



# Coupling agent-based with equation-based models to study spatially explicit megapopulation dynamics



Nicolas Marilleau<sup>a,b</sup>, Christophe Lang<sup>b</sup>, Patrick Giraudoux<sup>c,d,\*</sup>

<sup>a</sup> UMMISCO, Institut de recherche pour le développement – UPMC, Bondy, France

<sup>b</sup> UMR 6174 FEMTO-ST, Université de Bourgogne Franche-Comté/CNRS, Besançon, France

<sup>c</sup> UMR 6249 Chrono-environnement, Université de Bourgogne Franche-Comté/CNRS, Besançon, France

<sup>d</sup> Institut Universitaire de France, France

## ARTICLE INFO

### Keywords:

*Arvicola*  
Hybrid model  
Dispersal  
Travelling wave

## ABSTRACT

The incorporation of the spatial heterogeneity of real landscapes into population dynamics remains extremely difficult. We propose combining equation-based modelling (EBM) and agent-based modelling (ABM) to overcome the difficulties classically encountered. ABM facilitates the description of entities that act according to specific rules evolving on various scales. However, a large number of entities may lead to computational difficulties (e.g., for populations of small mammals, such as voles, that can exceed millions of individuals). Here, EBM handles age-structured population growth, and ABM represents the spreading of voles on large scales. Simulations applied to the spreading of a montane water vole population demonstrated that our model is quite efficient in representing the pattern observed and might help to highlight some key parameters during population expansion. This method paves the way for further developments, including the introduction of density-dependent parameters (predation, diseases, etc.) capable of triggering population declines in an explicitly spatial context.

## 1. Introduction

Rodent populations are keystone species in most temperate ecosystems, sustaining a large diversity of carnivores and other species benefiting from the role of rodents as ecosystem engineers (Delibes-Mateos et al., 2011). Rodents have been the focus of interest for humanity through history given the diseases they carry and their impact as pests in farmland, forest and stored products (Buckle and Smith, 1994). Vole population fluctuations of abundance in space and time have, however, evaded consistent explanations to date (Krebs, 2013) because they are part of multifactorial socio-ecological complex systems where multiscale spatial processes are crucial (Lidicker, 2000). Numerous processes can concurrently or synergistically shape patterns of population variations and spread on various spatial and temporal scales. These processes include the impacts of weather (and climate change) (Johnson et al., 2010) and resource depletion on mortality and/or reproductive success as well as the effect of dispersion (Sherratt et al., 2000) and density-dependent factors, such as prey–predator and host–parasite interactions (Ims and Andreassen, 2000) or sociality (Andreassen et al., 2013). Moreover, mortality, reproduction, and dispersal are most often age-specific. Furthermore, rare events difficult to quantify in nature, such as long-distance dispersal, can be critical in

colonizing habitats far away from the average dispersal distance of the population and may explain why colonization fronts are often patchy and population spread appears saltatory. A large number of studies have noted the role of landscape in shaping population dynamics in space and time (e.g., Lidicker (1995), Delattre et al. (1992, 1999), Giraudoux et al. (1997), etc.); however, the numerous factors and processes involved vary on multiple space scales and over the long term, which is ill-suited to most research programs (PhD-level, etc.) (Krebs, 2013). As a consequence, the lack of adaptable and realistic models able to be fitted to real landscapes prevents the development of tools that could be used to help make decisions on many issues, for example, rodent management and control (Delattre and Giraudoux, 2009).

Understanding the spatial dimensions of population dynamics is an endeavour in which the dialogue between theoretical and empirical studies has been particularly intense (Berthier et al., 2014). One particular aspect of the spatial dimensions of population dynamics is dispersal, the process by which organisms move, settle and reproduce away from their birthplace. When the environment is relatively homogeneous and the drivers and population structure are relatively simple, models based on reaction-diffusion equations have provided good descriptions of simple population spread driven, e.g., by

\* Corresponding author at: UMR 6249 Chrono-environnement, Université de Bourgogne Franche-Comté/CNRS, Besançon, France.

