# Dune Forest Restoration

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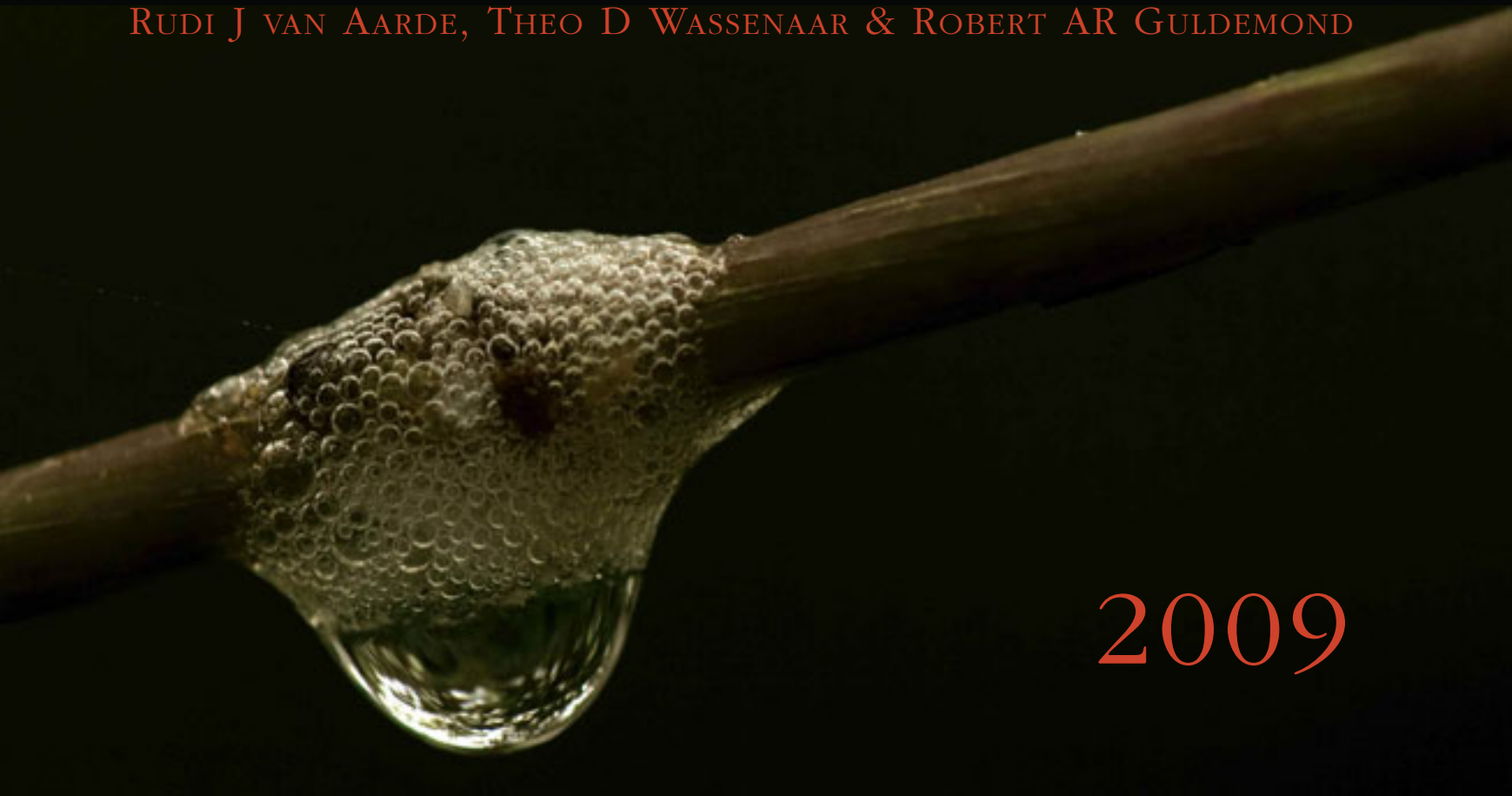

