Using Constrained Optimization to Understand, Predict and Control Knotweed Spread

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1 Motivations

In this abstract, we describe an open computational sustainability problem that aims at understanding, predicting and controlling the spatial spread of knotweeds which exhibit exceptional invasive capacities.

Biological invasions are increasingly recognized as an important element of global change and constitute an important factor of loss of biodiversity. Invaders cause impacts on native species and on ecosystems. Alterations resulting from invasions are often formulated in terms of economic consequences, and the high costs induced by the spreading of invasive species lead managers and researchers to seek for efficient methods of eradication. Nevertheless, invasive management has been proven to be difficult and some species have been demonstrated to resist to control. Understanding biological invasions in terms of biological and ecological processes, with an ultimate goal of controlling, predicting and preventing them, is of great importance.

Our biological model is the species complex of the genus Fallopia (or asian knotweeds, Polygonaceae) which is listed by the World Conservation Union as one of the world's 100 worst invasive species. Tiny pieces of rhizome or stem are capable of regrowth and are considered as important dispersal propagules. Clonal spread by rhizomes associated with rapid growth can result in vast monocultures and consequently has been considered as the major feature of aggressiveness of the Fallopia complex species. Ecological and biological studies are carried out in the LEHF laboratory which is specialized in ecology of plant communities. In particular, data were gathered on morphological and demographic traits, reproductive and dispersion traits of the different genotypes (parental species, interspecific hybrids) for this model Fallopia. Data were collected and will be collected on the invasibility of different ecosystems. In particular, we know the rate of expansion of a population of knotweeds as a function of the initial surface of the population in a given habitat. At the landscape scale, different populations can occur in and near different habitats. Those habitats vary in their properties in facilitating or limiting spread of knotweeds.

In section 2, we introduce a mathematical model of our problem and we discuss how to use this model for understanding and predicting spatial spread of knotweeds. In section 3, we discuss optimization issues and show how optimization techniques could help us controlling the spatial spread of knotweeds.

2 Mathematical model of knotweed spread

The speed of knotweed spread depends on its genotype, but also on its habitat, and a landscape is composed of different kinds of habitats (e.g., grass, forested area, river, road, etc). Hence, we propose to use a spatially explicit model such that the landscape is subdivided into a tesselation of discrete cells C, as proposed for example in (Marco et al 2002). Each cell $i \in C$ is spatially located and we denote $n(i) \subseteq C$ the set of cells that are neighbours to every cell $i \in C$. Each cell is associated with a kind of habitat and we denote $h(i)$ the kind of habitat of cell i (we assume that cells are small enough so that the habitat associated with a cell is homogeneous).

The spread of knotweeds is studied for one year periods. Hence, we associate a variable $x_{i,t}$ with every cell $i \in C$ and every year t. This variable gives the proportion of knotweeds in cell i at year t. From the collected data, we can model knotweed spread on every cell $i \in C$ by means of a constraint between the variables $x_{i,t+1}$, $x_{i,t}$ and $x_{j,t}$ for every $j \in n(i)$. In other words, we can define the relation between the proportion of knotweeds in cell i at time $t+1$ and the proportions of knotweeds in cell i and its neighbour cells $j \in n(i)$ at time t. This relation depends on the kind of habitat $h(i)$ of cell i.

This first model may be used to better understand and also to predict spatial spread of knotweeds: starting from an observed state at time t_0 (i.e., the observed proportion of knotweeds in every cell at time t_0), we can propagate constraints to compute the predicted proportions of knotweeds in every cell at times $t_i > t_0$. By comparing these predictions with our collected data, we shall validate our model (or correct it if differences are observed). A key point lies in the definition of the constraints that model knotweed spread: first observations have shown us that the invaded area is increasing linearly; however, we have to define this more formally. Also, we have to study the impact of the geometry of cells (e.g., squares or hexagones) and of the neighborhood (e.g., 4 or 8 cells for squares) on the progression of the spread (Holland et al 2007)

3 Using optimization techniques to control the spatial spread of knotweeds

Different methods may be applied to control the spread of knotweeds. For example, knotweed can be suppressed (but not eradicated) by cutting it back throughout the summer, so that its photosynthesis is never allowed to operate at high levels. Also, knotweed rhizomes can be dug up and bagged. The impact of these different methods on the spread of knotweeds is not yet known exactly, but researchers of the LEHF laboratory are currently studying and measuring them. Each method also has a different financial cost.

Hence, we could use optimization techniques to better control the spatial spread of knotweeds at the lowest cost. A decision variable $d_{i,t}$ can be associated with every cell i and every year t. The domain of these variables can be composed of the different actions that may be performed on a cell i at time t (e.g., cut, dug, ...) including doing nothing. We may consider two different objectives, i.e., minimize the cost of the decided actions and minimize the spread. As these two objectives are contradictory, we can either post a constraint on the total cost and search for a solution which minimizes the spread while satisfying the cost constraint, or we can post a constraint on the spread and search for a solution which minimizes the cost while satisfying the spread constraint.

By using optimization techniques (and not only simulating the model with respect to a given initial state and actions), we hope we shall discover good strategies for better controlling spatial spread at the lowest cost. For example, depending on the topology of the landscape, we may identify a small number of key cells on which actions should be done first because these cells constitute a kind of bottleneck between invaded cells and (not yet) invaded cells.

References

(E.P. Holland, J.N. Aegerter, C. Dytham, and G.C. Smith 2007) : *Landscape as a Model: The Importance of Geometry*, in Computational Biology 3(10): 1979-1992

(D. E. Marco, S. A. Paez, and S. A. Cannas 2002) : *Species invasiveness in biological invasions: a modelling approach*, in Biological Invasions 4: 193-205