

CHAPTER 8: POTENTIAL APPLICATION OF THE MODEL

8.1 Introduction

Returning a permanent vegetative cover on land affected by surface mining is required by governments in Australia (Minerals Council of Australia, 2003) for soil stabilisation and to minimise erosion, to reduce stream siltation, for aesthetic reasons and for satisfying ecological sustainability requirements.

Mining companies incorporate rehabilitation and pollution control into operating costs. Thus identifying rehabilitation goals and devising strategies to achieve them are important activities in mine planning. Most strategies adopted by mining companies address issues associated with the initial stages of rehabilitation such as landscape design and stability, the presence of benign overburden materials at the surface, topsoil collection and replacement, revegetation and to a lesser extent habitat development. However, little attention is paid to how such ecosystems develop over time and what management strategies may be needed to ensure that they reach the desired rehabilitation goal in the shortest time possible. This raises many questions as to how desired goals can be achieved and what issues should be considered? How long will it take from the disturbed state to the desired state and can we predict the vegetation colonisation pattern and avoid undesired states occurring, thereby saving costs associated with successful rehabilitation? The Agent-based Model developed and tested in Chapter 7 has the potential to simulate vegetation succession and to provide predictions on successional patterns in community composition and structure over time using different rehabilitation strategies. It

can also estimate the possible time required to achieve the endpoint of the rehabilitation plan. This chapter discusses the application of the model to rehabilitation strategies by demonstrating some examples of common rehabilitation methods.

8.2 Integration of Agent-based Model and the Desired Rehabilitation State

Revegetation is a major part of a rehabilitation plan and generally determines its success. A flowchart (Fig. 8.1) shows the integration of the simulation model developed in Chapters 6 and 7 with a rehabilitation plan for decision making and management.

The flowchart includes a conceptual model, a GIS model, a simulation model and a decision - making model.

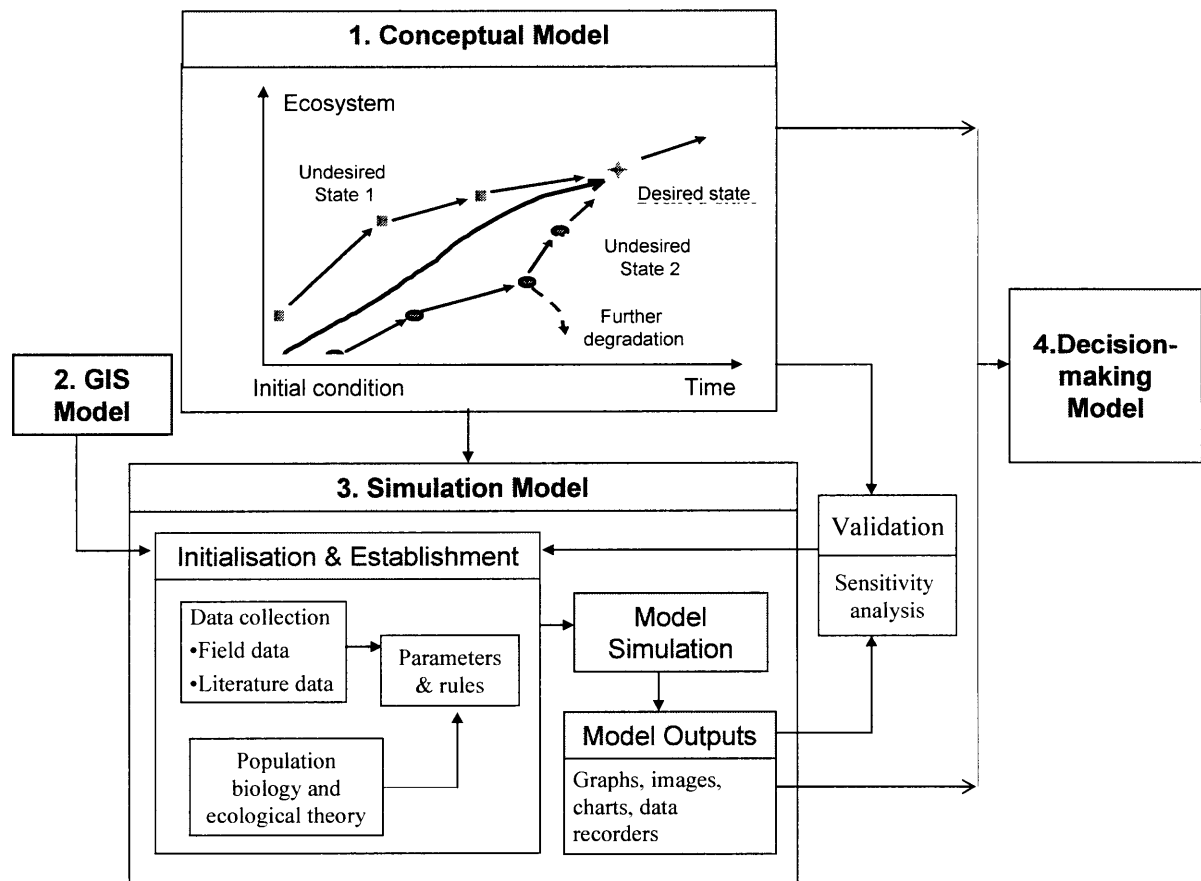


Fig. 8.1 Models flowchart of integrating a forest succession model with a conceptual model for rehabilitation management.

The conceptual model shows ecosystem development over time starting from its initial condition (state) moving through a range of states to a desired state along a successional trajectory (Hobbs & Norton 1996; Grant *et al.* 2001). The land condition after mining is considered as the initial state (for instance, the state of spoil heaps before revegetation), and the desired state means the endpoint or goal of land rehabilitation. The definition of the desired state depends on the objective of the end land use, and can be a similar state prior to mining or to some other land use deemed acceptable to the regulators, industry and the

community. The aim of the desired state is to ensure the development of a self-maintaining ecosystem. The solid line in the middle of the conceptual model represents the ideal trajectory from the initial state to the desired state (the 'gold star'). The other trajectories (ovals and rectangles) represent different states along other trajectories that are deemed less desirable. During rehabilitation, further degradation may occur. Rehabilitation methods and strategies need to ensure that progress from the initial condition to the desired state is successful. However, whether this can be achieved depends on impacting factors, such as seed biology, vegetation growth, vegetation succession, environment and weather conditions. The conceptual model determines what the simulation model will produce and what biophysical information should be used to initialise the simulation model.

Rehabilitation is a site-specific practice. Basic information (such as mine site maps, soil, topographic information etc.) for the disturbed site can be entered into a GIS model and transferred to the simulation model so as to provide a growth environment for plants in the simulation model. The simulation model includes initialisation, establishment, simulation process and outputs (Chapter 6). The initial site conditions (such as seed, soil, topography, and climate) and plant biological information are the parameters used to initialise the model. The selection of different parameters will result in different simulation results. The outcomes from the simulation model are validated through sensitivity analyses. The simulation model outputs are compared to the desired state in the conceptual model. Discrepancies between the two can be reduced by re-initialisation and establishment of the simulation. These are then used to ensure the simulation model provides reliable outcomes for achieving the desired state. Then the outputs from the conceptual model and the simulation model, along with the parameters

used to initialise and establish the simulation, can be used in the decision making-model to provide management strategies for rehabilitation.

8.3 Potential Applications

- As was shown and discussed in Chapter 7, the model predicted ecosystem development over time, and produced predictive successional patterns. The patterns shows species changes, community composition and structural changes over time.
- The model runs on a time step, it can be used to estimate the time for rehabilitation from the initial state to the endpoint.
- The simulation model will produce predictive patterns according to different initial conditions and strategic management. Undesired states can be adjusted more closely to the ideal trajectory until the desired state is achieved by specifying different initial conditions or changing the initial conditions (Fig. 8.1), such as using different seed mixes and sowing rates (varying species composition and abundance), changing soil types, or adding some topographical factors. In this way the model can then be used to predict the communities likely to develop.
- The model can be used to compare the outcomes for different rehabilitation strategies. The optimal strategy can then be selected to achieve the desired ecologically sustainable endpoint, and at the same time avoiding undesired states.

In this chapter, common rehabilitation strategies at mine sites are introduced and then simulated using the Agent-based Model developed in Chapters 6 and 7.

8.4 Rehabilitation Strategies

In practice, the major factors impacting on the success of the rehabilitation include the source of plant propagules, soil type and management strategies. The most common methods utilised in the revegetation after mining include providing a suitable substrate for plant growth, adding topsoil cover, providing fertiliser and other soil amendment, and introducing seed mixes of desired species with or without planting appropriate species (Hore-Lacy 1979; Jackson 1991; Norman 2005; Wills & Read 2007; Martinez-Ruiz *et al.* 2007). The model developed in Chapter 6 and used to simulate ecosystem development in Chapter 7 is now applied to different management strategies commonly used in mine rehabilitation. ***Assistance to natural regeneration*** may be achieved by supplementing seed source in seed banks and seed rain with seed mixes. In practice, the common post-mining process is to replace topsoil over overburden followed by seeding and/or planting to assist vegetation re-colonisation disturbed by mining (Bellairs *et al.* 1993). Despite the considerable time taken for ecosystems to obtain a complex structure and self-organised function in a sustainable state for the desired endpoint, this empirical work attempts to achieve a more or less stable vegetation cover stage in a relatively short period.

In the model, initialisation conditions includes seed rain of tree species from a natural forest, a seed bank in the topsoil and the introduction of seed mixes of trees and shrubs. The soil conditions include topsoil and two bare overburden patches (Fig. 3.6 in Chapter 3). The seed banks from surrounding natural forest and topsoil and other selected parameters will be the same as that input to natural regeneration in Chapter 7.

Changing the proportion of trees to shrubs in the seed mix is presented to show how seed mixes influence endpoint development. Using seed mixes is a very common rehabilitation strategy, so selecting suitable species and their combination for achieving the endpoint needs to be considered. Native species are generally chosen for developing communities similar to the system existing before mining.

