Excellence in post-mining restoration within a global biodiversity hotspot in Western Australia

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ABSTRACT. Perth – the capital city of Western Australia – sits at the centre of one of the world's 34 global biodiversity hotspots. For Hanson Construction Materials (Hanson), one of Australia's leading suppliers of heavy materials to the building industry, the extraction of sand in the south-west of Western Australia presents significant environmental and social challenges in demonstrating leading practice within public view.

This article outlines a 21-year research partnership forged between Hanson and the Western Australian Government's Botanic Gardens and Parks Authority to tackle the complex environmental and biodiversity issues associated with post-mining restoration of iconic *Banksia* woodland communities. Once a common and widespread feature of the Swan Coastal Plain on which the Perth metropolitan area has developed, today there remains less than 10% of the original *Banksia* woodlands, yet this ecosystem alone contains more plant species than all of the plant species found in the United Kingdom!

The research partnership tested ecological restoration theory based on melding the principles of adaptive management (decisions made on the basis of lessons learned) with integrated restoration science (linking core restoration disciplines—topsoil handling, mulch and seed enhancement treatments). The success of the research partnership has been a demonstration of innovation, leadership and environmental excellence with Hanson now having the highest levels of species and plant reinstatement per unit area of post-mined restoration in the Australian resources sector.

Excellence dans la restauration post-exploitation minière au sein d'un hotspot mondial de la biodiversité en Australie occidentale

RÉSUMÉ. Perth – la capitale de l'Australie occidentale - se trouve dans l'un des 34 points chauds de la biodiversité mondiale. Pour 'Hanson Construction Materials' (Hanson), l'un des principaux fournisseurs australiens de matériaux lourds pour l'industrie de la construction, l'extraction de sable dans le sud-ouest de l'Australie-Occidentale présente des défis environnementaux et sociaux significatifs pour démontrer des pratiques de pointe dans l'opinion public.

Cet article décrit un partenariat de recherche de 21 ans entre Hanson et l'Office des jardins botaniques et des parcs du gouvernement de l'Australie occidentale mis en place pour s'attaquer aux problèmes complexes environnementaux et de la biodiversité associés à la restauration post-exploitation minière des communautés forestières iconiques de *Banksia*. Jadis c'était une caractéristique commune et répandue de la plaine côtière de cygnes sur laquelle s'est développée la région métropolitaine de Perth ; aujourd'hui il reste moins de 10% des forêts originales de *Banksia*, pourtant ce seul écosystème contient plus d'espèces végétales que le Royaume-Uni.

Le partenariat de recherche a mis à l'épreuve la théorie de la restauration intégrée basée sur la fusion des principes de gestion adaptative (décisions prises sur la base des leçons apprises) avec la science de la restauration intégrée (reliant les disciplines de restauration de base - traitement des terres arables, paillis et traitements pour l'amélioration des semences). Le succès du partenariat de recherche a été une démonstration d'innovation, de leadership et d'excellence environnementale, Hanson ayant maintenant les niveaux les plus élevés de rétablissement d'espèces et de plantes par unité de surface de restauration post-exploration minière dans le secteur des ressources en Australie.

La excelencia en la restauración post-minería en un hotspot de biodiversidad en Australia Occidental

RESUMEN.[1] Perth - La capital de Australia Occidental - se encuentra dentro de uno de los 34 puntos calientes de biodiversidad [*hotspot*] del mundo. Para Hanson Construction Materials (Hanson), uno de los principales proveedores de materiales pesados en la industria de la construcción de Australia, la extracción de arena en el sur-oeste de Australia Occidental presenta desafíos ambientales y sociales significativos al buscar demostrar liderazgo en esta práctica ante la opinión pública.

En este artículo, se describe una asociación de investigación de 21 años forjada entre Hanson la Administración de Jardins Botánicos y Parqes del Gobierno de Australia Occidental para hacer frente a los complejos problemas ambientales y de biodiversidad asociados con la restauración post-minera de las icónicas comunidades boscosas de *Banksia.* Estas comunidades, una vez características y comunes en la Llanura Costera de *Swan*, en donde se ha desarrollado el área metropolitana de Perth, ocupan ahora menos del 10% de los bosques originales *Banksia*; sin embargo, este ecosistema por sí solo contiene más especies de plantas que todas las especies vegetales que se encuentran en el Reino Unido.

