the revegetation of some alpine and subalpine ecological communities (Johnson 1987; Carr *et al.* 1980; MacPhee 1998). Some commonly occurring colonising shrubs are readily propagated, including Mountain Hovea (*Hovea montana*), Common Shaggy Pea (*Oxylobium ellipticum*) and Alpine Shaggy Pea (*Podolobium alpestre*), while *Pimelea ligustrina* is difficult to propagate from seed or cuttings. Other common colonising species such as Leafy Bossiaea (*Bossiaea foliosa*) can be propagated, but often fail to thrive in planted situations – most likely due to specific microorganism requirements that are not present in a highly degraded environment.

Sourcing plant material and planting

Most of the native grass seed used in the project is produced at the Yarrangobilly Native Seed and Straw Farm (see www.emrprojectsummaries.org/2013/08/17/). This production area was specifically developed to provide suitable high-altitude native grass seed and straw for the revegetation work, irrigated by grey water generated by the nearby Yarrangobilly Caves wastewater treatment plant.

All plant propagules are collected under a scientific collection licence, and collection is consistent with the Guidelines for the Translocation of Threatened Plants in Australia (Australian Network for Plant Conservation 2006). Two years in advance of the works, seed and cutting material are collected (by the Restoration Team and contractors) from the actual site to be revegetated. The timing for seed and cutting collection and pretreatments for seed of a range of shrubs species follows MacPhee (1998). Some species (such as *Dianella* spp.) are also salvaged from the site prior to earthworks and used as propagation stock.

Plants are grown by local nurseries under contract. Nursery stock is required to be in prime condition at the time of planting, well hardened off, weed and pathogen free, and grown in an appropriate potting medium to avoid excessive drying and prolonged saturation. Most trees and grasses to date have been grown in forestry tubes. Many alpine shrub species, however, have strongly branching lateral roots and are better suited to grow in 7.5-cm round pots. Smaller pots are occasionally used, but larger tubestock is desirable as seedlings are more likely to cope with transplant shock.

For alpine species, about 5% of the volume of the growing medium is made up of local soil to ensure reintroduction of soil microflora to the site. Aged compost and wetted water crystals are also incorporated into the hole at the time of planting (Fig. 5), with watering-in occurring at that time with subsequent watering applied as required.

Compost, mulch thatch and litter cover

Compost provides the planting medium for tubestock planted into rock spoil, to mitigate the lack of organic material at most construction sites and spoil dumps. This is produced locally, using old decomposing sawdust stockpiled at regional sawmills that once milled Alpine Ash (*E. delegatensis*). The compost is designed to meet the requirements of montane and subalpine native species, using principles outlined in Handreck (1996) (Fig. 6); that is, dolomite is added to the highly acidic sawdust to adjust it to pH 5.5–6, with some woodchip added. Nitrogen is added in the form of urea. As the compost is low in phosphorus and potassium, a slow-release fertiliser is used at planting.

Native grass straw from the Yarrangobilly Native Seed and Straw Farm,

Figure 6. Compost used in the revegetation works is prepared for the project, based on aged waste fortuitously remaining from decommissioned regional sawmills.

along with rice straw, has also proven to be very effective in addressing the lack of organic matter on sites, modifying surface temperature for young plant survival and reducing competition by weeds. As the straw is the source from a very different environment, the weed risk in high-altitude sites is considered to be negligible. Small tree limbs and cut vegetation (thatch) are also applied to create habitat and microclimates, reducing wind velocity across bare rock surfaces and holding straw and mulch in place. The thatch used in the project is sourced locally from vegetation control activities occurring along roads, fire trails and power line easements in the park.

Protection from herbivore browsing

Most plants need protection from browsing until well established. The main herbivores are wallabies (*Macropus* spp.), Eastern Grey Kangaroo (*Macropus giganteus*), Wombat (*Vombatus ursinus*), European Rabbit (*Oryctolagus cuniculus*) and Brown Hare (*Lepus capensis*). Generally the sites are fenced or plastic mesh tree guards used around seedlings until they are established. Browsing deterrents such as egg powder and iron filings, as well as ultrasonic sound systems, have been trialled. After many years of protecting seedlings from grazing in the park, however, a fence or well-constructed tree guards have been found to be the most effective techniques in controlling browsing and grazing.