E-mail addresses: [nicolas.marilleau@ird.fr](mailto:nicolas.marilleau@ird.fr) (N. Marilleau), [christophe.lang@univ-fcomte.fr](mailto:christophe.lang@univ-fcomte.fr) (C. Lang), [patrick.giraudoux@univ-fcomte.fr](mailto:patrick.giraudoux@univ-fcomte.fr) (P. Giraudoux).

prey–predator or host–parasite relationships. For instance, reaction diffusion equations have been successfully used to explain complex patterns of populations fluctuating in synchrony but with a phase shift in space. Combining spatial temporal oscillations gives the appearance of a wave in population density called a “traveling wave” (Sherratt et al., 2002). In this case, landscape features seem instrumental in generating traveling waves (Sherratt et al., 2002, 2003; Johnson and Collinge, 2004).

When spatial heterogeneity, rare individual events, population structure and the different scales of factors occurring at different trophic levels are collectively important, purely mathematical techniques (equation-based models, EBM) are overcome. Thus, no general model has emerged to date that permits the forecasting of variations of small mammal population densities in a real landscape.

Agent-based modelling (ABM) is a spatially explicit paradigm that models space as a heterogeneous environment (e.g., crops, grassland, and forest patches) in which individuals (e.g., predators, preys, etc.) move and are represented as “agents”. The latter are autonomous entities that move in the virtual space and interact with each other and environmental patches. During the simulation, dynamics emerge and can be observed and quantified. ABM is versatile and has the following advantages: (i) data provided by a geographic information system (GIS) are easily included; (ii) model architecture is close to the ecological expert knowledge; and (iii) operational outputs can be tracked and explored in various manners, for example, for decision making. ABM permits producing large-scale models composed of several hundreds of thousands of interacting agents. For instance, a first object-oriented simulation modelling system was proposed by Westervelt and Hopkins (1999) for the simulation of mobile individuals in landscapes. Furthermore, using the ALMaSS system, Dalkvist et al. (2011) investigated the joint effect of predation (specialist versus generalist), landscape fragmentation and breeding season using an agent-based simulation model. Based on 4 types of regular fragmentation patterns and two habitats (optimal and suboptimal) in theoretical landscapes, the study aimed to examine three descriptive endpoints, including mean population size, cycle length and amplitude, and two mechanistic endpoints, including direct and delayed density dependence, but the pattern of population spreading in space was not assessed. In agreement with the literature, specialist predators generated delayed density dependence and vole population cycles, whereas fragmentation and generalist predators dampened these effects. Furthermore, using NetLogo, Radchuk et al. (2016) investigated the effect of predation only, predation and sociality, predation and dispersal, and predation and both sociality and dispersal on the long-term population dynamics of vole populations. Only the full model, which included both intrinsic factors and predation, yielded cycle periods, amplitudes, and autumn population sizes closest to those observed in nature, suggesting that the individual-based approach is useful for addressing the effects of social mechanisms on rodent populations at fine temporal and spatial scales. However, Radchuk et al. (2016) were mostly interested in the effect of intrinsic and extrinsic factors on time processes and less interested in integrating real landscapes on a large range and in the spatial patterns potentially generated by population spreading.

These models bring to light microscopic and spatially complex dynamics that could not be modelled with EBM. Nevertheless, computational limits are often exceeded with ABM. This problem frequently occurs in ecological studies, where giant populations (e.g., hundreds of thousands or millions of individuals, here termed a “megapopulation”) are at stake, such as in small mammal populations. On the other hand, EBMs allow for the quantification of the growth of such a large population but cannot easily integrate spatial (e.g., land use, soil, and elevation) and temporal (e.g., seasonal variations) heterogeneities, subsequent changes in population age structure parameters, and rare events such as individual long-distance dispersal.