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*Left:* Blue Commelina
Indangabane
*Commelina erecta*

*All photographs used in this publication were taken in the RBM mining lease areas by* RUDI VAN AARDE

# Introduction

Restoration ecologists assist with the recovery of ecosystems that have been damaged. Such restoration is crucial in the fight to counter the loss of biodiversity wrought by a variety of human activities. We prepared this booklet for the non-specialist to show that ecological concepts can be used to manage the restoration of a coastal dune forest in South Africa. The restoration of these dune forests is an essential part of the activities of Richards Bay Minerals (RBM) that mine coastal sand dunes for minerals such as ilmenite, rutile and zircon. These minerals are essential to the region's economic well-being, and so are the coastal dunes. The forest on these dunes is part of the internationally recognised Maputaland Centre of Endemism. We are therefore comitted to conserve them. RBM's restoration program is an ambitious project that places emphasis on the recovery of indigenous ecological processes that will re-establish coastal dune forests.

The restoration of an ecosystem requires a thorough interpretation and application of ecological information. The restoration program in the mining lease areas of RBM relies on succession and disturbance as key ecological concepts. Succession is the colonisation of a disturbed habitat by species adapted to handle prevailing local conditions. Succession thus enables many ecosystems to recover after disturbances. In ecological terms natural disturbances disrupt the structure and function of an ecosystem and in many cases such disturbances are essential for the maintenance of biodiversity.

From an ecological perspective mining partly mimics other large scale natural disturbances. It therefore makes sense to rely on principles of ecological succession to restore dune forests after they have been destroyed by mining. This can include assisting pioneer tree species that naturally flourish in all kinds of disturbed areas in the region, to establish and to initiate succession and patch-dynamics after the mining of sand dunes.

Ecological succession can be initiated on mined sand dunes. This is supported by our 18 year-long study of ecological change and regeneration patterns in seven indicator groups. Our research also predicts that most species may return to the mined areas within about 50 years after the start of succession. But success is not assured, simply because restoration is influenced by many forces, these include those that operate on the surrounding landscapes. From ecological theory, we also know that the spatial arrangement and size of forest patches, be they regenerating or intact, control the rate at which plants and animals colonise suitable habitats. In our study such forest patches




are threatened by activities other than mining. This may derail forest regeneration and thus calls for 1) the active protection of dune forest fragments to sustain the colonisation of previously mined areas through natural dispersal, and 2) the management of disturbances that may influence dispersal and colonisation rates.

The success of a restoration program relies on enabling ecological processes, on maintaining intact forest patches and on managing disturbances such as fire and grazing. Our continuous assessment of these management activities enables RBM to build its adaptive rehabilitation program on ecological processes. Dune forests that develop through these processes also provide local people with a variety of ecological services.

Ecosystems are structured in a complex manner and consist of many interacting parts that respond to changing conditions. We therefore have no guarantees that a particular combination of species (community) will recur after they have been removed by either natural or unnatural disturbances. Restoration provides a test of our understanding of the ecological principles that dictate their recurrence, both across time and space. Predicting the response of species and ecosystems to restoration allows us to design adaptive management interventions that tinker with complex processes. The question of whether we understand the consequences of our management depends on how successful our actions are in restoring the system that we have disturbed. Therefore, restoration ecology in essence provides the knowledge to kindle the maintenance of biodiversity as a conservation ideology.

Ecology focuses on the forces that maintain biodiversity – biodiversity in turn is the engine of life on earth. It touches people's lives in many important ways. In this booklet we explain some ecological concepts associated with the response of biodiversity to disturbance and succession because these are central themes in the regeneration of coastal dune forests after mining. We explain how the rehabilitation program is based on these fundamental ecological concepts and how the monitoring of the outcome of the rehabilitation program enables us to assess its success. We also describe some of our research findings on different life forms of the forest.

Finally, we discuss important management issues, and sketch the direction that the rehabilitation program should take in the future.