Weed management

The vegetation survey conducted by Duncan and Gillies (2000) found that weed at the sites ranged from minor to high infestations. The report recommended that major consideration be given to the reduction or elimination of all introduced species at the sites due to the likelihood of the weed invading neighbouring native vegetation, spreading along waterways and inhibiting native vegetation. The earthwork stage is used to bury some weedy substrates, and weed control is also carried out at all sites according to the Noxious and Environmental Weed Control Handbook (Department of Agriculture NSW 2005).

The main weeds of concern on the sites include Browntop Bent Grass (*Agrostis capillaris*), St Johns Wort (*Hypericum perforatum*), blackberry (*R. fruticosus*), Viper's Bugloss (*Echium vulgare*) and Grey Sallow Willow (*Salix cinerea*). In addition, the project includes control of weeds of concern in the vicinity of sites, including weeds subject to park-wide control programmes Scotch Broom (*Cytisus scoparius*) and Orange Hawkweed (*Hieracium aurantiacum*).

Works at Other Sites and Their Results to Date

Over the last 8 years, over 200 sites in the park have had restoration works applied to them, using the techniques described above, with over 100 sites still to have their environmental liabilities addressed. Over 1 million native plants have been established as part of the Former Snowy Scheme Sites programme to date (Table 1), at a total expenditure of approximately $18 M.

Plant establishment rate has exceeded 90% across the 200 sites in the first year, a result that has reinforced the value of the high level of site preparation undertaken. Levels of plant cover have increased over time, with very satisfactory levels of vegetation development by both woody and herbaceous native species across the vast majority of sites. As the initial application of mulch decomposes, it is expected that it will be replaced by litterfall from the growing revegetation, and it is hoped that this will occur prior to the breakdown of the applied mulch and woody debris.

Table 1. Summary of vegetation attributes for each site

Site	Length of transect (m)	% Cover														Number of exotic sp	Number of native sp	Woody Stems <10 cm dbh	Coarse woody debris (m)
		Native over-storey	Native mid-storey	Native grasses	Native ground shrubs	Native forbs	Sum of native ground cover	Exotic annual grasses	Exotic perennial grasses	Exotic forbs	Sum of nat + ex gd cover	Litter	Bare ground	Rock	Woody Debris				
Control (Nungar Quarry)	50	25	22	56	58	50	164	6	2	6	178	96	0	0	0	33	10	1120	17.5
Bourke's Gorge	40	0	1.3	7.5	20	7.5	35	0	0	0	35	75	0	32.5	5	19	2	1510	82.5
Jindabyne Valve House	50	0	0	2	18	2	22	0	0	0	22	80	10	10	2	15	7	425	190
Nungar	50	0	0	0	2	20	22	88	16	22	148	74	4	2	0	25	14	248	14
Pipers Creek	36	0	3	11	19	11	41	0	31	50	122	86	0	0	0	21	11	912	0
Snowy Adit 2008, inside exclosure	50	0	7.5	2	20	8	30	0	0	0	30	52	2	52	8	11	3	990	530
Sue City, outside exclosure	35	0	4.3	29	17	0	46	0	0	0	46	77	0	23	1	18	13	230	75
T2 Dogleg	50	25	27.5	2	14	2	18	12	2	18	50	68	6	28	0	13	13	640	105
Tumut Pond Hairpin	50	0	5	12	42	2	56	0	14	6	76	86	6	6	4	16	9	875	109

While vegetation establishment cannot guarantee stability of steep slopes alone, extremely low levels of rilling and subsidence have occurred on reshaped batters to date, despite some 100-year rainfall events, attesting to the appropriateness of the engineering standards adopted. There is no doubt that the revegetation has contributed to surface stabilisation, and it can be expected that the deeper root systems of larger species such as *Eucalyptus* can be expected to improve overall site stability over time.