La asociación de investigación, ha probado la teoría de ecología y restauración sobre la base de fusionar los principios del manejo adaptativo (decisiones tomadas sobre la base de las lecciones aprendidas) con la ciencia integrada de restauración (que une las disciplinas básicas de restauración - manipulación vegetal y tratamientos de mejora de semillas). El éxito de la asociación de investigación ha sido una demostración de la innovación, el liderazgo y excelencia ambiental, haciendo que Hanson tenga actualmente los más altos niveles de especies y restablecimiento de plantas por unidad de área en la restauración post-minera en el sector de recursos de Australia.

1 Translated by Daniela Cajiao

I. BACKGROUND

Hanson Construction Materials (Hanson) is owned by Heidelberg Cement Group, a global manufacturer of cement, aggregates, ready-mixed concrete and asphalt. Hanson extracts, processes and distributes sands, aggregates and cement for pre-mixed concrete, concrete products for industrial uses, landscaping and other building and construction applications. It operates 80 quarry sites of hard rock and sand relatively close to all major Australian capital cities.

Perth, the capital city of Western Australia, is built over a large and ancient coastal plain and its continued growth and development is highly dependent on significant sand resources generally restricted to isolated pockets in specific geological units within its metropolitan region. One key Hanson resource—and the initial site for research work—is located 30 km north-east of Perth's central business district. Hanson's sand-extraction processes, which deliver essential materials for the building industry, necessarily impact on plant communities—notably in what is known as *Banksia* woodland—supported by deep siliceous dune sands (figure 1).

The process of sand extraction requires clearing *Banksia* woodland vegetation, stripping topsoil and removing the underlying white and yellow quartz sand horizons which constitute some 18–40 metres of the sand profile.

FIGURE 1 Banksia woodland plant communities are among the most biodiverse woodland types in Australia (top). The woodlands have developed on deeply weathered and leached sands that form the basis of major sand extraction for silica products and building sands (bottom).

II. UNIQUE RESEARCH COLLABORATION

In 1995, Hanson approached the Kings Park Science Directorate of the Western Australian Government's Botanic Gardens and Parks Authority with a unique proposal and a highly ambitious plan of returning mined sites to an ecosystem closely resembling the species composition of naturally-occurring *Banksia* woodland.

The aim was to develop international-leading practice for the integrated restoration of post-mined sites (combining topsoil management; seed broadcasting, seed-germination enhancement technology, mulch management and smoke technology), using principles of adaptive management (management applied on the basis of lessons learned). Such an approach had not been attempted previously for a biodiverse ecosystem in a biodiversity hotspot.

Prior to the commencement of the collaborative research programme (which has now spanned more than two decades), the diversity and sustainability of postmined *Banksia* woodland was limited in both species diversity and plant abundance values (figure 2).

FIGURE 2 Although some plant cover was established, the diversity of species was well below that of natural recruitment levels of undisturbed woodland at Hanson sites pre-1995 and prior to the formation of the Kings Park and Hanson research partnership.

Research at the first site for restoration (more than 70 hectares located to the north of the Perth central business district) focused on two key scientific areas of inquiry: seedling recruitment and plant survival; and plant growth and development responses to a reconstructed soil environment.

The research programme aimed to demonstrate innovation and environmental research excellence through:

- Compiling the largest database on soil and plant development data for reinstated *Banksia* woodland species, benchmarked with natural *Banksia* communities;
- Detailing a better understanding and optimization of the regenerative potential of the soil seed bank.
- Resolving methods for topsoil handling and storage;
- Researching and developing innovative seedgermination enhancement pretreatments (e.g., smoke);
- Enhancing greenstock-enabling treatments (e.g. tree-guards, anti-transpirants);
- Definitively testing site treatments (e.g., mulching, irrigation and soilripping practices and application of soil stabilizers);
- Researching the autecology and selective control of dominant weeds species impacting upon native plant survival in restored sites;
- Investigating eco-physiological parameters (nutrient and soil water relations);
- Considering and designing engineering solutions for the restoration challenges facing industry.

