Evolutionary suicide and evolution of dispersal in structured metapopulations

Abstract. We study the evolution of dispersal in a structured metapopulation model. The metapopulation consists of a large (infinite) number of local populations living in patches of habitable environment. Dispersal between patches is modelled by a disperser pool and individuals in transit between patches are exposed to a risk of mortality. Occasionally, local catastrophes eradicate a local population: all individuals in the affected patch die, yet the patch remains habitable. We prove that, in the absence of catastrophes, the strategy not to migrate is evolutionarily stable. Under a given set of environmental conditions, a metapopulation may be viable and yet selection may favor dispersal rates that drive the metapopulation to extinction. This phenomenon is known as evolutionary suicide. We show that in our model evolutionary suicide can occur for catastrophe rates that increase with decreasing local population size. Evolutionary suicide can also happen for constant catastrophe rates, if local growth within patches shows an Allee effect. We study the evolutionary bifurcation towards evolutionary suicide and show that a discontinuous transition to extinction is a necessary condition for evolutionary suicide to occur. In other words, if population size smoothly approaches zero at a boundary of viability in parameter space, this boundary is evolutionarily repelling and no suicide can occur.

1. Introduction

In “The Origin of Species” Darwin (1859) explained the unexpectedly wide geographical distribution of certain fresh-water species, by “…their having become fitted, in a manner highly useful to them, to short frequent migrations from pond to pond, or from stream to stream.” It is clear from this quote that Darwin realized that dispersal is a life-history trait which is under selection and the change of which may have profound ecological implications. He also came very close to a verbal description of what is today known as a metapopulation – at least the
discreteness of habitat patches was made explicit. Presently, many researchers agree
that the metapopulation concept provides a suitable framework for studying evolu-
tion of dispersal, both theoretically (Gyllenberg and Metz 2001) and experimentally
(Clobert et al. 2001).

Today, habitat loss is the worst threat to endangered species in most parts of
the world (Barbault and Sastrapradja 1995). For instance, habitat loss has been
acknowledged as a significant cause of increased extinction risk in 82% of endan-
gered bird species (Temple 1986), and, in Finland, habitat loss or alteration is the
primary threat to 73% of the red-listed species (Rassi et al. 2000). In such changing
environments, an individual’s fitness depends of its ability either to rapidly adapt
to local conditions or to move to other habitats (Ferrière 2000). This dependence
is one of the main reasons for the renewed interest in the evolution of dispersal
which started about three decades ago. The literature on the subject is vast; here we
give only a few references to key papers in which mathematical modelling plays
a prominent role (Cohen 1967; Van Valen 1971; Hamilton and May 1977; Comins
et al. 1980; Hastings 1983; Levin et al. 1984; Cohen and Motro 1989; Doebeli 1995;
Doebeli and Ruxton 1997; Cadet 1998; Dieckmann et al. 1999; Gandon 1999; Gandon
and Michalakis 1999; Parvinen 1999; Gyllenberg and Metz 2001; Gyllenberg
and Parvinen 2001; Heino and Hanski 2001; Metz and Gyllenberg 2001; Parvinen
2001). For a review of mathematical models describing the evolution of dispersal
and of empirical tests that have appeared before 1990, we refer to the paper by

It is a well-known fact, observed already by Darwin (1859, 1871) and later
discussed in detail by Haldane (1932), that natural selection may favour traits that
eventually, through environmental change, turn out to be harmful to the individuals.
Darwin (1859) even pointed out that this may lead to the species becoming extinct.
The observation that what is advantageous for the individual may ultimately be
disastrous for the species raises the question as to the conditions under which
natural selection is expected to drive species to extinction. It is the purpose of
this paper to investigate this question in the context of structured metapopulation
models (Gyllenberg et al. 1997; Gyllenberg and Hanski 1992, 1997; Hanski and
Gyllenberg 1993, 1997) when the trait under selection is an individual’s tendency
to migrate from one patch to another.

This work utilizes the framework of adaptive dynamics (Metz et al. 1992, 1996;
Dieckmann and Law 1996; Geritz et al. 1997, 1998), which explicitly relates
evolution to population dynamics. We assume that individuals are characterized
by a one-dimensional trait (or strategy) that determines the dispersal rate of an
organism, and therefore the strategy space (that is, the set of all feasible strategies)
is a subset of the real numbers. A given trait value, together with the environmental
input, determines the life history of an individual expressing that trait. The viability
set is the set of all traits to which there corresponds at least one nonzero population
dynamical attractor.

A possible scenario in which evolution drives a species to extinction by small
mutational steps is as follows. Consider a resident population with a strategy in the
viability set and assume that it can be invaded and outcompeted by a mutant strategy
lying slightly closer to the boundary of the viability set (the so-called extinction