# Succession – Cycle of Life

Succession is an ecological process that gives rise to time related changes in the structure and function of ecosystems. Succession usually results in the addition and or replacement of species through natural colonisation of suitable habitat, thereby changing ecosystems from a primary to a climax state. The habitat needs of species and the roles they play form their niche dimensions, which in turn rely on complex interactions between biological and physical processes. The photographs on these pages show how dunes are colonised by *Acacia karroo* (a pioneer tree), which is replaced by mid-succession species, and ultimately by climax forest species. This sequence of changes in species composition and living conditions is the outcome of ecological succession.

However, the path of ecological succession does not always lead to a predictable and singular climax because non-equilibrium forces such as patch dynamics may provide for more than one outcome. Succession and other forces of change provide suitable opportunities for a variety of forest plants and animals to colonise new habitats from elsewhere. Consequently the variety of species that live on the regenerating dune forests changes in numbers and identity with time since the initiation of rehabilitation. Our research focuses on these changes, the processes that govern them and the similarity of each stage of regeneration to the bench-mark state typical of undisturbed dune forests.

*RBM's rehabilitation program provides opportunity for the regeneration of a coastal dune forest through ecological succession. From left to right: 2, 12, 16, 20, 24 and 30 year old rehabilitating vegetation.*

# Disturbance

Disturbance is a discrete event that disrupts ecological structure

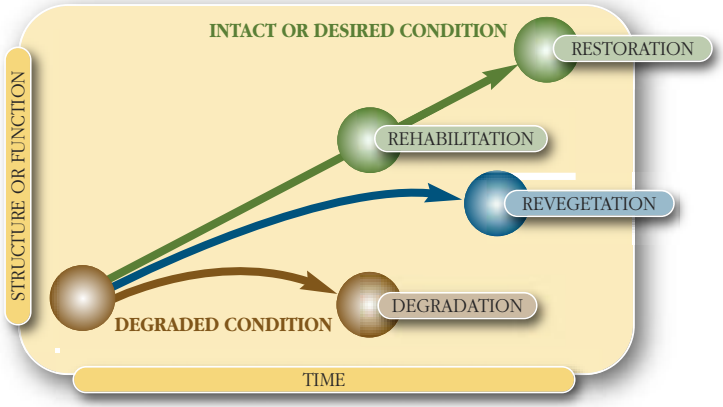
and function - it is an essential part of nature. Disturbances can be recognised on almost every scale. At a small scale a single drop of water may disturb a community of tiny organisms, while at larger scales a hurricane may disrupt most animals and plants in a forest.

Disturbance is also an important process for the maintenance and enhancement of biological diversity (defined as the diversity of species, types within a species and the diversity of ecological processes). Viewed from a broader perspective it is apparent that disturbance creates heterogeneity (variability) in an ecological system, allowing a variety of organisms to coexist and to maintain a diversity of processes that deliver important ecological services. Disturbances vary in intensity and scale. Disturbances also occur at different places and times across landscapes. Through the process of patch dynamics this asynchrony creates landscapes that consist of various stages of succession. Such heterogeneous landscapes are more stable than those that are more homogenous.

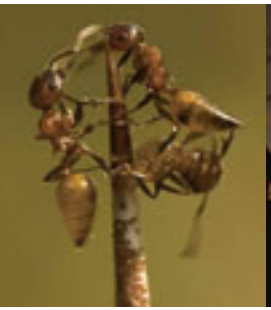
It is important to know how plants, animals and ecosystems respond to disturbances. These responses, singly or collectively, will determine the resilience (the rate at which a system regains its structure and function) and resistance (the length of time it resists changes in the face of a disturbance) that collectively bring about stability. Some of these responses may be predictable, with the system always tending to change to a former state. However, such predictable behaviour is rare in nature. More commonly ecosystems change in unpredictable ways. Understanding the reasons and identifying the drivers for such non-equilibrium dynamics is a key to successful restoration and a challenge for the restoration manager who has to make decisions in the face of uncertainty.