Seeds of nine species were selected and incorporated into two kinds of seed mixes, one being 75% trees seed with 25% shrub seeds and another being 25% tree seed with 75% shrubs seed based on a weight ratio. Topsoil is applied to cover the study site uniformly. The seed mixes are the only seed source used in this example.

Use of different soil types is a common option in the practice of mine rehabilitation. Two kinds of soil treatments are applied, one is topsoil and another is without topsoil (bare overburden). Topsoil is uniformly applied through the whole site. The same seed mix of trees and shrubs (2 to 1) is used in both examples without inputs from a seed bank or an alternative seed source.

8.5 Model Application for Different Rehabilitation Strategies

8.5.1 Assistance to Natural Regeneration

The strategy aims to rehabilitate to a condition similar to the surrounding natural forest as the endpoint with the surrounding natural forest used as the reference ecosystem. The endpoint ecosystem needs to be a sustainable self – maintaining system. A seed mix is used to supplement the seed source from the surrounding natural forest are seed source. Therefore, the

proportion of trees to shrubs in the seed mix is based on the proportion of trees to shrubs measured in the reference ecosystem (Chapter 4 Tables 4.3 & 4.4) which is 10 to 1. The seed weight proportion of eucalypts : *C. glaucophylla* : *C. cristata* is set as 1:1:2, and trees : shrubs is set as 10 : 1.

Table 8.1 shows that eucalypts increased steadily, but *C. cristata* showed a large population at the early stage of the succession, and then declined significantly. Shrub density also declined while *C. glaucophylla* increased over time (Fig. 8.2). In comparing the simulation with the natural forest, it is found that species density is similar at 30 year simulation except for *C. cristata* (Table 8.1, Fig. 8.3). Fresh and old stumps of eucalypts and *C. glaucophylla* in the surrounding natural forest indicated that logging has occurred occasionally, and this maybe the reason that promoted *C. cristata* regenerate on site. However, in the model, such event is not included, but it is possible to get the similar density by increasing the proportion of *C. cristata* in the seed mix. Therefore, if the desired endpoint here is the natural forest the model can estimate the rehabilitation time from the initial state to the endpoint. The composition and structural changes are shown in Figure 8.3. Trees emerged uniformly over the whole area rather than establishing from the edge (see Fig. 7.5 a in Chapter 7), and individuals steadily increased while shrubs declined. *Callitris glaucophylla* gradually dominate the study site with a high density.

Shrubs increased up to 40 years, then declined and were in low abundance at 200 years. Since the surrounding natural forest provides seed rain into the site at every time step, shrubs will not become extinct from the simulation after 200 years provided that there is space for their growth.

Table 8.1 Comparing the simulation with natural forest to determine a seed mix rate of trees and shrubs.

Species	Simulation (plants/ha)				Natural Forest (plants/ha)
	35 year	50 year	100 year	200 year	
Eucalypts	542	661	1020	1221	545
<i>Callitris glaucophylla</i>	581	812	989	1043	619
<i>Casuarina cristata</i>	779	786	504	417	1343
Shrubs	130	89	34	31	225

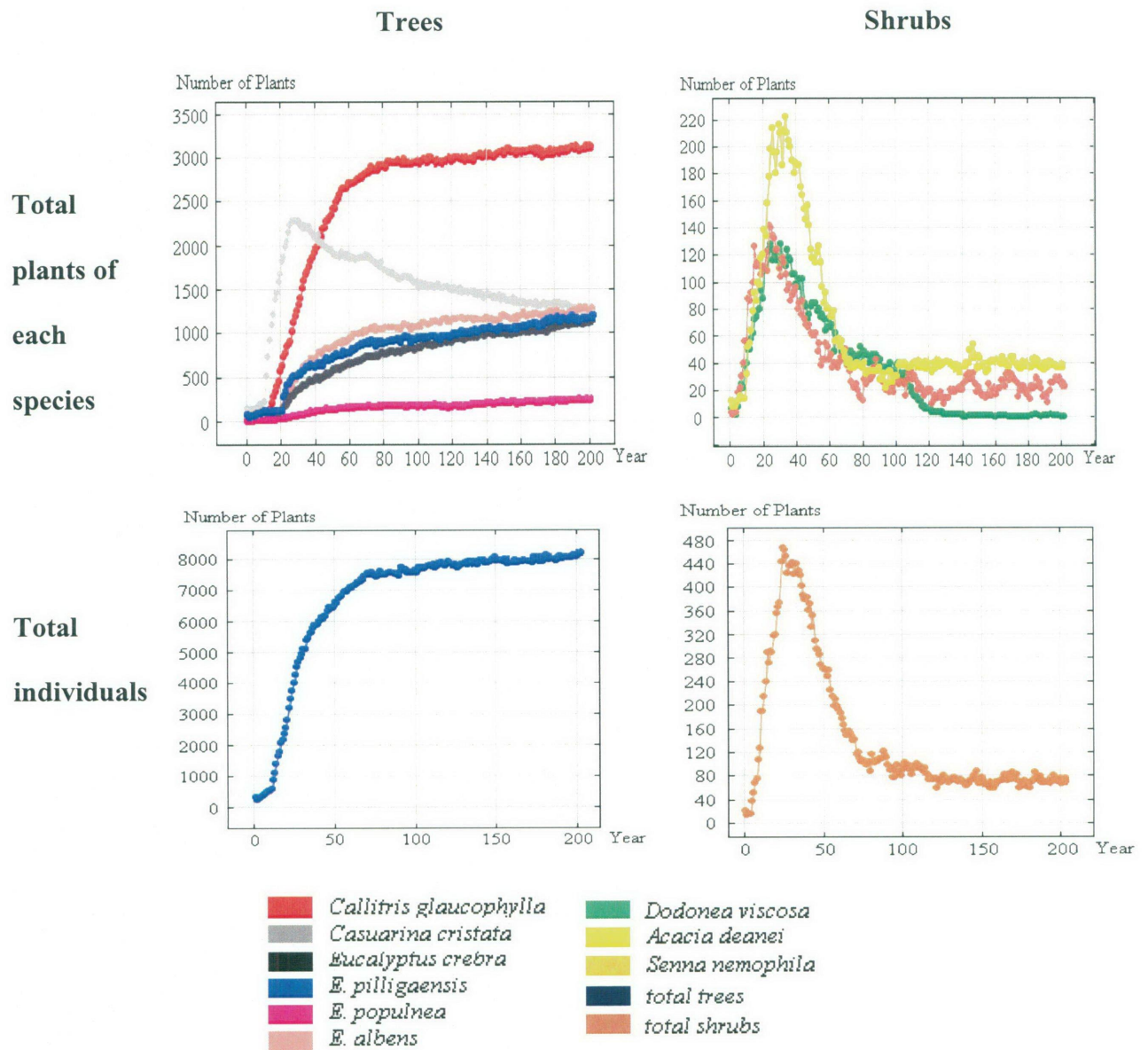
Model application: assistance to natural regeneration

Fig. 8.2 Simulation of rehabilitation strategy of assistance to natural regeneration: changes in number of plants of tree and shrub species, and changes in total individuals of trees and shrubs.

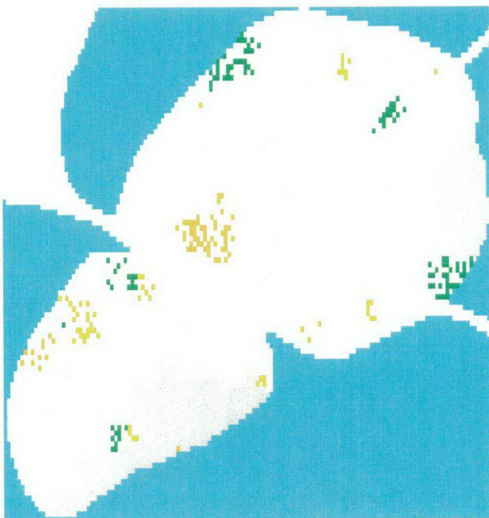
Model application: assistance to natural regeneration

Trees

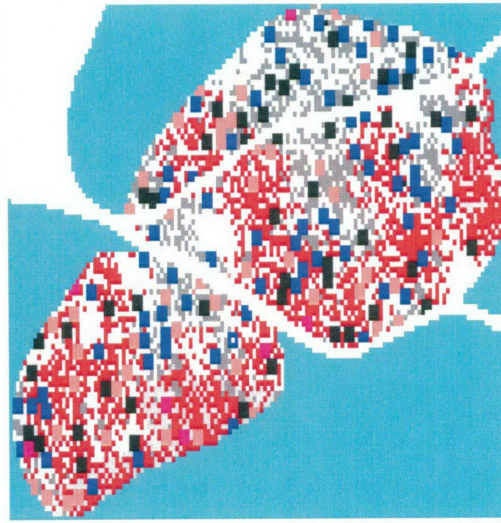


35
Year

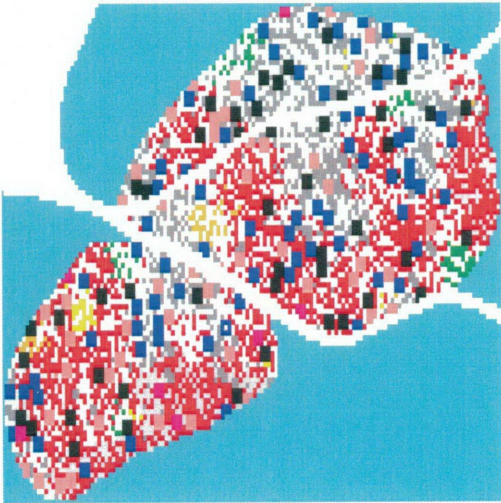
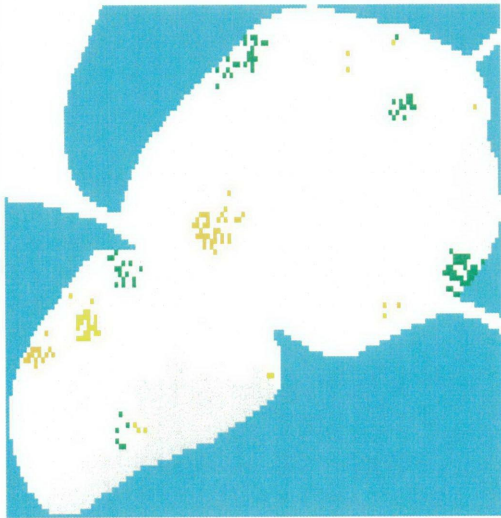
Shrubs