III. KEY ISSUES

A. Conservation Awareness

Banksia woodlands are such a familiar site on the Swan coastal plain (including in and around the Perth metropolitan area) that few people consider these plant communities to be of serious conservation concern. Yet only 10% remain within the metropolitan area. As a result, these woodlands had not been seriously researched. The challenge for the collaborative project has been to use research leadership and successes to increase the awareness of *Banksia* woodlands and to train the next generation of restoration practitioners. This has been supported by tours, lectures and undergraduate training onsite by Hanson, as well as community workshops by Kings Park.

B. Site-Specific Restoration

The *Banksia* woodlands represent a floristically rich and taxonomically diverse plant community, strongly affected by small edaphic differences. As a result, understorey assemblages have a complex spatial arrangement as a result of small changes in the topography, degree of leaching, kaolin content, and iron-mineral content. The challenge in restoration endeavours has involved habitat-matching to ensure that local-provenance seed of the correct floristic type is taken to post-sand-extraction sites.

A key finding that transformed restoration operational practice was that unlike many ecosystems elsewhere (e.g., in North America and Europe), plant ecological succession patterns do not occur in *Banksia* woodland—that is, what is restored in the first year remains the fingerprint for species composition into the long term.

Given the great age and geological stability of the landscape, *Banksia* woodland soils are typically well-formed, deep, well-drained, and low in moisture and nutrients. The age of the landscape has also led to a high level of speciation and evolutionary development. As a result, there is little chance for restoration activities (after the sand extraction process) to rely on site residuals and/or natural migration of seeds and gene flow across long distances. The research found that restoration principles for *Banksia* woodlands are sitespecific. Unlike other mining ecosystems, a key priority in developing restoration principles is to achieve the highest possible seedling recruitment levels in the first year of restoration, given poor recruitment after the second winter stemming from soil compaction issues associated with disturbance of *Banksia* woodland soils (figure 3). Furthermore, a high degree of human intervention is necessary; otherwise naturally migrating weeds out-compete the native species.

FIGURE 3 Reference sites sourced in Banksia woodland (top), are used as models to set benchmarks for seedling recruitment in restoration sites (bottom).

C. A Delicate Natural Balance

The *Banksia* woodland does not represent a resilient plant community; it is a delicately-balanced environment, far less able to withstand the impact of long-term urbanization than any other plant community adjacent to an Australian city. Human-use can lead to irreversible degradation. Indeed, the *Banksia* woodland appears to be more susceptible to weed invasion than any other plant community in the south-west of Western Australia. Woodland sites adjacent to Hanson's post-sand extracted sites are impacted by *Pinus radiata* and invaded by a pernicious weed, *Ehrharta calycina*.

Kings Park and Hanson endeavoured to keep the weeds at a distance from restoration areas through careful topsoil management (to minimize *Ehrharta calycina* invasion) and by ongoing woody weed removal (to eliminate *Pinus radiata* from restoration sites).

D. Soil Compaction and Impedance

The research uncovered a new concept – cryptic soil compaction (penetrometric changes occurring without evidence at the macro scale). Previously unknown in podzolic silica sands, cryptic soil compaction results in significant and lasting negative impacts upon restoration capability. By realizing that first principles in restoration ecology for *Banksia* woodland are site-specific and cannot be cross-applied from other ecosystems, approaches to minimize the impacts of cryptic compaction have been implemented. For example, the common practice of replacing the overburden profile is associated with greater soil compaction within *Banksia* woodland sands. Further, given the poor recruitment of plants after the second winter with the onset of soil compaction, a key priority is to strive for optimal seedling recruitment in the first year of restoration. These two principles alone have resulted in a five to eight-fold increase in seedling abundance in restoration outputs when compared with restoration success at the start of the research programme (figure 4).

FIGURE 4 Experimental plots implemented to test deep ripping of the soil profile (top) and broad-acre deep ripping based on ground-breaking research that demonstrated the impact of soil ripping and organic material on root architecture and plant survival (bottom).

