Chapter 1 General Introduction

An evaluation of coastal dune forest rehabilitation through ecological succession

Across the globe, the attainment of natural resources (such as minerals and timber) for human-use has similar consequences; namely, habitat loss, habitat fragmentation and habitat degradation (Foley et al. 2005). It is intrinsically evident that where the amount of habitat that can support biological diversity is reduced, the number of species will also decline. Habitat loss, fragmentation and transformation are thought to be one of the main threats to global biological diversity and ecosystem services (Fahrig 1997; Bender et al. 1998; Gaston et al. 2004; Goldewijk & Ramankutty 2004; Hoekstra et al. 2005). Traditional conservation practices (for example, conserving nature in parks) have not yet stemmed the tide of habitat change and species loss.

Several authors have heralded the activity of ecological restoration as a potential panacea to this trend of global habitat loss (Wilson 1992; Dobson et al. 1997; Young 2000). Ecological restoration according to the Society for Ecological Restoration International (SER 2004) is "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability." The eminent scientist E.O. Wilson believed that ecological restoration was "…the means to end the great extinction spasm…" and that "the next century will… be the era of restoration in ecology" (Wilson 1992). Ecological restoration has quickly become integral to biological diversity conservation and sustainable development, and is often a legally binding requirement of mining permission (Tischew et al. 2010). In addition to the conservation ethos, ecological restoration may be valuable to scientists who wish to test ecological theories that address the assembly of biological communities (Bradshaw 1983). Palmer et al. (1997) and Young et al. (2005) suggest that restoration ecology (the science of ecological restoration) is well equipped to address scientific questions with regard to community development, species diversity and its role in ecosystem function, seed limitation and the role of soil micro-biota in facilitating community assembly. In addition, the role of the landscape in restoration, metapopulations, niche theory, as well as many other areas of ecology offer unique opportunities to test key theoretical questions in ecology (Young et al. 2005).

However, some authors have suggested that restoration ecology is failing to live up to its potential with regard to scientific endeavour (Halle 2007; Weiher 2007). In addition, others have suggested that the conservation value of ecological restoration is overstated (Elliot 1982; Davis 2000; Katz 2003). In reality, the current practice of ecological restoration probably falls somewhere between these two polar views (panacea to an over-statement of conservation value). Ecological restoration always comes second to preservation, but it can enhance conservation (Young 2000; Rey Banayas et al. 2009). The extent to which ecological restoration enhances conservation is probably dependent on the goals, techniques, and locale of individual projects, and perhaps the views of individual restoration practitioners. Ecological restoration is characterised by intentional actions that facilitate ecosystem recovery (SER 2004). These intentional actions implemented by managers may vary between relatively passive approaches relying mostly on natural community assembly through to management intensive approaches where species are introduced directly in to disturbed sites (Prach & Hobbs 2008).

The reliance on natural community assembly has been criticised by some, as it is unpredictable and can result in multiple stable states that differ to and support less biodiversity than the pre-disturbed state (Handa & Jefferies 2000; Pywell et al. 2002; Suding et al. 2004). However, others have promoted passive approaches over technical interventions because they result in a more natural species composition and greater biological diversity (Hodačová & Prach 2003). Prach & Hobbs (2008) suggest that ecological succession is preferable to technical interventions but adaptive management can be implemented to direct succession if required. Whatever the management action taken it is important to monitor the biotic (and abiotic) responses within rehabilitating sites and to evaluate the success of the technique in ensuring progress toward stated objectives or targets.

In South Africa, the restoration target for mining companies is stipulated in the Mining and Petroleum Resources Development Act (2002; South Africa). This act states that mining companies (other land uses are not bound by this legal requirement): "…must as far as it is reasonably practicable, rehabilitate the environment affected by the prospecting or mining operations to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development." The mining company Richards Bay Minerals (RBM) initiated what is now the longest running rehabilitation programme, in South Africa in 1977. The programme aims to restore indigenous coastal dune vegetation to one third of its lease area. The mining company relies on ecological succession after ameliorating the mine tailings to accelerate initial colonisation (see below for further details). Through this thesis, I wish to evaluate the ecological consequences of this programme for coastal dune forest.