Community



50
Year



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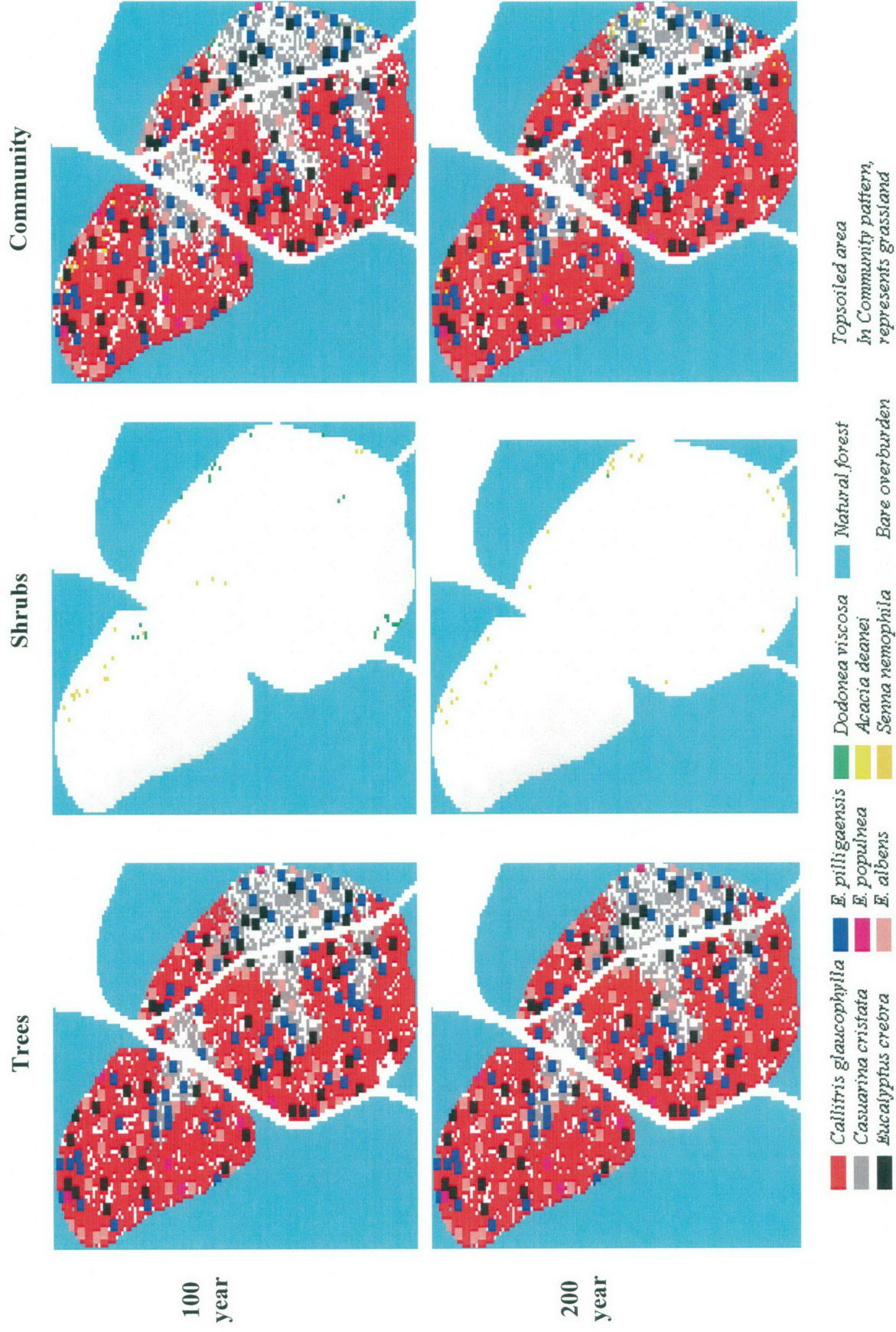


Fig. 8.3 Community composition and structural changes, shrubs and trees colonisation patterns at year 35, 50, 100 and 200 in simulating a rehabilitation strategy of assistance to natural regeneration.

Compared with the natural regeneration (Fig. 7.7 in Chapter 7) the strategy used here shows that the time taken to achieve the endpoint in terms of species composition was much shorter (35 years). This means that by assisting natural regeneration the successional process is accelerated.

8.5.2 Changing Proportion of Trees to Shrubs Seed Mix

Changing the proportion of seeds in the mix influences vegetation succession significantly. The soil type for this strategy is topsoil covering the study site uniformly.

Figures 8.4 and 8.5 show the community composition and structural changes for the trees and shrubs mix is 3 : 1. Figure 8.4 shows population changes by species and total shrubs and trees changes in the community. Shrubs are present at a low density and had a peak population at 50 years and then dropped. *Casuarina cristata* also declined, but eucalypts and *C. glaucophylla* increased steadily over time. Trees dominated most of the site (Fig. 8.5). Shrubs persisted in the site for over 100 years, but by 200 years, only a few patches remained.

Model application of seed mixes (Trees : Shrubs mix = 3: 1)

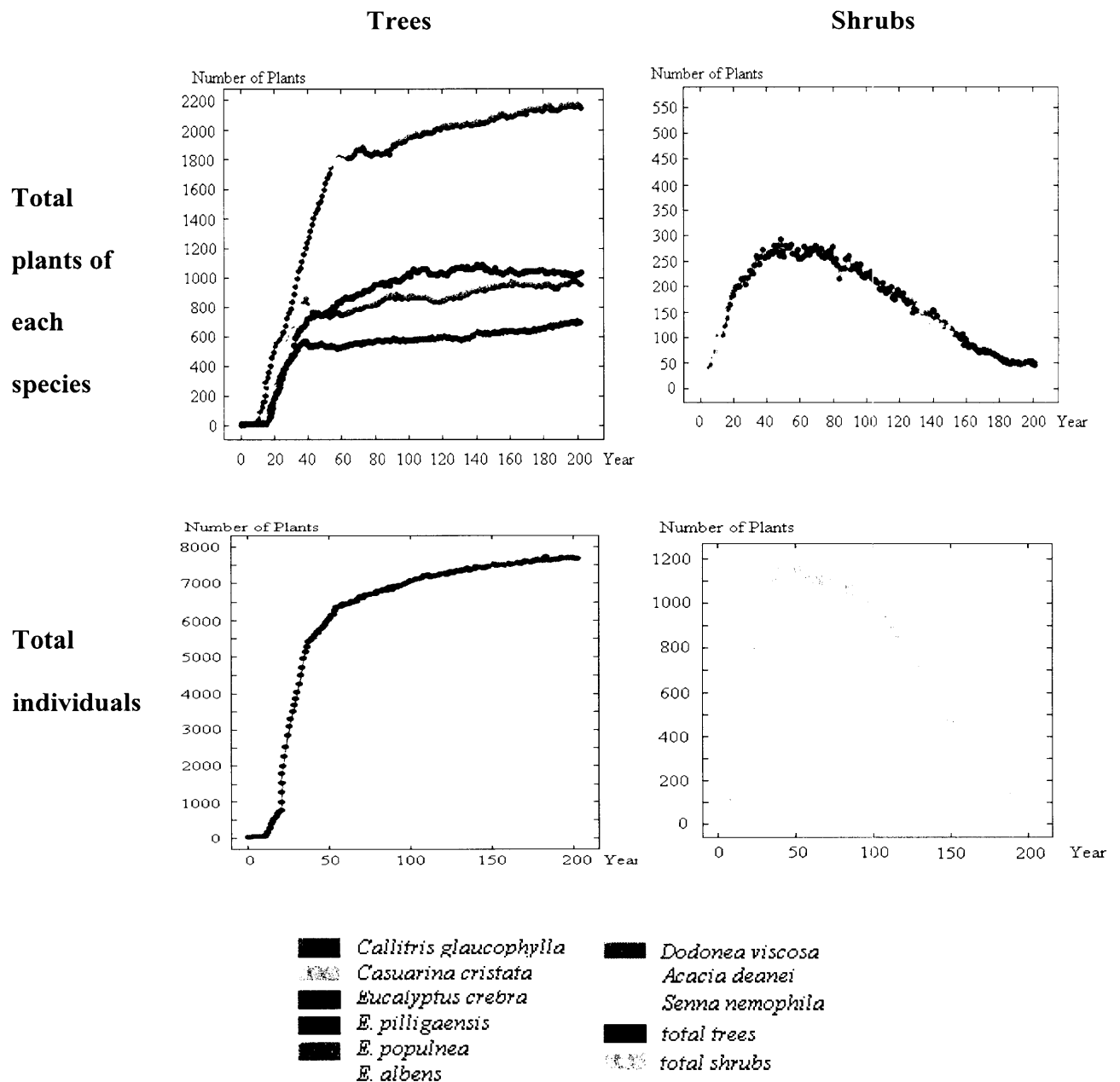
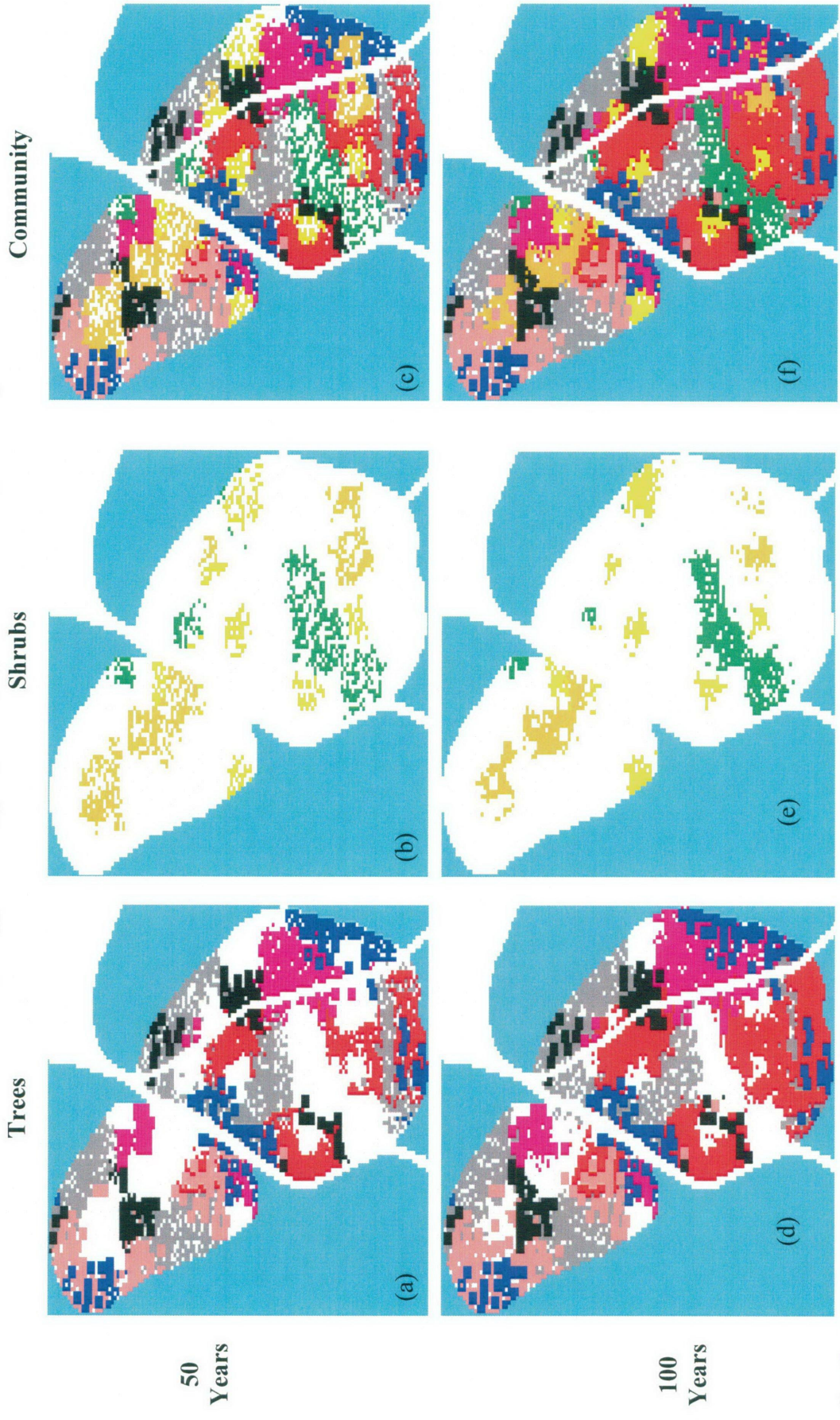