An initial indicator that the goal of restoring self-perpetuating vegetation communities is commencing is the occurrence of natural colonisation in the microsites created by the application of thatch and log ladders at a number of sites. These represent a range of growth forms including trees (particularly Ribbon Gum, *Eucalyptus viminalis*), shrubs (Silver Wattle and *Leptospermum obovatum*) and a range of grasses and forbs. These include some species that have been sown as well as some unsown species. Many of the sites are now being visited by fauna including Lyre Bird (*Menura novaehollandiae),* Wombat, Red-necked Wallaby (*Macropus rufogriseus*), Swamp Wallaby (*Wallabia bicolor*), Eastern Brown Snake (*Pseudonaja textilis*) and Tiger Snake (*Notechis scutatus*).

Major works at the following four sites are briefly summarised as examples of the results currently being achieved, with more data and photographs of two of these cases provided at www.emrprojectsummaries.org.

1 *Snowy Adit:* This is a large rehabilitation site in the Snowy River valley. A stockpile of millions of tonnes of rock spoil from the Island Bend-Geehi tunnel (measuring 1000 m by 400 m) was reshaped in 2008 and revegetation works completed in 2011. The site had relatively high cover levels of weed prior to treatment, including St Johns Wort, Vipers Bugloss and Bokhara Clover (*Melilotus albus*). Some 260 tonnes of waste steel was salvaged from the site and sold, netting $61 K that was reinvested in the project. The site was reshaped to create linked dams, planted with 110 000 tubestock of 11 species in three stages and mulched with straw. After high initial browsing by wallabies, part of the site was fenced, resulting in almost 100% plant establishment success. Monitoring found 30% native plant cover in the ground stratum with 7.5% cover of Ribbon Gum at mid-storey height and very few exotic species.

2 *Bourkes Gorge Spoil Dump # 2:* This spoil dump containing some 300 000 m^3 of rock was reshaped for stability, accessibility and safe water movement across the site in 2009–2010. Slope angles were reduced from around 38° to between 26° and 30°. It was planted with 50 000 tubestock in 2010–2011 and had specific management practices applied to minimise the impact on potentially present threatened species. In the 3 years since the works, there have been two major (>100-year intensity rainfall) events in the region, but there has been no evidence of erosion or slumping following these events. Vegetation monitoring since that time has proven outstanding survival and growth rates of over 19 site-native species, with an average of over 35% cover in the monitored plots within 1 year (See Fig. 7 and www.emrprojectsummaries.org/2013/08/22/).

3 *Jindabyne Valve House:* This required major earthworks, which commenced in May 2010 and were completed in July 2010. Some 35 000 tubestock were planted in 2010–2011. Observations 3 years after treatment showed that about 80% of all seedlings survived. Due to the steepness of the site, it was impractical to fence it, and grazing of seedlings by Eastern Grey Kangaroos and wallabies occurred, which has restricted some plant development. Overall the site is well on the way to recovery and will be mulched with woodchips in November 2013 to increase the litter levels on the site (See www.emrprojectsummaries.org/2013/08/20/).

4 *Khancoban Tip:* This former tip and spoil dump contained tunnel spoil from the Murray 1 and Murray 2 Power Station developments and had also been subjected to

Figure 7. Rehabilitation Officer Liz McPhee is pictured at Bourke's Spoil Dump #2, where monitoring has shown outstanding survival and growth rates within 1 year, with 19 native species establishing, all sourced from the surrounding vegetation. Other native species are now colonising (Photograph NPWS Tumut).

100 years of grazing. At a lower elevation than many of the other locations, the site had a well-established weed population and populations of feral animals. In 2010, the sites were reshaped and the tip capped with a clay liner. In 2011, the site was ripped and planted with 30 000 tubestock (confined to grasses at the tip site). Observations 2 years after treatment show that the seedlings have established very well and growth rates have exceeded expectations.

Observations from formal monitoring (Data in this section derived from Greening Australia 2012)

Quadrat and transect data collected at eight of the revegetated sites in April–May 2012 show that the results at that date varied depending on the age of the restoration work and various site-specific factors such as altitude, slope, vegetation type and herbivore grazing pressures (Table 2).