From 1977 to the present day, RBM continues to mine the minerals zircon, ilmenite, and rutile through a dredging process (van Aarde et al. 1996a). The mining process involves the clearing of dune forest and topsoil, and then dredging of the underlying sand (see Plate 1-1). After removal of the minerals from the sand, the "tailings" (the stockpiled sand that has been through the dredging process) are shaped to reform dunes. Post-mining habitat rehabilitation is directed in one of two pathways, either to commercial land-use, which has historically been commercial *Casuarina equisetifolia* plantations, or to indigenous coastal dune vegetation. For sites earmarked for indigenous forest rehabilitation, topsoil, seeded with annuals, is returned to the dune (Plate 1-2). Topsoil is further stabilised by wind-breaking fences (Plate 1-3). After this process, management is limited to the removal of non-native plant and animal species, and the prevention of fires. Continuous mining and subsequent restoration has resulted in a sere of regenerating patches in the landscape (van Aarde et al. 1996a, Wassenaar et al. 2005, see Plates 1-4 to 1-7).

Through the amelioration of stressors associated with the establishment of species at disturbed sites and later the control of other potential disturbances (in the form of fires and non-indigenous plants and herbivores) the RBM rehabilitation programme aims to “kick-start” and facilitate the processes involved in ecological succession (van Aarde et al. 1996a). Our previous research on the rehabilitation of coastal dune forest has been explicitly founded on the theoretical predictions of succession (for example, van Aarde et al. 1996b; Kritzinger & van Aarde 1998), and this is common in the restoration ecology literature (for example, Jansen 1999; Fagen et al. 2010; Gould *In press*, see also Prach & Hobbs 2008 and references therein).

I have divided this thesis in to 7 chapters. In Chapters 1 and 2, I provide a general introduction and more detail on the context of coastal dune forest ecology within South Africa. In Chapters 3 through 6, I present four papers, all of which address the consequences of the use of a succession-based approach to the restoration of coastal dune forest destroyed after strip-mining. In the final Chapter, I assess the ecological consequences of the succession-based approach for the likelihood of restoration.

We can only really evaluate the restoration of coastal dune forest by comparing the desired outcomes of restoration with the actual outcomes. As community reassembly is a dynamic process, we cannot rely on a single snap-shot evaluation, but need to repeatedly monitor and evaluate progress. The long-term monitoring and research of rehabilitating coastal dune forest provides a case study to investigate the outcomes of rehabilitation. In keeping with other rehabilitation projects, the ultimate goal of coastal dune forest rehabilitation is the recovery of functioning communities and the ecological processes associated with them (Young et al. 2005). Restoration ecology is fundamentally about the spatial and temporal influences on the process of how plants and animals reach a disturbed site and survive there. Therefore, it is hardly surprising that restoration ecology has as its conceptual foundation, theories that address the assembly of communities (Young 2000). The theory of ecological succession appears to have had the most influence on restoration ecology (Young et al. 2005). Successional theory has been an important part of the history of ecology for over a century (Walker & del Moral 2008). This theory in its most basic form suggests that the recovery of ecosystem structure, composition and function after a disturbance event is largely predictable and progressive (Clements 1916). The basic premise is that all sites that share a regional climate will also eventually acquire the same stable set of species. As succession offers several predictions of the trends in species composition and other community properties that can be expected after a disturbance event, the outcomes of rehabilitation actions should be predictable (Van Andel & Aronson 2006).

However, many factors may detract from the predictability of the reassembly of disturbed communities. For example, the order in which species colonise the disturbed site may be important in determining community composition (Connell & Slatyer 1977). This assembly theory was alluded to by both Gleason (1926) and Egler (1954) who pre-empted Diamond (1975) in suggesting that the timing of species colonisation can lead to alternative stable states (Chase 2003). This is the key difference between the two approaches. Successional theory predicts that species composition will be similar in sites with similar climatic conditions recovering from disturbance. In contrast, assembly theory predicts that if all species in the regional pool have equal access to disturbed sites, but the order by which species colonise the sites differs, so will the eventual stable community composition (Chase 2003; see also Young et al. 2001). Obviously, these two theories have different consequences for restoration ecology. If the historical contingency is a reality then the goal of restoring a particular habitat to its former state may be unattainable (even with intensive management intervention) as a number of alternative stable states can result from the order by which species establish (Young et al. 2001). In Chapter 3, I evaluate if succession is a suitable conceptual basis for the restoration of coastal dune forest. I compare patterns of community characteristics observed in rehabilitating coastal dune forest sites with those predicted by theory.

Many other factors may compromise the efficacy of succession-based restoration management (Suding et al. 2004). For example, changes in the species pool such as the establishment of strong dominants (Walker & del Moral 2003; Matthews & Spyreas 2010) may lead to divergence of regenerating trajectories away from the desired endpoints. Non-indigenous species may also influence the re-assembly of communities by out-competing native species for limited resources (Hartman & McCarthy 2004; Suding et al. 2004), consuming or infecting native species with novel diseases (D'Antonio & Meyerson 2000) as well as altering the nutrient inputs in to the ecosystem (Vitousek et al. 1990). This forms the theme of Chapter 4, which addresses the role of non-native plant species in the rehabilitation of the herbaceous plant community.

