CONCLUSION

All results have been previously summarised and discussed in detail in the conclusions of the individual chapters. Particularly, sections **??** and **??** provide discussions of the results regarding habitat loss, and the inferences of species interactions respectively. In this chapter were reiterate the main findings from each of the research chapters (sections **??** - **??**), before summarising the main avenues for further work that have been revealed throughout the thesis (section **??**).

1.1   Habitat loss with high immigration rate

In this chapter we discovered that the default immigration rate ($IR = 0.005$) was sufficiently high as to prevent the local extinction of species, even in landscapes where 90% of the cells were destroyed. This feature allowed us to study changes in simulated communities in the absence of extinctions. Empirical studies have indicated that habitat loss can cause structural changes to communities without the loss of species []. The results of this chapter are a relevant contribution towards understanding those structural changes.

Communities responded differently to the two types of habitat loss: random and contiguous. Random HL reduced the temporal variability in species population dynamics, and reduced the average strength of species interactions. Random HL also increased the evenness in species abundance distributions, with associated changes in network properties, and made communities less aggregated in space. All of these changes, it was argued, could be understood as resulting from an increased dependence of communities on immigration. The random distribution of destroyed cells throughout the landscape provided a barrier to the motion of individuals, meaning that it was harder to 1) find food, and 2) find a mate. As a results, immigration became the dominant source of new individuals in the landscape.

Contiguous HL increased the temporal variability in species population dynamics, due to an increase in species interactions strengths. The increased probability of interaction resulted from the confinement of individuals, with the same level of mobility, into smaller contiguous regions of habitat. Since trophic interactions remained strong, immigration did not come to dominate these communities. The structural properties of communities under contiguous HL, including network properties, were mainly unchanged.

1.2 Community dynamics under variable immigration rate

Having established, in chapter **??**, the importance of immigration in mediating community responses to HL, we then studied community dynamics under different immigration rates. This chapter focused on the effect of changing the immigration rate in the absence of habitat loss. We saw that, without any immigration ($IR = 0.0$), many species go extinct when all other parameters take the default values. For antagonistic communities all non-basal species went extinct, while mutualistic communities displayed persistence of a few non-basal species (facilitated by the mutualism). Parameter adjustment was able to slightly improve species persistence, but in general communities were unstable without immigration. We concluded that competition between species in the IBM was strong, and partly responsible for the extinctions. It appears that immigration reduced the effects of competition.

Reducing the immigration rate was found to increase temporal variability in population dynamics, resulting in more species with non-stationary long term distributions. Employing recurrence quantification analysis, we determined that reducing the immigration rate increased the signature of determinism in the population dynamics. In general, high abundance species were found to have dynamics that was less stationary and more deterministic, while low abundance species were more stationary and less deterministic. Taken together, these results developed a picture of the relative contributions of species interactions and immigration to the dynamics. Immigration represents a random mechanism, but one that suppresses temporal variability. Whilst species interactions contribute to high temporal variability via deterministic non-stationary fluctuations.

At the end of this chapter we considered the effect that high temporal variability has on the accuracy of our results. We compared species abundance measurements, calculated from samples of increasing length. It was determined that short samples produced significant errors when temporal variability was high, but that infeasibly long samples ($> 40,000$ time steps) were required in order to guarantee convergence on the long term average. This poor convergence is likely due to non-stationarity, as previously discussed, and highlights the need for a trade-off between accuracy and computational expense when sampling from the IBM simulations. In this chapter we also demonstrated a high level of repeatability between simulations using the same network structure (which was demonstrated using rank abundance spectra).

1.3 Habitat loss under variable immigration rate

In chapter **??** we returned to study the effects of habitat loss, this time under different immigration rates. The same two types of habitat loss were used: random and contiguous. Community responses were largely consistent with those observed at high IR in chapter **??**. In particular, contiguous HL increased interaction strengths, resulting in more variable dynamics. The converse was observed for random HL. These results held across most of the region of parameter space explored, but not at some extreme values of IR and HL.

Certain new results were observed as the immigration rate was changed. Most notably, at lower immigration rates species extinctions were observed. Here we saw more extinctions under contiguous HL than random HL, and more extinctions in mutualistic communities than antagonistic ones. These differences were unexpected. Previous modelling studies suggested that random HL should produce more extinctions (see section **??**), and prior intuition suggested that mutualism may confer some benefit on the wider community that would mitigate extinctions. Contiguous HL resulted in more extinctions because of strong trophic interactions and highly variable dynamics. Mutualistic communities displayed more extinctions because mutualism acts to make communities uneven, with a dominant core of species out-competing the others. The observed effects of mutualism, and contiguous HL on species extinctions find some support from empirical studies (see section **??**). Further field work is required to determine the role of species interaction strengths in these cases.

The total number of individuals in communities with high levels of mutualism was insensitive the changes in IR. However, as IR was reduced, these communities became less even as the mutualistic core became more dominant. Therefore we see that, in the IBM, immigration serves to reduce the damaging effects of mutualism on the wider community. In general, we observed a subtle interplay between immigration rate, mutualism and habitat loss, in determining community evenness. For example, at $IR = 0.0005$, antagonistic communities tended to become less even under random HL, while mutualistic communities became more even. Different changes in evenness were observed at different immigrations rates, but not studied in detail.

1.4 Towards inferring species interactions from population dynamics

In chapter **??** we developed a novel method for inferring species interactions from population dynamics. The method was adapted from []. The task was explained as the inverse of the research undertaken in the previous chapter, where we modelled low level mechanics and studied the high level properties that emerged. In this chapter we attempted to work back from the high level properties to recover the underlying structure of the system. The approach was met with limited success. Accurate inference of interaction strengths was possible for two species systems. For three and five species systems, the method produced reasonable prediction of demographic

rates, but it was not possible to reliably infer the correct interaction topology. The method was hampered by a sensitivity to emergent phase relationships between non-interacting pairs of species, resulting in the identification of spurious interactions. The application of the method to infer interactions between functional groups of species in larger systems shows some promise. However further development of the method is required.

1.5   Further work