For the successful restoration of a wide suite of species, efforts need to be directed to the management of the soil environment. The research programme found that a key factor for describing soil conditions was soil impedance related to the development of deep, penetrating root systems that may have direct impact on seedling survival within restoration areas. Researchers found that the commonly reconstructed soil profile in the resources sector of topsoil over overburden reflected the highest impedance values, highest moisture levels, least favorable root development and architecture and consequently the highest seedling mortality than any other reconstructed soil profile. With results indicating that reconstructed soils have higher soil impedance and more fluctuations in impedance through the year than in natural sites, penetrability becomes an important criterion for estimating rehabilitation success and as a benchmark for defining the restorability of *Banksia* woodlands.

FIGURE 5

Testing new techniques. Aerosol smoke application to post-sand extracted sites leads to a threefold increase in plant numbers to restoration sites (top), while innovative seed coating developed for Banksia woodland species has trebled seedling performance in restoration efforts (middle and bottom).

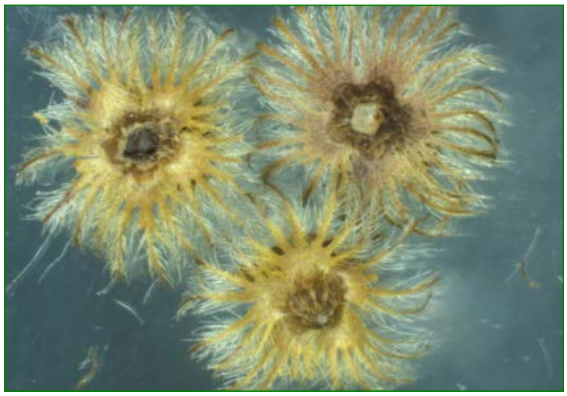
E. Topsoil Preservation

Given the sequence of operations, fresh topsoil is not always available for use in new restoration sites, resulting in the lack of a plant source. The challenge involved investigated ways to conserve topsoil. Innovative research on seed burial effects and topsoil stripping and replacement depths found that topsoil can be stripped at a greater depth (but less than 10 cm) and spread at a shallower depth (less than 5 cm). As a result, Hanson developed innovative precision stripping technology and embarked on operator training to ensure that topsoil stripping and replacement was optimized for plant recruitment. Outstanding seedling recruitment results have been achieved from topsoil replacement (e.g. more than 100 plants/5 m^2 in year 1). The development of unique smoke application techniques have enabled a threefold increase in seedling recruitment from topsoil. Furthermore, the collaborative partners have determined that coating and raking seeds, and sowing prior to winter rains, leads to a tenfold increase in seedling recruitment (figure 5).

F. Seed Biology and Displacement

There was a lack of general understanding of seed biology for restoration, including what constituted genetic provenance in seed, as well as almost a total lack of knowledge of seed dormancy, viability and germinability characteristics (figure 6).

The availability of *Banksia* seeds is generally declining on the Swan coastal plain as climate change, water extraction and loss of habitat result in a poor seed set and a loss of seed catchment. Through innovative research into seeding phenology and applying principles of seed quality and viability as well as seeduse optimization, there has been a four- to tenfold improvement in use of seed resources collected from the wild (species-dependent). This has resulted in improved collection knowledge for commercial seed-collecting companies meaning less wastage of seed and better environmental outcomes through more efficient use of wild-sourced seed.



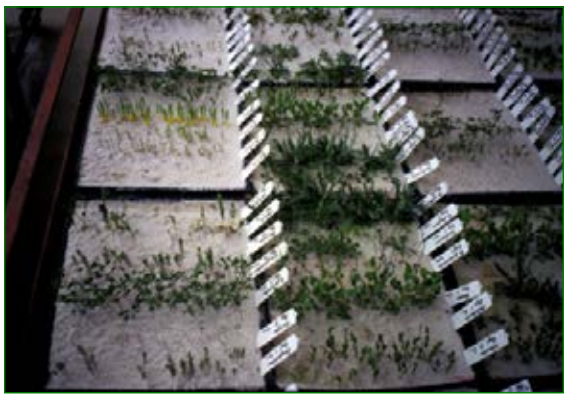


FIGURE 6 Testing seed viability via a cut test (top), and seed germinability via a seedlingemergence test (bottom).