Fig. 8.4 Simulation of different proportion of trees to shrubs in a seed mix (trees : shrubs = 3 : 1) on topsoil: changes of number plants of tree species and shrubs, and changes of total individuals of trees and shrubs.

Model application of seed mixes (Trees : Shrubs mix = 3: 1)



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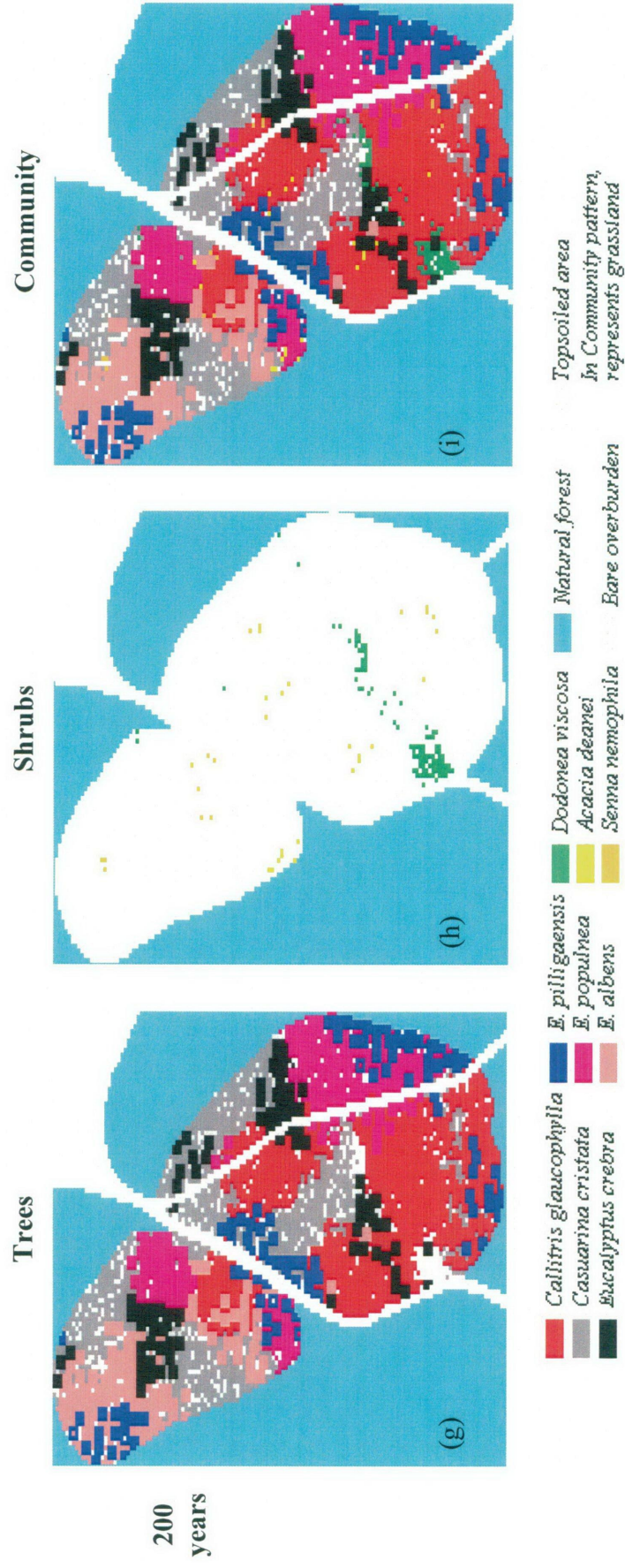


Fig. 8.5 Simulation for a rehabilitation strategy of a seed mix (trees : shrubs mix = 3:1) on topsoil: shrubs and trees colonisation patterns and community composition and structural changes by (a – c) 50 years, (d – f) 100 years and (g – i) 200 years.

Figures 8.6 and 8.7 showed the community composition and structural changes for a trees : shrubs mix =1 : 3. Figure 8.6 show population changes by species in the community. Shrubs are present at high density and continued increasing up to 80 years thereafter declined. In year 50, over 2/3 of the site was dominated by shrubs (Fig. 8.7). In year 100, shrublands still dominated nearly half of the site. After 200 years of succession, over 85% of the site has formed a forest with small patches of woodlands (Fig. 8.7). Shrubs persisted in the site for over 100 years, but by 200 years, only a few remained.

Model application of seed mixes (Trees : Shrubs mix = 1 : 3)