A range of 11–25 native plant species had been established at the eight sites. At most sites, the greater proportion were shrub species; however, at the two high-altitude sites, naturally regenerating native forbs made up the majority of species. The number of woody stems (shrubs and tree saplings) ranged from 230 to 1510 per plot, with only one site (Bourke's Gorge #2, Fig. 7) with a higher number of stems than the reference site (1120).

Native plant cover at the eight restoration sites varied with stratum. Between 18% and 56% cover was achieved in the ground stratum (0–1 m height). Some native plants had grown to mid-stratum height at six of the sites, with the exceptions being the two higher-altitude sites (Pipers Creek and Nungar Quarry). At the oldest (7-year-old) T2 Dogleg site, percentage cover in both upper and mid-stratum had developed to levels similar to that of the reference site (Fig. 4b). This site, however, had the lowest native ground layer, perhaps due to the rapid growth of a dense mid-storey and overstorey.

Litter cover at the monitored sites varied from 52% to 86%. The amount of coarse woody debris was within a satisfactory level, with most sites having levels well above that of the reference site (17.5 m).

Exotic species (grasses and forbs) were generally a greater component of the older sites than the younger ones. It is not clear whether this is a function of time since restoration or whether it is due to cleaner, more sterile substrates on the more recent sites. The two high-altitude sites located in Snow Gum (*E. pauciflora*) woodland (Pipers Creek and Nungar Quarry) are particularly high in exotic species cover. Again, it was not evident whether this is because of the earlier restoration methods or the presence and type of exotic species in the area around these sites.

Other Outcomes

Twenty comprehensive fauna surveys have been completed as part of the project. Few sites had been surveyed, and hence, little data were available from any previous surveys. The 20 surveys carried out have added over 1200 species locations to the Wildlife Atlas database for Kosciuszko National Park, including 63 sites for threatened species. Approximately 360 individual threatened species records have been added to the database. These figures do not include the extensive annual recording and radiotracking of Mountain Pygmy Possum (*B. parvus*) at Happy Jacks that has occurred since the initial discovery of two individuals (Schultz *et al.* 2012). Three surveys recorded multiple individuals of the recently described Tan-backed Rock Skink (*Liopholis montana*) for which minimal data are available on its occurrence, with only one previous record existing for the park.

The project is also playing a key role in supporting the ongoing park-wide programme to remove significant weeds within the park, includ-

Table 2. Summary of vegetation attributes for each site

Site	Length of transect (m)	% Cover														Number of native sp	Number of exotic sp	Woody Stems <10cm dbh	Coarse woody debris (m)
		Native over-storey	Native mid-storey	Native grasses	Native ground shrubs	Native forbs	Sum of native ground cover	Exotic annual grasses	Exotic perennial grasses	Exotic forbs	Sum of nat + exgd cover	Litter	Bare ground	Rock	Woody Debris				
Control (Nungar Quarry)	50	25	22	56	58	50	164	6	2	6	178	96	0	0	0	33	10	1120	17.5
Bourke's Gorge	40	0	1.3	7.5	20	7.5	35	0	0	0	35	75	0	32.5	5	19	2	1510	82.5
Jindabyne Valve House	50	0	0	2	18	2	22	0	0	0	22	80	10	10	2	15	7	425	190
Nungar	50	0	0	0	2	20	22	88	16	22	148	74	4	2	0	25	14	248	14
Pipers Creek	36	0	3	11	19	11	41	0	31	50	122	86	0	0	0	21	11	912	0
Snowy Adit 2008, inside exclosure	50	0	7.5	2	20	8	30	0	0	0	30	52	2	52	8	11	3	990	530
Sue City, outside exclosure	35	0	4.3	29	17	0	46	0	0	0	46	77	0	23	1	18	13	230	75
T2 Dogleg	50	25	27.5	2	14	2	18	12	2	18	50	68	6	28	0	13	13	640	105
Tumut Pond Hairpin	50	0	5	12	42	2	56	0	14	6	76	86	6	6	4	16	9	875	109

ing Scotch Broom in the upper Snowy River Catchment, exotic trees on Guthega Road and willows (*Salix* spp.) in the upper Murrumbidgee and Tumut Rivers. It is also making a significant contribution to the Orange Hawkweed (*Hieracium aurantacum*) Program, an emerging weed of significance that has destroyed many native ecosystems in New Zealand.