Given the high wind activity and soil erosion experienced on site, displacement of seeds broadcast to site is high (greater than 50% of seeds are displaced). Research found that traditional topsoil stabilizers, such as paper mulches, impede seed germination, with restoration deficits related to the thickness of the stabilizers. As a result, innovative research using wind-tunnel experiments in the Faculty of Engineering at the University of Western Australia is developing new concepts in wind-abating fencing based on understanding height and spacing criteria.

G. Planning, Management and Engineering

Careful planning is vital, vigilant management is important, up-to-date engineering approaches are necessary, and well-executed timing is critical in delivering successful restoration. Any restoration schedule needs to incorporate these factors, with timing associated with soil-profile reconstruction and topsoil handling viewed as the most important aspect. Restoration has now begun to drive the operational programme. This is particularly relevant to topsoil where poorly handled topsoil or ineffective direct seeding causes restoration to rely on the more expensive use of planted seedlings. These new engineering approaches have a direct and significant impact on restoration success. For example, the project saw the first introduction of new land-plane techniques that have now been widely adopted, with more than 20 land planes operating in the southwest of Western Australia. Similarly, new approaches to counter weeds have been employed widely following the finding that when earthmoving machinery was used to shape the land (e.g., in the formation of batters), the disturbance could stimulate germination of weed seeds. Weed liability near the soil surface is now removed (to at least 100 mm) prior to commencing operations and is either taken offsite or is deeply buried within earthworks and then capped with more than one metre of weed-free soil to reduce the risk of weed seedlings emerging.

H. Increased Native Species

The excellence of the research has increased the number of native species returning following sandextraction activities to levels significantly greater when compared to natural recruitment cycles in undisturbed *Banksia* woodland. Indeed, in the second and third years, the number of native species per $5m^2$ is almost double the best achieved in undisturbed ecosystems.

FIGURE 7 Experimental restoration sites are demonstrating pre-sand extracted species composition.

Today, as a result of the collaborative research partnership, and with more than 100 plants per 5 m^2, Hanson boasts the highest levels of species and plant reinstatement per unit of area of post-mining restoration in the resources sector (figure 7).

IV. ONGOING OUTREACH

The continuing commitment by Kings Park and Hanson to the restoration of biodiverse *Banksia* woodland plant communities has been marked by:

- Continuous support by Hanson of graduate and postgraduate research programmes since 1995;
- Co-sponsorship of six PhD and 10 honours-level student research programmes since 1995.
- Hanson's sponsorship of the first ever restoration eco-physiologist dedicated to understanding the ecophysiology of *Banksia* woodland species;
- Development of an innovative research programme that will apply and further refine restoration principles from the Hanson/Kings Park programme for restoration of plantation pine forest sites within the Perth metropolitan area;
- Extension of the restoration message to a broader national and international audience through sponsorship of conferences related to plant ecology and restoration, including the 2001 International Orchid Congress, the 2007 Mediterranean Ecosystems (MEDECOS) Conference, the 2007 Seed Ecology Conference, and the 2009, 2013, 2014, 2015 and 2016 Society of Ecological Restoration Australasian and International Conferences.
- Using restoration excellence at sites to promote leading practice in the resources sector through sponsorship of ongoing educational tours (by universities in particular) to allow participants to learn first-hand about the importance of *Banksia* woodland and its ecology, conservation and restoration.

V. CONCLUSION

For more than two decades, the unique partnership of government research through Kings Park and an industry partnership with Hanson, has enabled the restoration and management needs of the biodiverse *Banksia* woodland ecosystem to be seriously addressed. By examining restoration research and monitoring within both intact urban bushlands and post-sand extracted sites, the collaborative partners have gained a holistic understanding of *Banksia* woodlands.

The research has established for the first time, a set of integrated principles for the restoration biology and ecology of plant communities for sand extraction industries mining in these biodiverse ecosystems. The research partnership has delivered world-class improvements in biodiversity replacement and created a new industry benchmark for post-mining restoration.

The significance of this work does not only provide key information for the ecologically sound restoration and management of the plant communities in *Banksia* woodlands within Hanson's postsandextraction sites; it also is of great value to conservation and restoration of *Banksia* woodlands right across Western Australia's Swan coastal plain. The partnership has shown that restoration of biodiverse ecosystems within a biodiversity hotspot is possible through dedicated, long-term environmental research excellence and leadership,

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FURTHER READING

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