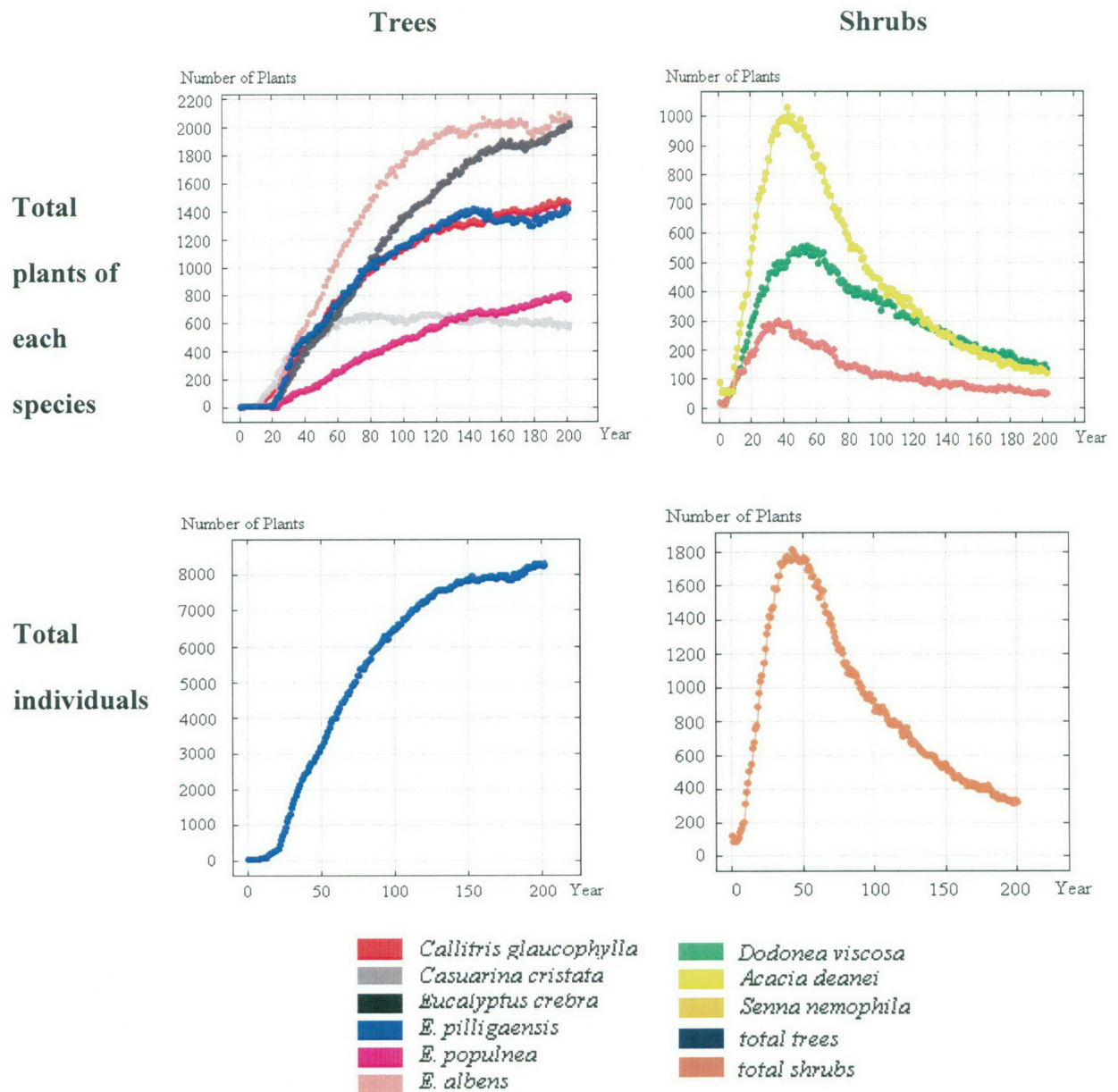
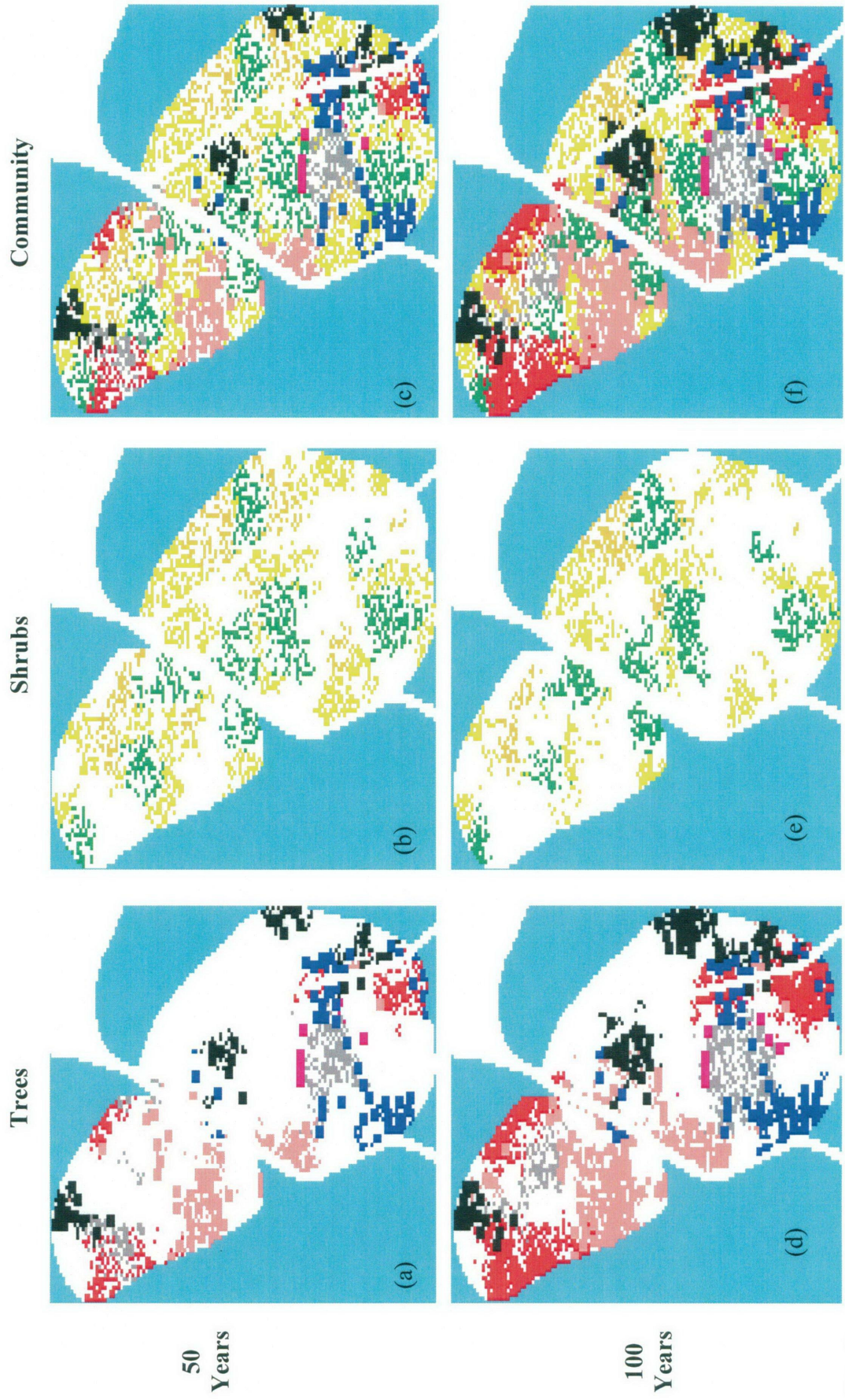


Fig. 8.6 Simulation of different proportion of trees to shrubs seed mix (trees : shrubs mix = 1 : 3) spread on topsoil: changes in number of plants of tree and shrub species, and changes in total individuals of trees and shrubs.

Model application of seed mixes (Trees : Shrubs = 1 : 3)



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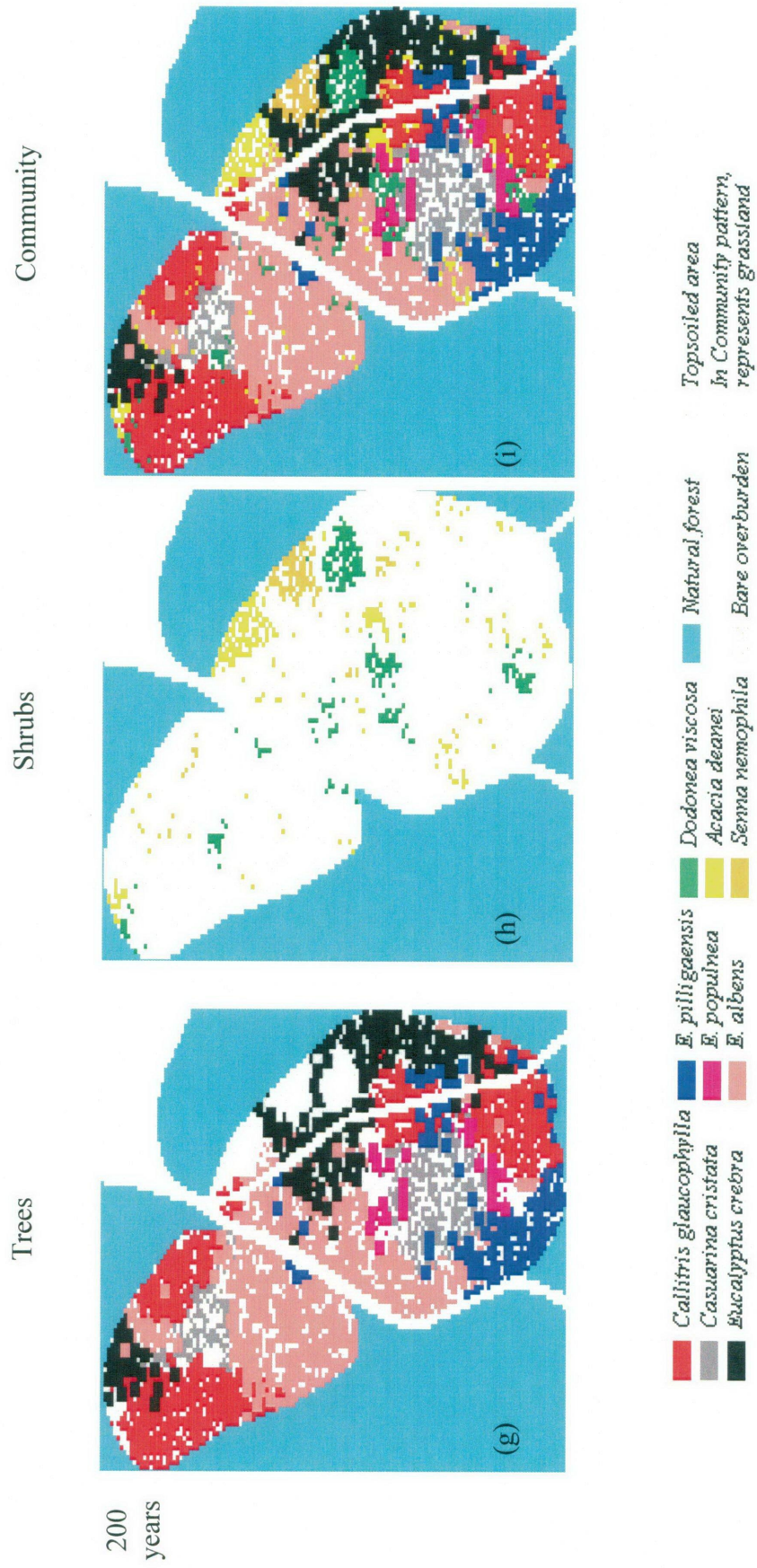


Fig. 8.7 Proportion of trees to shrubs seed mix Species applied in rehabilitation, trees : shrubs mix = 1 : 3, shrubs and trees colonisation, and community composition and structural changes by (a – c) 50 years (d – f) 100 years and (g – i) 200 years.