Large herbivores, such as cattle, also disturb vegetation on various levels and scales. For instance, a fresh dung pile is high in ammonia and other substances that are not good for plants in such high concentrations. Moreover, herbivores trample plants and soils, thereby increasing the chances for erosion and, depending on species, either stimulate or inhibit growth and regeneration. Large scale disturbances degrade vegetation and destabilise ecosystems. If given an opportunity some vegetation should recover from this disturbance (if it is resilient enough), and ecological stability will be regained. The challenge is to recognise the scale at which to determine whether disturbance has led to degradation or not.

Severe disturbances, such as large-scale changes of land use by people, can lead to ecological degradation. Management to restore ecosystems that have been damaged in these ways is expensive and requires intensive involvement. Strip mining, as conducted in our study area, is a relatively short but intense local disturbance that removes all species and consequently destroys ecosystem structure and function. Strip mining destroys vegetation and leaves no habitat for plants and animals to survive. Mining therefore removes natural goods and services provided by an intact forest system. Although similar disturbances can also occur in nature (e.g. cyclone Domoina), there are many reasons to expect that a dune forest will not necessarily regenerate of its own accord. Intervention, based on the similarities and differences between damage induced by mining and by natural disturbances, is therefore crucial.




*In this diagram we illustrate the changes that theoretically may occur in response to active restoration after mining. Here the degraded state that exists immediately after mining lacks ecological structure (the diversity and identity of species) and function (the ability to capture and cycle energy and minerals). Through restoration management the ecosystem recovers its structure and function over time and may develop to an intact state (the dark green circle in the diagram) that represents the restored state. An ecosystem that has been placed along the developmental trajectory towards the intact state is rehabilitating, meaning that it is in the process of being restored. An ecosystem that recovers some of its function but not all of its structure, has been revegetated (the blue circle in the diagram), while one that does not recover any structure or function remains in a degraded state (the brown circle in the diagram).*





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# Determinants of Restoration Success

What determines restoration success? The answer to this question provides

A ROAD MAP for management. It could be a matter of removing the obstacles that stand in the way of success, at the same time supporting processes that will ensure success. However, there are many other factors that will influence the outcome of a restoration initiative, some that can be managed, but others that are beyond management. For instance, rainfall regimes, the ecology of inter-continental migratory species, the occurrence of disease, social unrest, economic uncertainties and political interpretation of environmental laws are all beyond the control of restoration managers.

Our work focuses on the ecological problems that face a restoration manager. Because RBM has defined their restoration objective as the reinstatement of coastal dune forests on one third of their mined lease area (the other two thirds are planted with a commercial species for charcoal production) we focus our research on the ecological factors that determine coastal dune forest restoration. We therefore study and compare patterns in intact forests, spontaneously regenerating forests and rehabilitating forests. Our work focuses on how and why ecological variables change across time and space in these forests. This enables us to define the consequences of secondary disturbances for colonisation, the interactions between species that drives colonisation and extinction, and the way animals and plants colonise the forests.

| IMPORTANT DRIVERS OF RESTORATION SUCCESS | |
|---|---|
| | • Stability of ecological processes<br>• Availability and maintenance of sources of species pools to colonise regenerating landscapes<br>• Environmental laws and regulations<br>• Company environmental policy<br>• Shareholder expectations and management structure<br>• Needs and perceptions of neighbouring communities and future land owners<br>• Land use practises in surrounding landscapes<br>• Effective monitoring and evaluation of rehabilitation<br>• Scientific research on ecological questions<br>• An adaptive restoration and management strategy |

# RBM's Forest Rehabilitation Program

RBM RELIES ON ECOLOGICAL SUCCESSION AND ON PATCH DYNAMICS TO REGAIN COASTAL DUNE FOREST on dunes that they have mined. Annual exotic seeds are sown in indigenous topsoil that is thinly spread over reshaped dunes. This stabilises conditions for the development of an early grass cover. Grasses are replaced by dense stands of indigenous *Acacia karroo* trees that serve as pioneers.

