The Animal Landscape and Man Simulation System (ALMaSS): a history, design, and philosophy

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Abstract

This article is the first article in the new topical RIO journal collection for ALMaSS. This editorial introduces ALMaSS, its history, component parts and philosophy, and forms a first access point for those interested in knowing more. It is written from my own personal perspective as the instigator and main developer for the system, effectively as the 'father' of ALMaSS.

Keywords

Landscape simulation, Individual-based simulation, Software ecosystems, Applied simulation modelling, Social-ecological simulation

A simple overview of ALMaSS

This GIF provides a simple overview of ALMaSS (Fig. 1).

ALMaSS childhood years

ALMaSS was born as a functioning simulation system with its first use in Danish projects in 2000, but it was conceived as an idea in 1996. ALMaSS was a response to a request from the then Danish Ministry for Energy and Environment to be able to answer unspecified questions related to the impact of human management on wildlife. This rather unspecific question was the impetus for developing a then revolutionary and ambitious idea that became ALMaSS. At that time (and even today) the ecological modelling paradigm approached tasks by designing specific models for specific purposes, and as simply as possible. The idea for ALMaSS to represent landscapes and the animals contained in them in detail for applied use was considered by most as completely unrealistic, compared at one time to building a giant spaceship that would never fly.

The 1990s were a time of transition for individual-based models (IBMs), both from a methodological perspective and due to rapid computer hardware development. IBMs at that time were quite simple, often based on non-spatial expansion of stage-structured population models to the individual (Maley and Caswell 1993). However, a new type of model was emerging towards the end of the 90s, the agent-based model. Coming originally from computer science agent-based modelling introduced the concept of reflective agents (Costantini et al. 1992) and this spread quickly in ecology and social science (Grimm and Revilla 2005). However, the majority of the models developed under this new paradigm were also rather simple, due probably to the novelty of the approach and the lack of easily accessible powerful computing support more complex simulations. Thus, in 1996 the design of ALMaSS was advanced, since it relied on development of cutting-edge hardware that was outside the scope of off-the-shelf computing at that time. Luckily, as anticipated, affordable desktop hardware capable or running the simulations arrived quickly on the scene. By 2000 when the first ALMaSS simulations were ready to run it was possible to buy a suitable PC, albeit still restricted to using small landscapes and needing its own office due to the noise generated!

Initial ALMaSS design was based on programme development using a domain-specific language called Viola (Topping and Rehder 1999), but this was quickly dropped in favour of development in pure C++. The first ALMaSS publications showing the basic design of simulation a detailed landscape which provides the necessary information for detailed agent-based models appeared in 2003 (Topping and Hansen 2003). At the same time some scientific applications of ALMaSS also quickly appeared in the areas of population genetics (Topping and Ostergaard 2003, Pertoldi and Topping 2004a, Pertoldi and Topping 2004b), pesticide impacts assessment (Topping and Sibly 2003, Topping and Odderskaer 2004) and ecology (Jepsen and Topping 2004, Jepsen and Baveco 2005). Sadly, the population genetics was not continued further, but ALMaSS has subsequently been used extensively in the pesticide impact and risk assessment and as a means for assessing management impacts on wildlife.

ALMaSS design

The underlying design from 1996 has changed little in 25 years. The basic separation is between the landscape simulation and agent-based models. The Landscape is a large C++ class that holds all the information and behaviour associated with the physical landscape and the farms and farm management contained therein. This class includes classification of habitats, mapping of the landscape, vegetation growth modelling and environmental fate modelling of pesticides. Farm management is represented in detail, with each farmer knowing which fields he manages and what rotation to apply, and then what management to apply to the field for a particular crop. Management can be flexible with changes in activities related to weather, history of management, and can be modified experimentally. Spatial resolution is a 1-m^2 with a usual time-step for landscape modelling of one-day. The overall size of landscape simulated is dependent on the power of the computers used to run simulations, but typically 10x10 km is used. This landscape simulation basis has been significantly expanded recently but remained rather constant until the last two or three years.

The agent-based animal model included at launch was the field vole (*Microtus agrestis*). This was quickly followed by the skylark (*Alauda arvensis*) (Topping and Odderskaer 2004), roe deer (*Capreolus capreolus*) (Jepsen and Topping 2004) and a carabid beetle (*Bembidion lampros*) (Bilde and Topping 2004). The design supporting these developments was based on combining a state-transition approach to modelling behaviour, effectively creating a state machine, and combining this with a 'administrative' class, the PopulationManager. This class provides the functionality to manage multiple lists of animals in different developmental classes and to ensure that interactions in time and space are handled consistently.

Combining both the Landscape and PopulationManager together provides the environment for these detailed behavioural models, allowing the animal agents to sense information from their surroundings and to use this to act/behave to fulfil their own agenda, i.e., a definition of agents in agent-based models.

ALMaSS philosophy and the teenage period

Like any child, ALMaSS suffered from growing pains, also like the unusual child in the class it was not well understood or always accepted by the other children. It took almost 15 years to break through some of these barriers, before mainstream acceptance occurred.

ALMaSS did not fit the simple modelling paradigm, and ecology did not seem ready to embrace this alternative approach. The key to unlock further progress was probably the publishing of the underlying philosophy guiding ALMaSS modelling (Topping and Alroe 2015). This involves including all real behaviour and mechanisms that are needed to describe the system to be modelled, such that we aim for a realistic systems representation. This is quite different to the usual maxim used in ecological modelling, i.e., an implantation of Ochams's Razor that focuses on simplicity being good in itself. ALMaSS is more akin to an engineering approach building a simulation to a specification. In this case the aim is to reflect socio-ecological reality as closely as possible, following the concept of engineering a digital twin. At the time it was not well understood that the two approaches were complementary, the general modelling approach aimed towards basic understanding and the detailed simulation to applied use. ALMaSS simulations are therefore targeted primarily towards the support of real-world decision making and policy, rather than general concepts. However, it is becoming increasingly clear that these models can also contribute to the underlying theoretical science, particularly in the key role of context in ecological systems responses.