In comparing Figure 8.4 with Figure 8.6, it is interesting to note that although shrub populations dropped significantly in both ecosystems over time from 50 year to 100 year, there was a 50% drop in shrub populations in the 1: 3 mix, but only 17% in the 3 : 1 mix. Trees, particularly eucalypts, reach an equilibrium in the 3 : 1 mix, but kept increasing in the 1 : 3 mix and were at a lower density. *Casuarina cristata* showed different patterns of development from these two strategies. *Casuarina cristata* increased up to 40 years and then declined in 3 : 1 mix, but increased up to 80 years and then stabilised in 1 : 3 mix. The differences reflect competition between trees and shrubs. In the 3 : 1 mix, besides competition between shrubs and trees there is also a strong competition between trees, but in 1 : 3 mix, competition occurred mostly between trees and shrubs.

8.5.3 Use of Different Soil Types

Soil type impacts on vegetation succession (see Chapter 4). In order to show how it influences the density of shrubs and trees in the rehabilitation strategy, topsoil and bare overburden were used as soil types, and the proportion of trees to shrubs in the seed mix is set at 1 : 1.

Succession patterns are significant different. When the topsoil is applied, shrubs were slow to develop in the first two decades (Fig. 8.8) but formed well defined shrublands. Even after 100 years, some parts of the site were still classed as shrublands without the invasion of trees (Fig. 8.9). However, trees population increased (Fig. 8.8) and ultimately invaded shrubland and after 200 years dominated the site and formed a forest (Fig. 8.9) but with some small patches of shrublands.

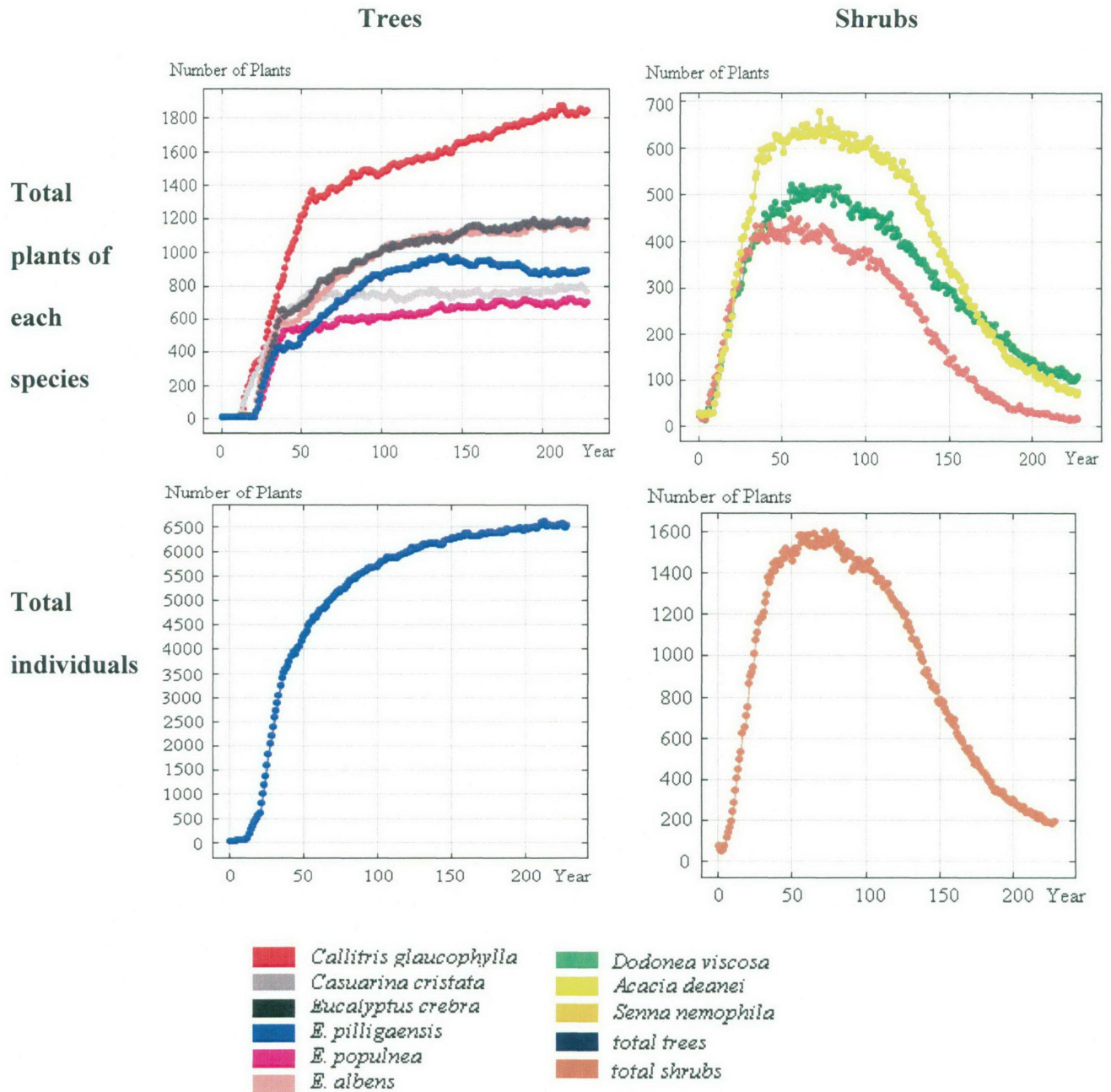
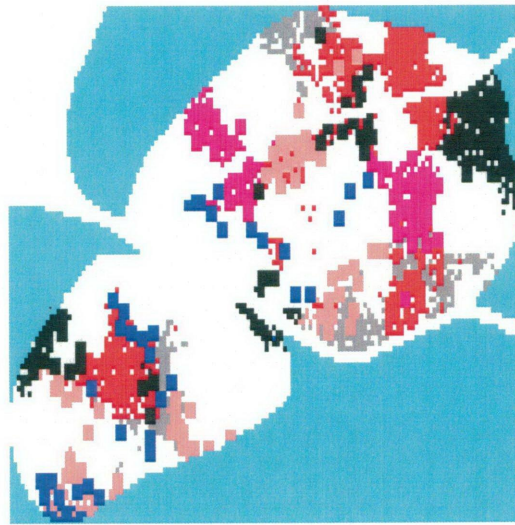
Model application : soil type is topsoil

Fig. 8.8 Simulation of mix seeds (trees : shrubs mix = 1 : 1) on topsoil for over 200 years, changes in number plants of tree species and shrubs, and changes in total individuals of trees and shrubs.

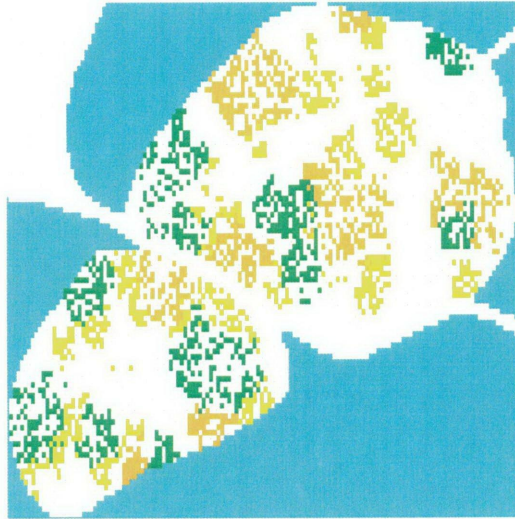
Model application: soil type is topsoil

Trees



50
Years

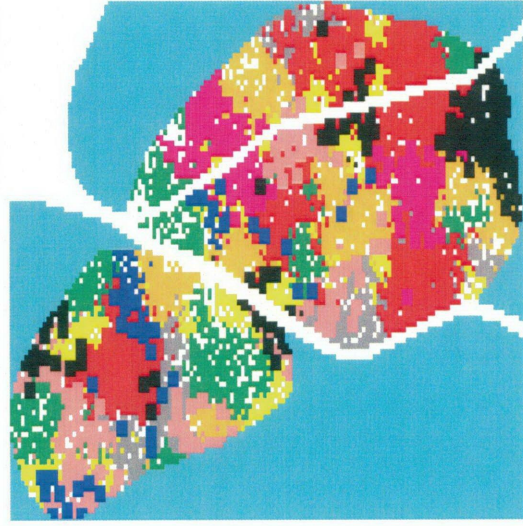
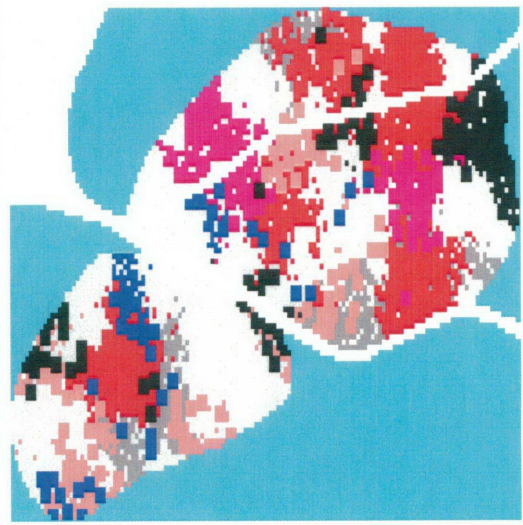
Shrubs