Changes in the disturbance regime under which species have evolved may lead to arrested succession. For example, Chapman et al. (1999) showed that large-scale (unnatural) disturbances led to arrested succession in Ugandan forests. This was due to the lack of pioneer tree species adapted to survive in large logging gaps (Chapman et al. 1999). The restoration of coastal dune forest relies on the *Acacia karroo* successional pathway (see von Maltitz et al. 1996). This pathway has been criticised because *Acacia* dominated woodlands may stagnate succession (West et al. 2000). In Cape Vidal, to the north of the RBM lease area, *A. karroo* is replacing itself in the canopy suggesting arrested succession (Boyes et al. 2010). According to the gap-dynamics theory (Whitmore 1989), large gaps in the canopy promote shade intolerant species, such as *A. karroo*, which may lead to self-replacement. In Chapter 5, I test this theory in three of the oldest rehabilitating sites, and evaluate the role that canopy gaps play in the regeneration of coastal dune forest.

Neither succession nor assembly theory pay much heed to the role that the surrounding landscape composition can play in the assembly of communities. The theory of Island Biogeography (MacArthur & Wilson 1967), one of the most influential theories in ecology, provides predictions about how landscape composition influences community assembly. It predicts that the biological diversity of an island is determined by the outcome of two fundamental ecological processes: colonisation and extinction. Colonisation is the sum of all events that culminate in a species finding and occupying a new island habitat. Local extinction, the opposite of colonisation, is the disappearance of a species from an island habitat because of competitive interactions, or simply not finding enough resources there. These two processes are in turn determined by how large an island is and how far from the mainland it is. In general, the theory of Island Biogeography predicts that larger islands will suffer less extinction than smaller islands and hence will support a higher biodiversity. In the same way, islands that are closer to a mainland source will experience higher colonisation rates, and thus support more species than islands further away. This theory and its more modern extensions to terrestrial ecosystems in the form of mainland island, metapopulation and metacommunity theories, predicts that landscape pattern will be the major determinant of not only the number of species that a discrete habitat patch can support, but also its species composition.

This theory has profound consequences for the restoration of disturbed habitat. If the landscape is a dominant driver of community assembly processes after disturbance, it should form a distinct part of rehabilitation management planning. The relative position of rehabilitating sites to source areas may be an important and often manageable factor. This forms the theme of the next chapter in the thesis (Chapter 6). In this chapter, I evaluate the role that landscape composition has for the rehabilitation of coastal dune forest. In particular, I relate patch occupancy for forest associated birds and trees, and relate the probability of patch occupancy to the patch age, isolation from the largest intact forest, patch area, and patch shape in rehabilitating, regenerating and remnant forest patches.

In the final Chapter (7), I provide a synthesis of my findings and an evaluation of the rehabilitation of coastal dune forest in terms of the ecological consequences and threats that stem from the rehabilitation efforts of the last 33 years. This final evaluation includes discussion on the measurement of restoration success and assesses the progress that the rehabilitating coastal dune forests of KwaZulu-Natal have made toward a successful outcome.

Literature cited

Bender, D., T.A. Contreras and L. Fahrig. 1998. Habitat loss and population decline: A meta-analysis of the patch size effect. Ecology **79**: 517-533.

Boyes, L.J., R.M. Gunton, M.E. Griffiths and M.J. Lawes. *In press*. Causes of arrested succession in coastal dune forest. Plant Ecology DOI:10.1007/s11258-010-9798-6

Bradshaw, D. 1983. The reconstruction of ecosystems: Presidential address to the British Ecological Society. Journal of Applied Ecology **20**: 1-17.

Chapman, C.A., L.J. Chapman, L. Kaufman and A.E. Zanne. 1999. Potential causes of arrested succession in Kibale National Park, Uganda: growth and mortality of seedlings. African Journal of Ecology **37**: 81-92.

Chase, J.M. 2003. Community assembly: when should history matter? Oecologia **136**: 489-498.

Clements, F.E. 1916. Plant succession: An analysis of the development of vegetation. Washington, D.C.: Carnegie Institution of Washington, Washington D.C. USA.

Connell, J.H., and R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organisation. The American Naturalist **111**:1119–1144.