EBM and ABM are “top-down” and “bottom-up” techniques that promote aggregative and descriptive methods (Edmonds and Moss,

2004; Varenne and Silberstein, 2013) to model a complex system, respectively. Models reproducing real phenomena (Deffuant et al., 2015; Franck, 2012) developing at different scales are often constructed. “Macroscopic” models (based on EBM) are often opposite to “microscopic” models (based on ABM), whereas the scale indicates only the perspective on the phenomena. For example, an ABM provides a macroscopic perspective on a complex system, whereas an EBM describes a part of this system (e.g., MIOR Masse et al. (2007) vs. Momos Pansu et al. (2009)). The observed boundaries that have been defended in past decades by scientific communities have been trimmed back in favour of coupling several modelling techniques into hybrid models (Osgood, 2007). Coupling EBM and ABM provides the advantages of each approach (spatial heterogeneity and individual dynamics for ABM and population size and analytical solution for EBM) while reducing their limitations (limited population size for ABM and spatial homogeneity for EBM) (Banos et al., 2017). In ecology, the combined use of system dynamics and individual-based modelling has been proposed by Vincenot et al. (2011) in cases where classes of systems are difficult or in some cases impossible to model dynamically using any of these approaches alone. Furthermore, the implementation of a behavioural ecology case was achieved in theoretical landscapes of various patchiness (Vincenot et al., 2015) and Bradhurst et al. (2015) developed a hybrid model employing EBM to model within-herd spread of foot-and-mouth disease and a stochastic, spatially-explicit ABM to model between-herd spread and control in a number of farms.

Here, we propose coupling ABM and EBM in a multiscale model to overcome these limits, and as an example, we seek to build a model to simulate the spread of a montane water vole, *Arvicola scherman*, population in the Haute-Romanche valley (France). The population surges of montane water voles have been studied in a number of mountain ranges in France (Giraudoux et al., 1997; Fichet-Calvet et al., 2000; Delattre and Giraudoux, 2009; Berthier et al., 2014; Michelin et al., 2014; Halliez et al., 2015). This work provides basic knowledge on the ecology of this species and its population dynamics. The colonization of an alpine valley, where the species was absent previously, was observed from 1998 to 2010 (Halliez et al., 2015), reaching peaks of 500–1000 voles/ha and a total population of several hundreds of thousands to millions of individuals.

## 2. Study case observation and analysis

### 2.1. Study case observation

The empirical data were obtained from the Hautes-Alpes in the subalpine and alpine zones of the upper Romanche river valley and its tributaries. Until the occurrence of the first vole colony in 1998 at the end of the Buffe valley (6.25E 45.08N), the species was unknown in the Romanche valley and the connected tributaries (Halliez et al., 2015). Given the proximity of the Parc National des Écrins and considering the potential risk to wildlife posed by the side effects of vole control, the staff of the park carefully mapped the annual progress of the colonization from 1998 to 2010 until it reached the Col du Lautaret and stopped in the 13th year. Mapping was based on the observation of surface activity indices after the snowmelt, which is a reliable indicator of variations in vole abundance (Giraudoux et al., 1995, 1997; Berthier et al., 2014). This unique situation of primary colonization made it possible to know the characteristics of an invasion pattern of a valley from a known starting point (the end of the Buffe valley) over a surface area of approximately 2500 ha constrained by the relief of valleys.

#### 2.1.1. Population characteristics

Age categories and reproductive status are derived from Quéré and Le Louarn (2011), Pascal and Boujard (1987), Cerqueira et al. (2006), Quéré (unpublished, based on breedings), and Villette (unpublished, based on captures in nature). Young voles become juveniles after 18 days, and juveniles become adults at 56 days post birth. Adults and

Download English Version:

<https://daneshyari.com/en/article/8845974>

Download Persian Version:

<https://daneshyari.com/article/8845974>

[Daneshyari.com](https://daneshyari.com)