100
Years



Community



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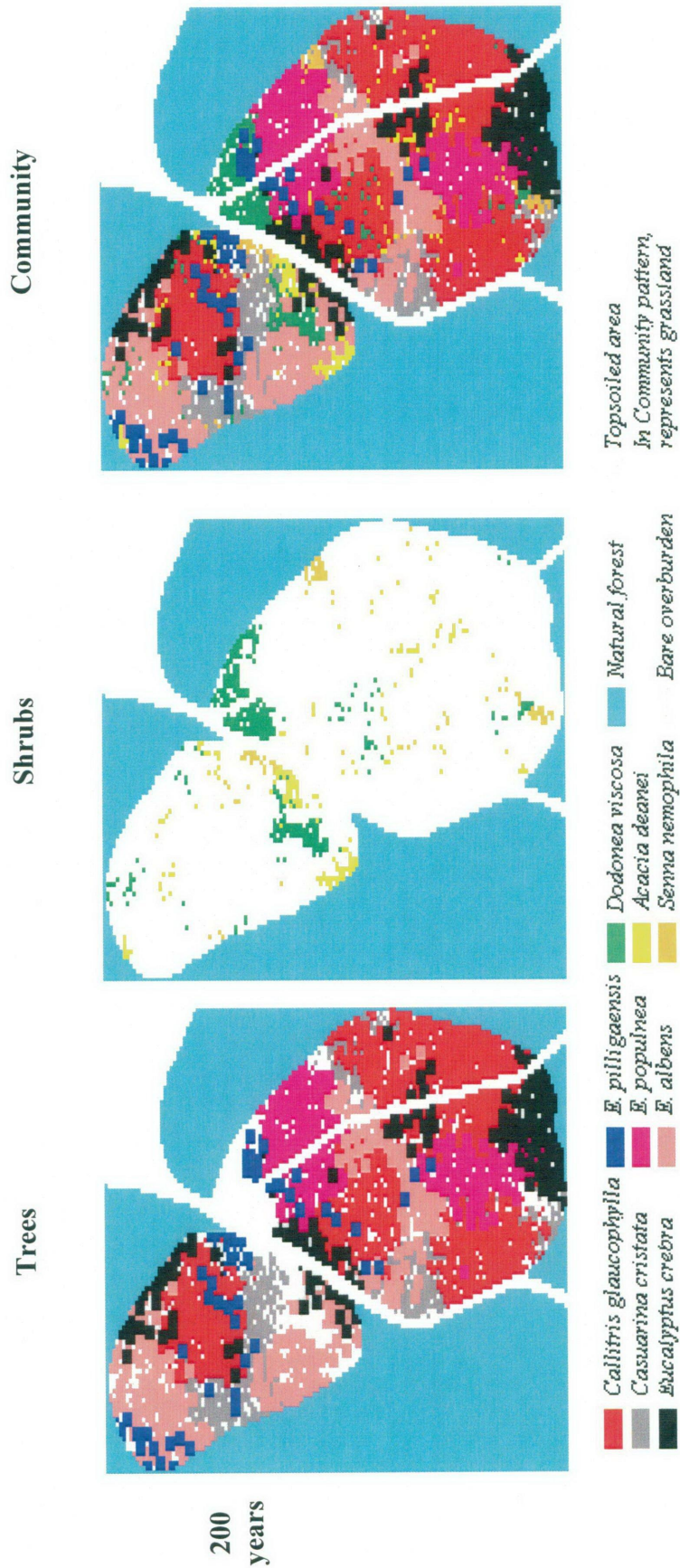


Fig. 8.9 Simulation of rehabilitation by applying a seed mix of tree and shrub (1 : 1) on bare overburden, trees and shrubs colonisation patterns and community changes by 50, 100 and 200 years.

When the overburden is used as the soil types, shrubs established but have a low survival rates with high mortality (see Chapter 4), and are ultimately eliminated from the site after 50 years (Figs. 8.10 and 8.11). Trees dominated the site and form a forest (Fig. 8.11). However, since mortality rates for each species in bare overburden are high (see Chapter 4), low density forests form (Fig. 8.10) with many bare overburden patches that could be susceptible to erosion. This issue need to be considered if such a strategy is to be adopted.

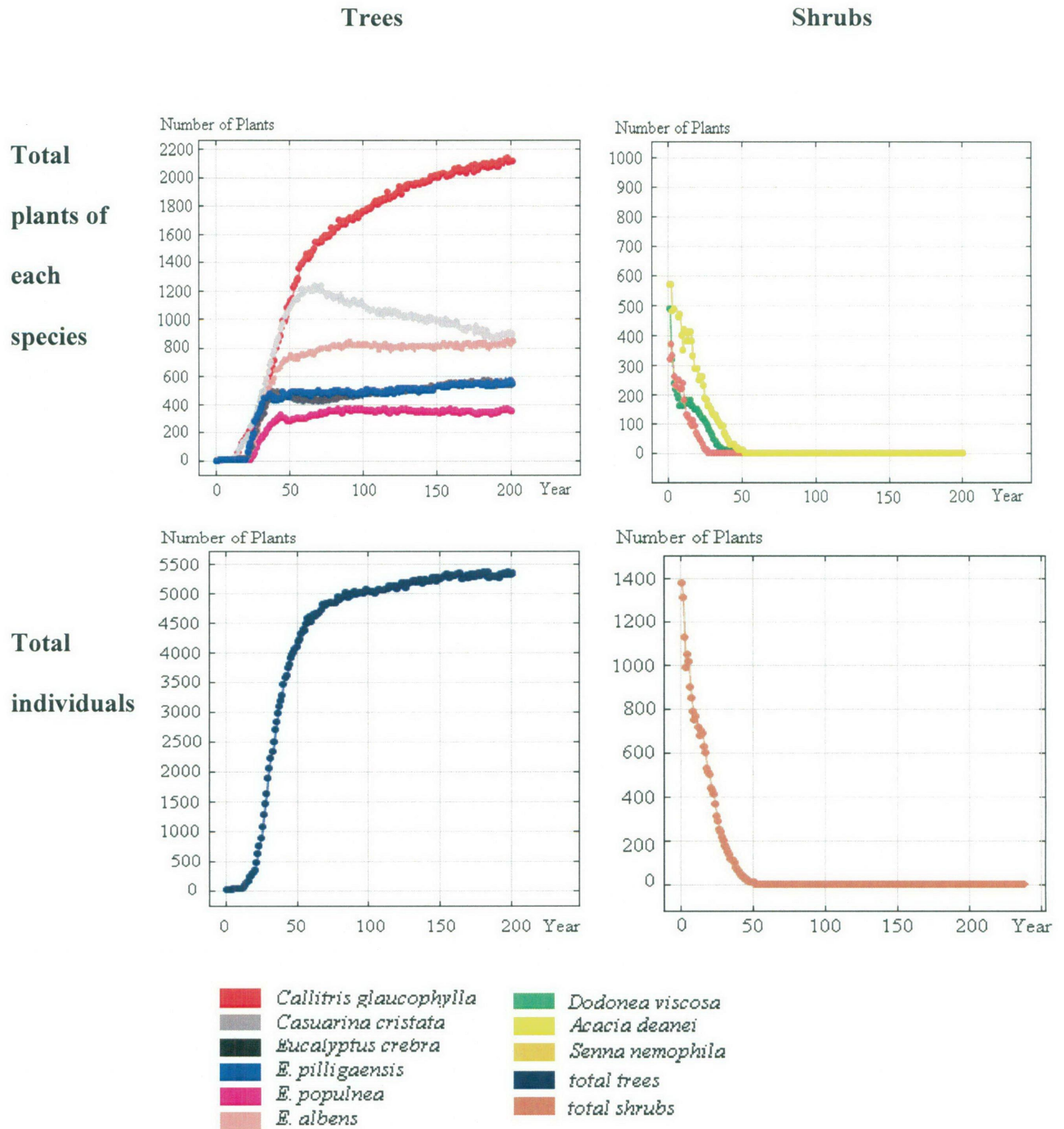
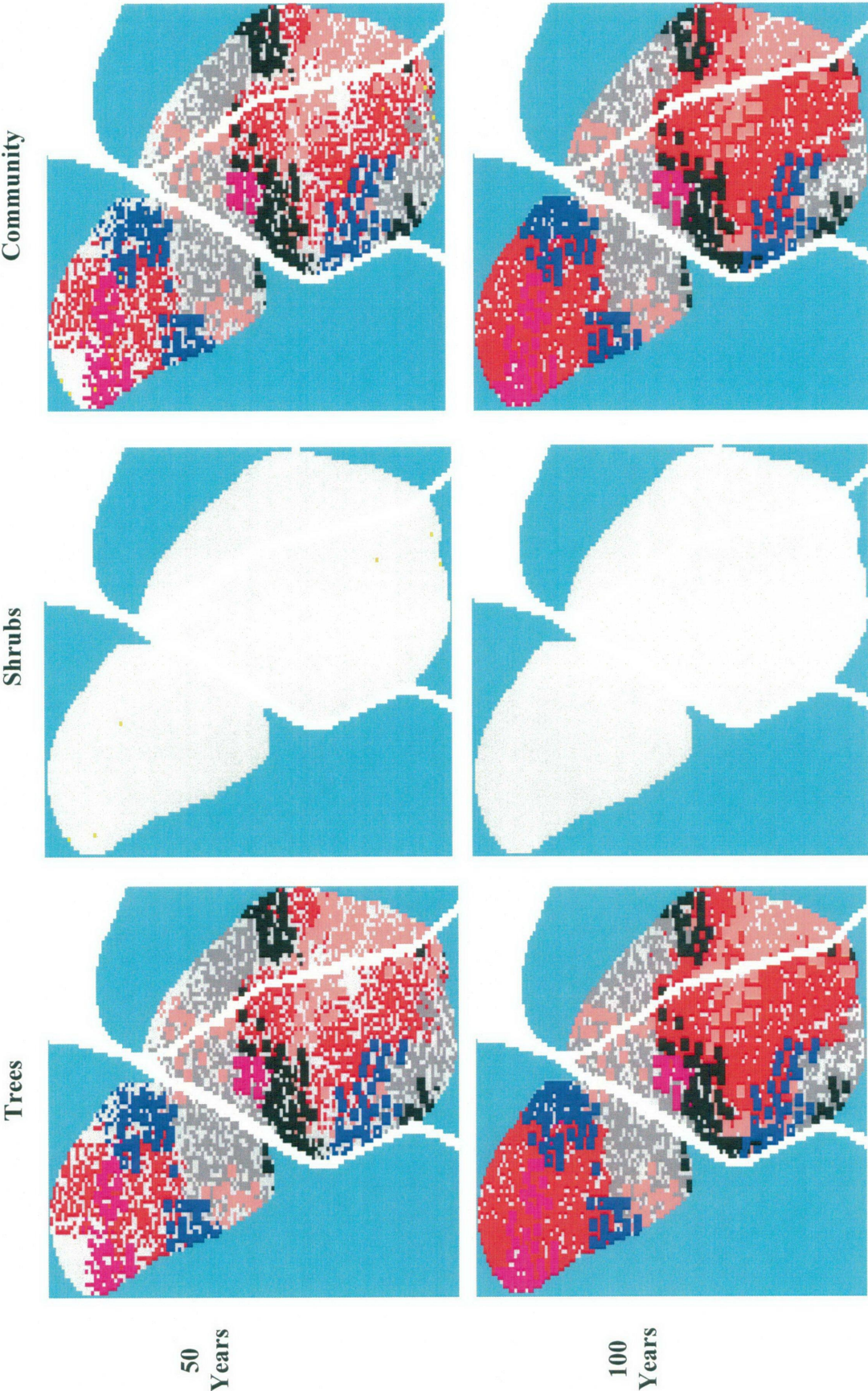
Model application : soil type is bare overburden

Fig. 8.10 Simulation of a seed mix (trees : shrubs = 1 : 1) spreading on bare overburden by 200 years, changes in number plants of tree species and shrubs, and changes in total individuals of trees and shrubs.