ALMaSS today

The ALMaSS system has matured considerably with particularly rapid growing spurts over the last five years. The initial list of agent-based model species has expanded since the early years, key ALMaSS species now implemented include the European brown hare (Topping and Hoye 2010a), the grey partridge (Topping and Hoye 2010b), and linyphiid spider (Thorbek and Topping 2005). These species have seen considerable use in impact assessment and policy support along with the original species set. Many of these are related to pesticides (e.g., Topping and Sibly (2005), Dalkvist et al. (2013), Topping and Kjaer (2014), Mayer and Duan (2020)). Work continues to expand ALMaSS species with forthcoming models of *Osmia bicornis*, *Bombus terrestris*, three species of geese, two more carabid beetles, ladybirds, and crested newt.

Much of the new work has been related to pesticides and risk assessments (e.g., Topping and Dalkvist (2009),Topping and Craig (2015), Topping and Dalby (2016)), including the newest model in the ALMaSS group, ApisRAM (Duan and Wallis 2022). This is a highly detailed honey bee colony model and will also be the first ALMaSS model to demonstrate the use of machine learning for calibration and testing.

A new departure for ALMaSS is the inclusion of subpopulation modelling for very numerous or simple species. This works by dividing the landscape into small areas (e.g., 10x10m) to represent each sub-population, then defining the rules by which individuals will move between sub-populations, whilst otherwise treating the sub-population as a stage-structured population model. This approach is currently being applied for modelling aphids, lacewings and some pests of olives.

From the human perspective, ALMaSS has been used in studies of farmers (Malawska and Topping 2016, Malawska and Topping 2018) and hunters (Williams and Topping 2018). In fact, ALMaSS was the first example of a fully integrated biocomplexity model (Malawska and Topping 2018), whereby the typical management effects on animals and the environment were extended to include reflexive models of farmers that could sense their impacts on the system around them and adjust management accordingly. Since then, there development of human dimensions within ALMaSS has been slow. However, recently new projects have allowed the extension of the Farm and Farmer classes in ALMaSS to include a full economic accounting, multiple countries, as well as social interactions and farmer behavioural attributes. This area should be a fertile ground for new developments.

All these new developments are supported by extensions of the ALMaSS landscape capability which now includes 12 countries in Europe (Fig. 2). Denmark and Polish models are still the most detailed but operational models should be available for all the countries during this year. The degree of support for agent and sub-population models has also been increased dramatically over recent years, with the newest major addition of pollen and nectar resource models parameterised for Europe using local context to define flowering phenology and nectar and pollen production.

This component has been made possible through long-standing collaboration with colleagues from Krakow and Coimbra. They form part of an expanding network of researchers currently contributing and developing ALMaSS components for the future. Many exciting initiatives are underway and the number of people in the ALMaSS network continues to grow.

All these expansions feed towards the use of ALMaSS as a multi-criteria decision making support system (Topping and Dalby 2019), and also towards the systems approach to risk assessment needed to bring more ecology to the regulatory risk assessment for pesticides (Topping and Aldrich 2020), but also to connect the human dimension through simulation of landscapes as systems of many and various interconnected entities.

Compared to ALMaSS, most ecological models do not survive beyond infancy. They are designed for specific purposes and like cardboard boxes they are discarded or recycled after use. In contrast, ALMaSS was designed to represent systems not cases, it is flexible and adaptable, and has lived for over 20 years already. Thus, as ALMaSS moves from adolescence to maturity, the future seems bright for a long and fruitful life in research and policy support.

Conflicts of interest

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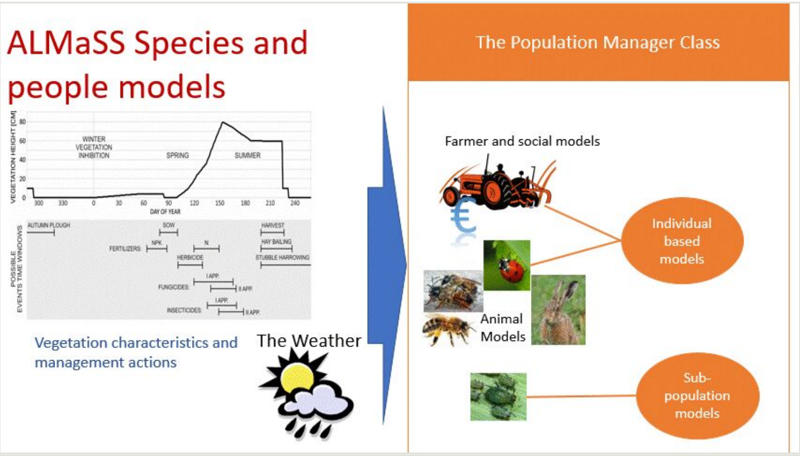

Figure 1.

A simple overview of ALMaSS.

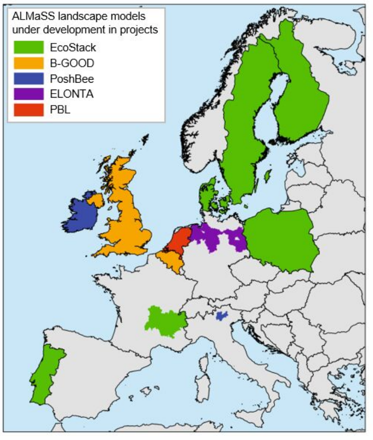

Figure 2.

ALMaSS landscape simulation coverage in Europe. All expected to be fully operational during 2022.