On Agent-Based Models of Sex, Plants and Sustainability

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Summary

This thesis examines various real-world phenomena by means of models and simulations. All these phenomena are modeled by an agent-based approach, using quite different model properties in each case. The modeling approaches differ per chapter, varying from static to discrete-time and continuous-time models and from non-spatial to discrete-space and continuous-space ones. We use a non-spatial discrete-time model to compare sexual and asexual reproduction in general (Chapter 3), a discrete-space discrete-time model to examine the influence of explicit spatial aspects like positions of plants and distance restricted pollen/seed dispersal on the prevalence of sex types in annual plants (Chapter 4), a continuous-space discrete-time model to test the hypothesis that oak trees exercise a female ovule choice to increase the genetic diversity in a stand (Chapter 5) and a discrete-space continuous-time pollution model to investigate conditions under which the EU countries have incentives to produce their goods environmentally friendly (Chapter 6).

In Chapter 3, we compare sexual and asexual reproduction in stable and unstable environments. Although in the literature sexual reproduction is considered more costly, for example due to needing two individuals for reproduction, our simulations show that sexual reproduction can anyway be more successful in terms of the population fitness, even in a stable environment. Moreover, we observe that all sexual populations pass a learning phase before they are able to increase their fitness and that they do not increase the genetic diversity in populations (as often assumed) but specialize on a single genotype, just like with asexual reproduction. By tracking the genetics of the individuals during our simulations, we can examine the underlying mechanisms that lead to the observations in more detail. Furthermore, our simulations show that, if the environment suddenly changes, the populations face a trade-off between being robust against such changes and fitness improvement due to specialization.

Populations of plants appear in different compositions of males, females, and hermaphrodites. It is well-known that the sex allocation of hermaphrodites influences the prevalence of the different types. In Chapter 4, we examine the influence of explicit spatial aspects like positions of plants or distance restricted pollen/seed dispersal on the prevalence of the sex types. Our simulations show that a dioecious breeding system (only males and females in the population) prevails only when males and females can use more resources than hermaphrodites. In all other cases, hermaphrodites do not go extinct. Depending on the amount of resources available to hermaphrodites and on their sex allocation, either females or males may stay in the population as well, leading to an androdioecious or gynodioecious breeding system. Additionally, we investigate the influence of a type-dependent pollen dispersal on the prevalence of sex types. If males can distribute their pollen farther than hermaphrodites, then it is more likely that only males and females survive than with equal pollen distribution distances. Furthermore, the chances for males to survive increase, and thus, androdioecious populations become more likely than gynodioecious populations.

Oak trees are one example for hermaphroditic plants, i.e., they produce both pollen and ovules. Remarkably, oaks produce six ovules in a flower, but only one becomes an acorn even though all ovules within the flower are fertilized. Moreover, compared to other tree species, long-distance fertilization in stands of oaks is more common, while short-distance fertilization is more rare. In Chapter 5, we examine the hypothesis that oaks exercise a female choice of ovules in a flower to increase the genetic diversity, using a two-step lottery model. Next to showing that this female choice mechanism indeed increases the genetic diversity, we show that this mechanism explains the data of published field studies on oak reproduction better than if one of the ovules is chosen randomly.

In Chapter 6, we model EU countries maximizing their own benefits by choosing more or less environmentally friendly ways of producing goods. This is to understand how such decisions are made and to analyze what would be the best stimuli to lead the countries to more environmentally friendly policies. The EU countries control their own air pollution but, by doing so, influence the air pollution of neighboring countries. We analyze three variants of this model: 1) each country chooses its investment into clean policies such that the expected costs are minimal, 2) each country imitates the investment of neighboring countries no matter whether they are successful (basic mimicking) and 3) each country imitates the investment of neighboring countries only when they seem to bring a profit (smart mimicking). For each of the considered variants, we show that the pollution can indeed be reduced by the influence of an external government exposing high costs for pollution. Without such an influence and when all countries only have their own benefits in mind, the pollution stock increases a lot before saturation. While the basic mimicking variant is very sensitive to initial conditions, the smart mimicking variant is a very promising approach for pollution reduction.

Overall, we demonstrate how simulation models can be used for describing, understanding, and predicting the behavior of real-world systems.