Model application : soil type is bare overburden



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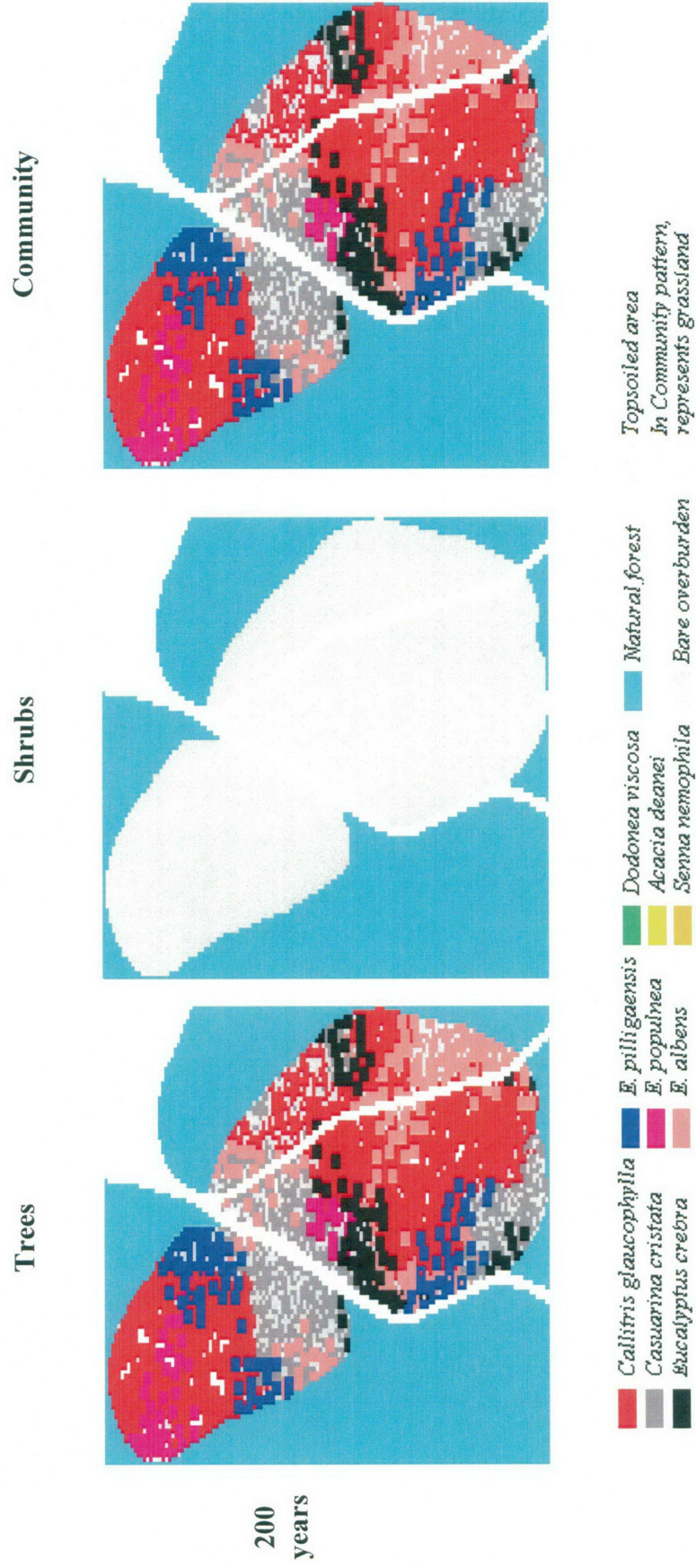


Fig. 8.11 Simulation of rehabilitation by applying a seed mix of tree and shrub (1 : 1) on bare overburden, trees and shrubs colonisation patterns and community changes by 50, 100 and 200 year.

8.6 Summary

The development of both a rehabilitation plan and strategy are essential to ensure the progression from the initial condition to the desired state is successful. The development of an Agent-based Model as outlined in Chapters 6 and 7 and applied in this chapter to different rehabilitation strategies has the potential to assist managers in predicting likely outcomes in relation to the desired endpoint.

The model can be adapted to different circumstances by changing the initialisation and establishment components and has the capability to simulate ecosystem succession and display the outcomes both spatially and temporally. Different rehabilitation strategy, such as suitable seed mixes and soil type selection again can be simulated to follow successional development to the endpoint. The model can compare different strategies and provide predictive patterns for ecosystem development, and allow the user to select the optimal strategy to achieve the desired endpoint and avoid undesirable states.

CHAPTER 9: CONCLUSIONS

Issues

Mining occurs in many locations with contrasting environments throughout Australia (Figure 2.1). Open-cut mining activities removes all soil, vegetation and fauna and may cause long-lasting degradation that ultimately generates undesirable impacts on the environment. The mining industry in Australia is committed to maintaining sustainable environments after mining and the disturbed and degraded land is required to be rehabilitated to ensure ecologically sustainable development. Appropriate rehabilitation strategies are essential to ensure successful rehabilitation from the disturbed state to the desired goals. Rehabilitation research on mining sites has been undertaken to develop rehabilitation strategies for a range of mine sites, particularly in relation to vegetation establishment and landscape stability. However, very few long-term studies on ecosystem development have been undertaken to demonstrate whether the developing ecosystem will achieve the desirable endpoint, and very few methods or models can be used to test different strategies for rehabilitation.

Objective

The objectives of this thesis are to investigate the natural colonisation of native species and the dynamic interactions between individuals in relation to developing ecosystems and then to develop a predictive model to simulate ecosystem development, in particular vegetation succession for mine site rehabilitation, and test its ability to predict the outcomes of different

rehabilitation strategies. Theories and principles of rehabilitation methods were reviewed and models that might be appropriate for simulating rehabilitation were identified and discussed.

Outcomes

- Boggabri in NSW, Australia, was used as a case study to observe the natural vegetation succession after open-cut mining. Twenty years of data were available on colonisation of small overburden heaps surrounded by natural forest. The observed vegetation development was presented and discussed.
- An Agent-based Model was designed and developed using historical data from Boggabri to simulate the natural regeneration process and provide predictive patterns both spatially and temporally. Individual-based processes, such as life span, growth, development and regeneration, interspecific and intraspecific competition, and interactions with the environment were used as the basic rules for simulation of succession.
- The developed model was verified by predicting the condition after 20 years and comparing the output with field measurements. The results show that the model can reproduce historical pattern of colonisation and therefore may be used to simulate vegetation succession beyond 20 years.
- Simulation was undertaken to 200 years in yearly time steps to show the predicted outcomes. Species changes, community composition and structural changes over time were presented both spatially and temporally. The results of the simulation and the

sensitivity analysis showed that natural succession after open-cut mining was mainly controlled by seed source, seed dispersal distance, and species composition of the community in the surrounding ecosystem. Soil type was also noted to affect both succession and species distribution.

- Potential applications of the model were presented and discussed using different rehabilitation strategies, such as applying different seed mixes of trees and shrubs to two different soil types. The model can be also used to estimate the possible time required from the initial disturbed condition to the desired endpoint of the rehabilitation plan.
- The model can be used for testing different rehabilitation strategies by simply changing the data values according to the requirements of each strategy. Outcomes from different strategies can be compared graphically and an optimal strategy can be selected to achieve the desired ecologically sustainable endpoint. This model has the potential to improve the rehabilitation of mine sites by testing different strategies in relation to achieving the desired end point.

This model has the potential to address research and management problems through simulation experiments that have not, in the past, been produced by predictive patterns considering the dynamics from individual to the community amongst ecological processes at temporal and spatial scales. This study presented a new approach, and this will be value to ecologists and land managers for mining rehabilitation.

Limitations and further developments

The developed model assumed mining activity is the only disturbance with no further natural or human disturbances during succession. Any other disturbances such as fire, weed invasion, grazing, storms or diseases have not been considered. However, the impact of bushfire, which is a common disturbance in Australia, should be evaluated in further modelling studies. In addition, non-woody species is not considered in this study.

Although climate change, such as rainfall has been considered, the model hypothesised that there was no significant impact of climate change on the succession in the study. Nor did it include the impact of extreme weather condition on succession.

Although there is 20 years historical data analysis supplemented for the parameter estimates, some information of main species such as maximum age is from literatures. It is not possible to get precise estimates for each parameter due to the long time series.

The model has shown the ability to simulate the first 20 years of succession and it has been validated in Chapter 7. However, there is no monitoring data beyond 20 years; it is impossible to validate the model appropriately.

Rehabilitation is a site-specific practice (Morin & Hutt 1999). The geographic characters of the site, soil, local climate, seedbank and seed sources, and even rehabilitation strategies impact on the success of rehabilitation. Although this model is designed for the mining rehabilitation at Boggabri, NSW and most parameters estimates are from the data collection at Boggabri, the structure, parameters selections and logic rules of the model are developed on

the basis of the ecological theories of succession and restoration. It makes the model testable by changing the values of parameters. However, since rehabilitation is site-specific, the model needs to be tested for other mine rehabilitation sites to extend the practical applications of this model.