D'Antonio, C. and L.A. Meyerson. 2000. Exotic plant species as problems and solutions in ecological restoration: A synthesis. Restoration Ecology **10**: 703-713.

Davis, M.A. 2000. "Restoration" – A misnomer? Science **287**: 1203.

Diamond, J.M. 1975. Assembly of species communities. Pages 342-444 in M.L. Cody and J.M. Diamond, editors. Ecology and evolution of communities. Harvard University Press, Cambridge, USA.

Dobson, A.P., A.D. Bradshaw and A.J.M. Baker. 1997. Hopes for the future: Restoration ecology and conservation biology. Science **277**: 515-522.

Egler, F.E. 1954. Vegetation science concepts. 1. Initial floristic composition, a factor in old-field vegetation development. Vegetatio **4**: 412-417.

Elliot 1982. Faking nature. The ethics of environmental restoration. Routledge, London, UK.

Fagen, K.C., R.F. Pywell, J.M. Bullock and R. H. Marrs. 2010. Are ants useful indicators of restoration success in temperate grasslands? Restoration Ecology **18**: 373-379.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. The Journal of Wildlife Management **61**: 603-610.

Foley, J., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. Science **309**: 570.

Gaston, K.J., T.M. Blackburn and K.K. Goldewijk. 2004. Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London B. **270**: 1293-1300.

Gleason, H.A. 1926. The individualistic concept of the plant association. Bulletin of the Torrey Botanical Club **53**:7–26.

Goldewijk, K.K. and N. Ramankutty. 2004. Land cover change over the last three centuries due to human activities: The availability of new global data sets. GeoJournal **61**: 335-344.

Gould, S.F. *In press*. Comparison of post-mining rehabilitation with reference ecosystems in Monsoonal Eucalypt woodlands, Northern Australia. Restoration Ecology Doi: 10.1111/j.1526-100X.2010.00757.x

Halle, S. 2007. Science, art, or application – the "Karma" of restoration ecology. Restoration Ecology **15:**358-361.

Handa, J.T. and R.L. Jefferies. 2000. Assisted relegation trials in degraded salt-marshes. Journal of Applied Ecology **37**: 944-958.

Hartman, K.M. and B.C. McCarthy. 2004. Restoration of a forest understory after the removal of an invasive shrub, Amur Honeysuckle (*Lonicera maackii*). Restoration Ecology **12**: 154-165.

Hodačová, D., and K. Prach. 2003. Spoil heaps from brown coal mining: Technical reclamation versus spontaneous renegotiation. Restoration Ecology **11**:385–391.

Hoekstra, J.M., T. M. Boucher, T. H. Ricketts and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters **8**: 23-29.

Jansen, A. 1999. Terrestrial invertebrate community structure as an indicator of the success of a tropical rainforest restoration project. Restoration Ecology **5**: 115-124.

Katz, E. 2003. The big lie: Human restoration of nature. Pages 390-397 in A. Light and H. Rolston III. Environmental ethics an anthology. Blackwell Publishers, Oxford, UK.

Kritzinger, J.J. and R.J. van Aarde. 1998. The bird communities of rehabilitating coastal dunes at Richards Bay, KwaZulu-Natal. South African Journal of Science **94**: 71 – 78.

MacArthur, R. H., and E. O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution **17:**373-387.

Matthews, J.W. and G. Spyreas. 2010. Convergence and divergence in plant community trajectories as a framework for monitoring restoration progress. Journal of Applied Ecology **47**: 1128-1136.

Palmer, M.A., R.F. Ambrose and N.L. Poff. 1997. Ecological theory and community restoration ecology. Restoration Ecology **5**: 291-300.

Prach, K. and R.J. Hobbs. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology **16**: 363-365.

Pywell, R.F., J.M. Bullock, A. Hopkins, K.J. Walker, T.H. Sparks, M.J.W. Burke and S. Peel. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. Journal of Applied Ecology **39**: 294-309.

Rey Banayas, J.M., A.C. Newton, A. Diaz and J.M. Bullock. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. Science **325**: 1121-1124.

Society for Ecological Restoration International Science & Policy Working Group (SER). 2004. The SER International Primer on Ecological Restoration. www.ser.org, Tucson: Society for Ecological Restoration International.

Suding, K.N., K.L. Gross, and G.R. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology and Evolution **19**:46–53.