Within ten years these quick-growing pioneers form a woodland canopy that provides the conditions needed by broad-leaved forest tree and shrub species to colonise. From 15 years on canopy gaps form naturally as some trees die. This initiates the dynamics that allow mid- and late successional trees to establish and become part of the new canopy. At this stage a sub-canopy layer of shrubs and creepers is well-established, leading to a structured dune forest habitat about 25 years after kick-starting succession. In spite of this about 60 per cent of forest tree species are still not present after some 32 years of development. This calls for the development of adaptive management protocols to ensure and stabilise the recovery process.

Different to plants, most beetles, millipedes, spiders, mammals and birds that commonly occur in intact dune forests also occur in rehabilitating areas. Some forest specialists, especially among the birds, continue to be either rare or absent, for reasons we are now studying. The pattern of regeneration of forests on areas rehabilitated by RBM is very similar to that which we study on disturbed areas that are regenerating spontaneously in the region.

RESTORATION MANAGEMENT FACES A CHALLENGE: natural systems often behave in unpredictable ways. Management therefore requires a careful approach to decision making, and a sound basis for predictions. Science and the scientific method of setting and assessing hypotheses provides for these predictions. For that reason, restoration management at RBM is based on the principles of adaptive management that allows for continuous evaluation of outcomes and the proactive implementation of educated decisions. Management outcomes are carefully monitored against defined objectives, and management is adapted on the basis of new information. Adaptive management can therefore be defined as "learning by doing".

# Components of the Forest

## RESEARCH

The rehabilitating mining lease areas serve as our outdoor laboratory. Questions arising from problems identified by us or by management, or from our monitoring program are investigated through research. These questions often are addressed as part of our peer-reviewed papers and post-graduate dissertations.

Criteria that we have developed during 18 years of research allowed us to develop methods to predict the rate and direction of ecological changes towards the endpoints of restoration. These endpoints are targets that may or may not be reached within the time frame of active restoration management. Factors that may limit processes that can lead to these endpoints continue to be investigated through the research program that provides the basis for the monitoring program.

## MONITORING

To monitor the outcome of RBM's rehabilitation program we study time and spatial related changes in the number of individuals per species, the number of species (richness), diversity, species composition, and the way the system recycles nutrients. Along with soil properties such as Carbon and Nitrogen contents, and bio-assays of soil fertility, we survey important forest life forms such as trees, herbs, millipedes and birds. Monitoring is an essential component of the restoration program and it is important that we set and define reasonable restoration targets. We consequently measure, describe and characterize undisturbed dune forests to set restoration targets. These 'reference' forests provide benchmarks against which we evaluate restoration success. This means that we check that the development of the rehabilitating areas can lead to an intact forest.

# Rehabilitation Program

## EVALUATION

Based on information obtained through research and monitoring, we decide whether the rehabilitation program is still on track. We evaluate the information in the light of general ecological models and knowledge, as well as our own experiences. We then take a decision to adapt current management practices, instigate new ones, or start new research projects where information seems insufficient. For the evaluation it is important that suitable indicators of restoration success are selected and measured. These indicators should represent the structure and function of a dune forest as well as the natural variability that is typical of an intact or regenerating dune forest. These indicators must meet certain criteria, which define the standards against which we judge restoration success.

## IMPLEMENTATION

Management objectives which stem from research and monitoring define the management targets. Specific management actions to achieve these objectives are then implemented and the outcome thereof is carefully monitored. Implementation includes physical actions such as the shaping of dune profiles, the spreading of a certain volume and quality of topsoil, the structured removal of alien vegetation and control of grazing by cattle, fire prevention and the protection of fragments of forests that serve as source pools.

# Ecological Research

Our research program follows scientific protocols to determine time and space related changes in the species composition. It estimates the number of individuals and species in each of the taxa that we have elected to study and to monitor. Species are identified against herbarium and other reference collections.