A series of training and site inspections have also taken place to inform and educate NPWS staff, SHL staff and community volunteers on the restoration programme. Specifically this has included conducting site tours for Landcare Nursery volunteers, NPWS staff and Utilities (SHL, Transgrid), as well as Site Restoration Courses for NPWS staff.

Standards have been developed in this project covering erosion control, tubestock management, species selection, contractor planting standards and maintenance requirements and are embedded in contract documents and management plans.

In addition, a 'Green Book' field guide has been published, drawn from the lessons learned throughout the project (MacPhee 2013). This field guide covers goals, restoration standards, planting lists, principles and techniques that can be interpreted at each site by skilled officers.

Looking Forward

The programme is scheduled to run for another 9 years, drawing to a close in 2022. The Restoration of Former Snowy Sites Project team still has many new challenges ahead to address. The following projects are already in the initial stages of development.

1 Construction of critically endangered frog breeding habitats within restoration areas, providing pools for the reintroduction of these frogs across the park that has commenced and will run for 5–10 years. If successful, the techniques developed will have implications for survival of riverine frog species both in the park and further afield.

2 The standards and guidelines developed within this project are currently being revised for application to all restoration and revegetation work within National Parks in NSW and other parks within the Australian Alps. Our ambition is to see the restoration standards developed within this project, applied to all protected natural areas in the parks estate so that native vegetation and restoration is incorporated in every planning stage, and to optimise potential for all development proposals to include budget allocation for restoration.

3 Development of a 'green card' Accreditation system ensures land managers and construction workers are trained in protecting environmental values when developments are occurring. In NSW, all construction workers must have a white card for safety and comply with the 'Blue Book' for erosion and water controls. A green card will ensure everyone from managers to site workers understand and take responsibility for the long-term impacts of disturbance works and comply with set vegetation protection standards.

4 Restoration of large and high-risk Former Snowy Scheme Sites in the Happy Jacks and Tumut valley.

5 Design of Mountain Pygmy Possum habitat including artificial boulderfields within restoration projects (See Schultz *et al.* 2012).

6 Installation of interpretative panels and 'apps' that convey the cultural values and history of sites and the restoration achievements.

Is the Work Making a Difference?

Over the 10 years since the project commenced, the restoration team has undertaken landform stabilisation, stream channel stabilisation and revegetation works at over 200 sites. It is clear that the sites, many which were unstable and located in gullies affecting downstream watercourses, now have limited potential for sedimentation and contamination discharge into waterways. The risk of spoil collapsing into streams has been greatly decreased, and previous surface stream flow has been reinstated through reshaping some creek lines, with riparian vegetation planted on the new banks. Over 900 000 plants have been successfully established on the sites, including on 18 major sites previously bare for 40 years.

Efforts have been made to match plant species to the main species in the local species pool, although differences are inevitable due to the changed nature of the landforms and substrates. It is anticipated that functional, locally native vegetation communities will develop on the sites, reducing the vulnerability of surrounding vegetation to weed invasion. Already, recruitment and colonisation of trees, shrubs and ground covers is occurring on most sites – an early indication that conditions are likely to be suitable for recruitment of other species over time. Further study of the sites' levels of similarity or difference to locally occurring communities over time will help park managers continue to optimise restoration outcomes. Such study will also contribute to the body of knowledge on the degree to which restoration is possible or not on highly modified sites.

We believe that the work demonstrates that, even in these extreme conditions, long-term commitment, secure funding and skilled staff can combine to achieve a promising ecological restoration result. These results should encourage people working in less extreme sites, to strive to solve problems with careful, informed and determined effort.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Rehabilitation treatments and results for the T2 Dogleg site in KNP.