Tischew, S., A. Baasvch, M.K. Conrad and A. Kirmer. 2010. Evaluating restoration success of frequently implemented compensation measures: Results and demands for control procedures. Restoration Ecology **18**: 467-480.

van Aarde, R.J., Coe, M. and Niering, W.A. 1996a. On the rehabilitation of coastal dunes of KwaZulu-Natal. South African Journal of Science **92**: 122-124.

van Aarde, R.J., S.M. Ferreira, and J.J. Kritzinger. 1996ab. Successional changes in rehabilitating coastal dune communities in northern KwaZulu-Natal, South Africa. Restoration Ecology **4**: 334 – 345.

van Andel, J., and J. Aronson. 2006. Restoration Ecology. Blackwell, Oxford, U.K.

Vitousek, P.M. 1990. Biological invasions and ecosystem processes. Towards an integration of population biology and ecosystem studies. Oikos **57**: 7-13.

von Maltitz, G.P., G.F. van Wyk and D.A. Everard. 1996. Successional pathways in disturbed coastal dune forest on the coastal dunes in north-east KwaZulu-Natal, South Africa. South African Journal of Botany **62**: 188–195.

Walker, L.R. and R. del Moral. 2008. Lessons from primary succession for restoration of severely damaged habitats. Applied Vegetation Science **12**: 55-67.

Walker, L.R., and R. del Moral. 2003. Primary succession and Ecosystem Rehabilitation. Cambridge University Press, Cambridge, UK.

Wassenaar, T. D., R. J. van Aarde, S. L. Pimm, and S. M. Ferreira. 2005. Community convergence in disturbed sub-tropical dune forest. Ecology **86:** 655-666.

Weiher, E. 2007. On the status of restoration science: Obstacles and Opportunities. Restoration Ecology **15**: 340-343.

West, A., W. Bond, and J.J. Midgley. 2000. Dune forest succession on old lands: implications for post-mining restoration. Pages 35-39 in: A.H.W. Seydack, W.J. Vermeulen, and C. Vermeulen, editors. Towards Sustainable Management Based on Scientific Understanding of Natural Forests and Woodlands. Department of Water Affairs and Forestry, Knysna, South Africa.

Whitmore, T.C. 1989. Canopy gaps and the two major groups of forest trees. Ecology **70**: 536-538.

Wilson, E.O. 1992. The diversity of life. Belknap Press of Harvard University Press, Cambridge, USA.

Young, T. P., D. A. Petersen, and J. J. Clary. 2005. The ecology of restoration: historical links, emerging issues and unexplored realms. Ecology Letters **8:**662-673.

Young, T.P. 2000. Restoration ecology and conservation biology. Biological Conservation **92**: 73-83.

Young, T.P., J.M. Chase and R.T. Huddleston. 2001. Community succession and assembly. Comparing, contrasting and combining paradigms in the context of ecological restoration. Ecological Restoration **19**: 5-18.

Plate 1-1. Mining operations at Richards Bay Minerals result in the removal of all vegetation and topsoil in front of the mining pond. Topsoil is stockpiled for use on rehabilitating sites. Immediately post-mining sand is formulated to an approximation of the dunes previous topography. The photograph was taken by Prof. R.J. van Aarde and is used with his permission.

Plate 1-2. This plate shows a rehabilitating site at less than 1 year old. Topsoil stockpiled prior to mining is replaced on re-shaped dunes and wind-breaking fences are erected to limit soil erosion. The soil is seeded with exotic annual seeds that provide a cover crop, further stabilising the soil. The photograph was taken by Prof. R.J. van Aarde and is used with permission.

Plate 1-3. This rehabilitating site is around 1 year old. Here the dune has a layer of topsoil and wind-breaking fences have been erected. In the foreground, a cover crop of exotic annual herbaceous plants has established. In the background, there are active mining operations, adjacent to previously rehabilitated coastal dune forest.

Plate 1-4. This rehabilitating site is around 3 years old. Various graminoids have established alongside the pioneer tree species *Acacia karroo*, which is shown in the foreground. The photograph was taken by Prof. R.J. van Aarde and is used with permission.

Plate 1-5. This ~8 year old site is dominated by *A. karroo*, with a developing herbaceous layer. Self-thinning of *A. karroo* potentially allows secondary species to colonise the site. The photograph was taken by Prof. R.J. van Aarde and is used with permission.

Plate 1-6. At ~28 years old, *A. karroo* is still the dominant canopy tree species. However several forest-associated species have established in the site, and there is a developed herbaceous layer. The photograph was taken by Prof. R.J. van Aarde and is used with permission.

Plate 1-7. At ~32 years old, individuals of *A. karroo* are beginning to reach senescence and the death and subsequent collapse of these canopy individuals may allow broadleaved secondary species to replace them in the canopy. The photograph was taken by Prof. R.J. van Aarde and is used with his permission.