Our sampling protocols meet international standards and we place emphasis on measuring variability and the precision of all estimates. For instance, we use distance survey methodologies to estimate bird numbers. We take special care to ensure the repeatability from year to year and from one survey area to another. Our plant and millipede survey quadrates are also replicated and randomly located within each of the sampling sites. These quadrate surveys allow us to estimate species-specific densities and several variables that reflect on community structure.

The completeness of sampling is determined using rarefaction protocols through which accumulation curves are designed. These curves represent the cumulative number of species that have been seen as a function of sampling effort. This approach ensures both cost efficiency and scientific rigour.

We analyse data and compare our results against ecological theories, hypotheses and our own empirical experience over the years. Our approach ensures that the monitoring of ecological recovery meets scientific criteria and improves our understanding of the dynamics of dune forests. Postgraduate training is integral to our approach and we regularly disseminate our findings at national and international conferences. Regular feedback meetings to mining management also ensure that our research findings are implemented.

# Our Work in Context

The recovery of an ecosystem relies on natural processes that bring about desirable patterns. Modern conservation focuses on maintaining and restoring these patterns. This stabilises the processes that supply vital ecological services to people. Predicting patterns and processes is the core business of ecological sciences and restoration ecology rightly deserves the status of an 'acid test for ecosystem dynamics'. RBM's commitment towards long-term ecological research in a natural research laboratory lends opportunity to refine these 'acid tests' – this is the core of our academic program on forest recovery and restoration in and around the RBM mining lease areas.

The application of restoration ecology needs well designed action plans that may have long-term outcomes. The implementation of these plans is costly and as scientists we have to ensure that our protocols meet the qualities dictated by the academic world. We do this by publishing our findings in scientific journals (see the reference list at the end of this booklet and the complimentary CD in the back cover). This assures exposure to a peer-reviewing system that is typical of primary scientific activity. We also present our work at local, national and international scientific symposia and relevant workshops. Our annual technical reports and frequent meetings aid in the planning of RBM's rehabilitation activities.

Some 18 years of research support by RBM explicitly allowed for freedom of expression and provided for continuity and a platform to build academic and applied capacity within the field of restoration ecology. To this end, 28 postgraduates have completed their studies in this program.

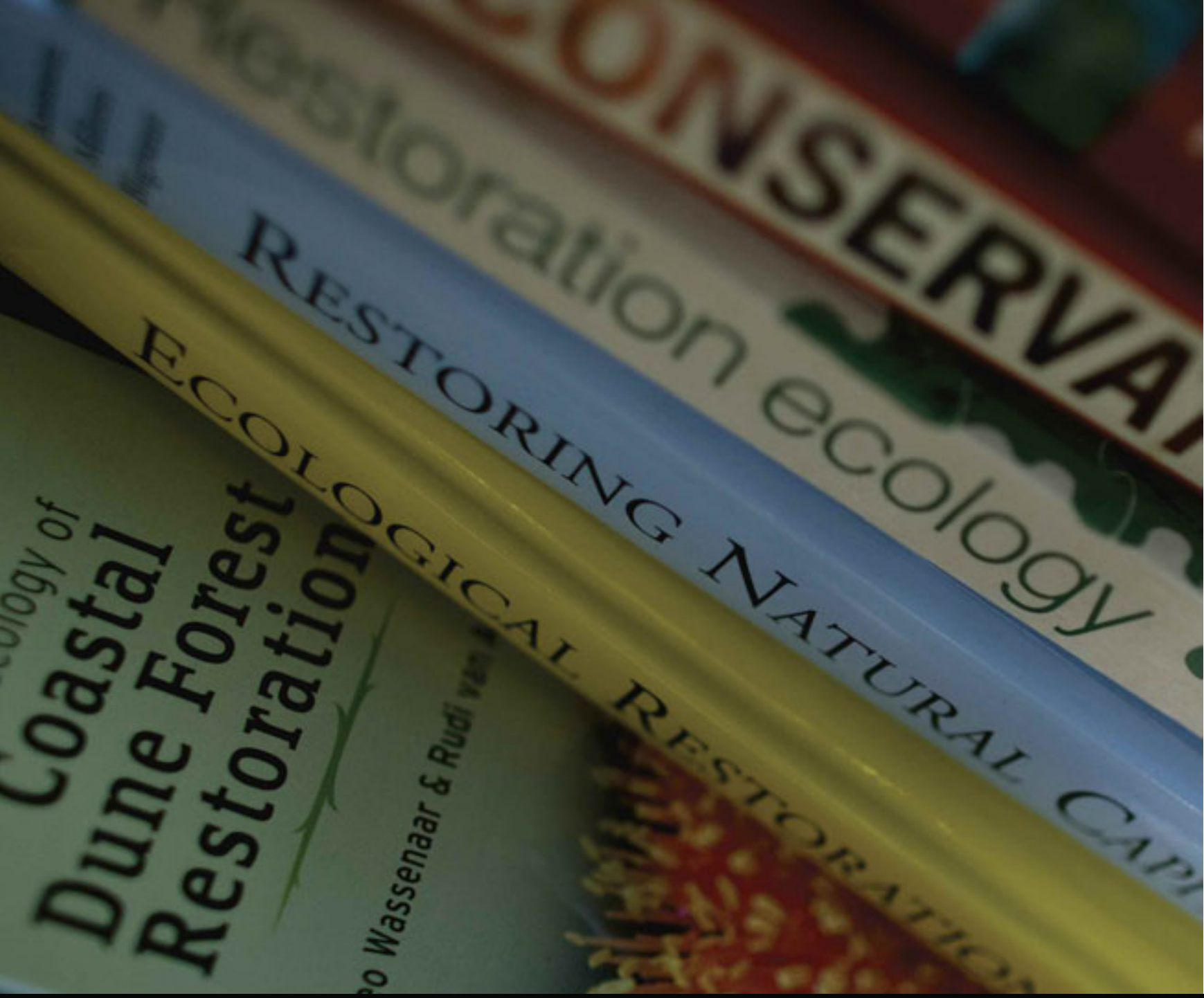
# The Future

Adaptive management by definition requires continual updating based on the

findings of research and monitoring protocols. The life expectancy of mining and active rehabilitation is much shorter than the time that may be needed for the full development of an indigenous and self-sustaining coastal dune forest. RBM's rehabilitation program emphasises the establishment and maintenance of a self-sustaining forest regeneration process that has a high likelihood of giving rise to a dune forest typical of the region. Such a goal rather than one of establishing a dune forest per se, makes both ecological and economic sense and can be achieved within the lifetime of the mining operation.

Restoration management cannot ignore the effects of landscape characteristics on the colonisation of rehabilitating areas by forest species. In the future our research therefore will continue to focus on the implications of landscapes for colonisation, extinction and dispersal so as to improve the management of rehabilitation. The monitoring program will also be adapted to fit into this approach. We will continue to improve cost efficiency by seeking the simplest indicators of ecological structure and function.

Long-term ecological studies have an advantage over studies conducted over short periods in that complex patterns often only show themselves after a number of years of study. In our quest to guide RBM in their effort to rehabilitate a severely disturbed system, we continue to describe new phenomena, and test current theoretical models that have been published by us and others.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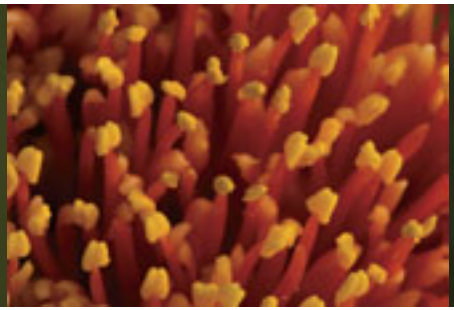



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