HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

The role of space in invasive species management

Julia Touza, Martin Drechsler, Karin Josh, Katharina Dehnen-Schmutz

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Outline

1.- Introduction

2.- Objectives

3.- State-of-the-art review

4.- Numerical simulations

5.- Conclusions

Introduction

Spatial dimension in the policy analysis of biological invasions

Increasing interest by environmental economists in the study of resource management from a spatial perspective (e.g. Smith et al. 2007)

This research driven by spatial heterogeneity:

- Natural resources vary across space
- Costs and benefits vary across space
- Policy instruments may be spatially explicit (e.g. protected areas)

Introduction

Spatial complexity: landscapes are made up of a large number of habitats that interact in space

This is important for example in the analysis of evolution of cooperative behaviour (e.g. Doebeli and Hauert, 2005)

“Games on grids”, i.e. evolutionary games that are played in populations whose individuals occupy sites on a spatial lattice

Introduction

Spatial heterogeneity affects invaders spread through complex landscapes and the susceptibility of individual areas to invaders establishment

Heterogeneity and complexity are important for the analysis of biological invasion policies

An invasion front in a landscape is a “collective phenomenon” rather than a localised process between two land patches

Aims

1.- Review how spatial heterogeneity and complexity have been analysed in the economic literature on invasive species

2.- Illustrate numerically the importance of considering heterogeneity and complexity in the control of invasive species

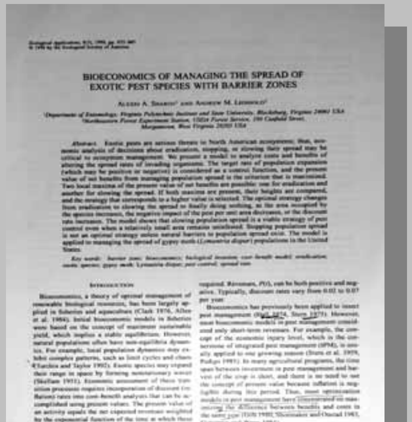
Economics of BI: spatial aspects

Emerging economic invasive species literature that takes into account spatial issues

How space has been taken into account?

Which characteristics of space have been explored in the economic analysis?


Management of a transboundary wildlife population: A self-enforcing cooperative agreement with renegotiation and variable transfer payments


BIOECONOMICS OF MANAGING THE SPREAD OF EXOTIC PEST SPECIES WITH BARRIER ZONES


USING A DYNAMIC LANDSCAPE MODEL FOR PLANNING THE MANAGEMENT OF ALIEN PLANT INVASIONS

Economics of BI: spatial aspects

Non-spatial

Several sites (which can have different states)
Sites have explicit locations, so that
distances between sites are different

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Spatially implicit

Spatially explicit

Sites have different exogenous
properties, e.g. different sizes or
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Spatially differentiated and explicit

Economics of BI: spatial aspects

Spatially Implicit: several sites (no location, distances..)

Invaded/Noninvaded - Social Decision

Perrings (2002)
Max benefits from non-invaded space
Reduce invaded space
Establishment threshold
(costs of controlling & impact of invader)

Potapov et al. (2006)
Min invasion costs
Reduce further spread
3 types of policies: control invaded space, control non-invaded space & no control
(efficiency of prevention and control costs)

Owned/Adjacent - Private Decision

McKee (2006)
Max agricultural benefits
Greenhouse whiteflies - California
Timing of pesticide use
Migration effect: adjacent crop removal
Coordination: share information

Grimsrud et al. (2006)
Max pasture benefits
Yellow Starthistle -New Mexico
Reduce infestation level
Migration: constant proportion
Mutual control efforts (free-rider problem)
Control cost-prohibitive - incentives

Economics of BI: spatial aspects

Spatially Differentiated: sites have exogenous differences

No specific studies for invasive species, although there are (many) economic studies in this setting

Huffaker et al. (1992), Skonhoft and Olaussen (2005), Bhat and Huffaker (2007) focus on damaging species

Two interacting areas with spatial differences (e.g. carrying capacity, damage level)

Institutions:

- Control under unified management (public planner)
- Cooperative control with adjustable side payments to maintain cooperative agreement

Economics of BI: spatial aspects

Spatially Explicit: site location and distance

Sharov and Liebhold (1998): Barrier zones at the front of the invader population

Direction of the invasion, shape of the area (rectangular, circular), and distance

Eradication within barrier zones is economically justified even when only a small proportion of potential area remains noninvaded

Spatially Explicit & Differentiated: location, distance plus heterogeneities

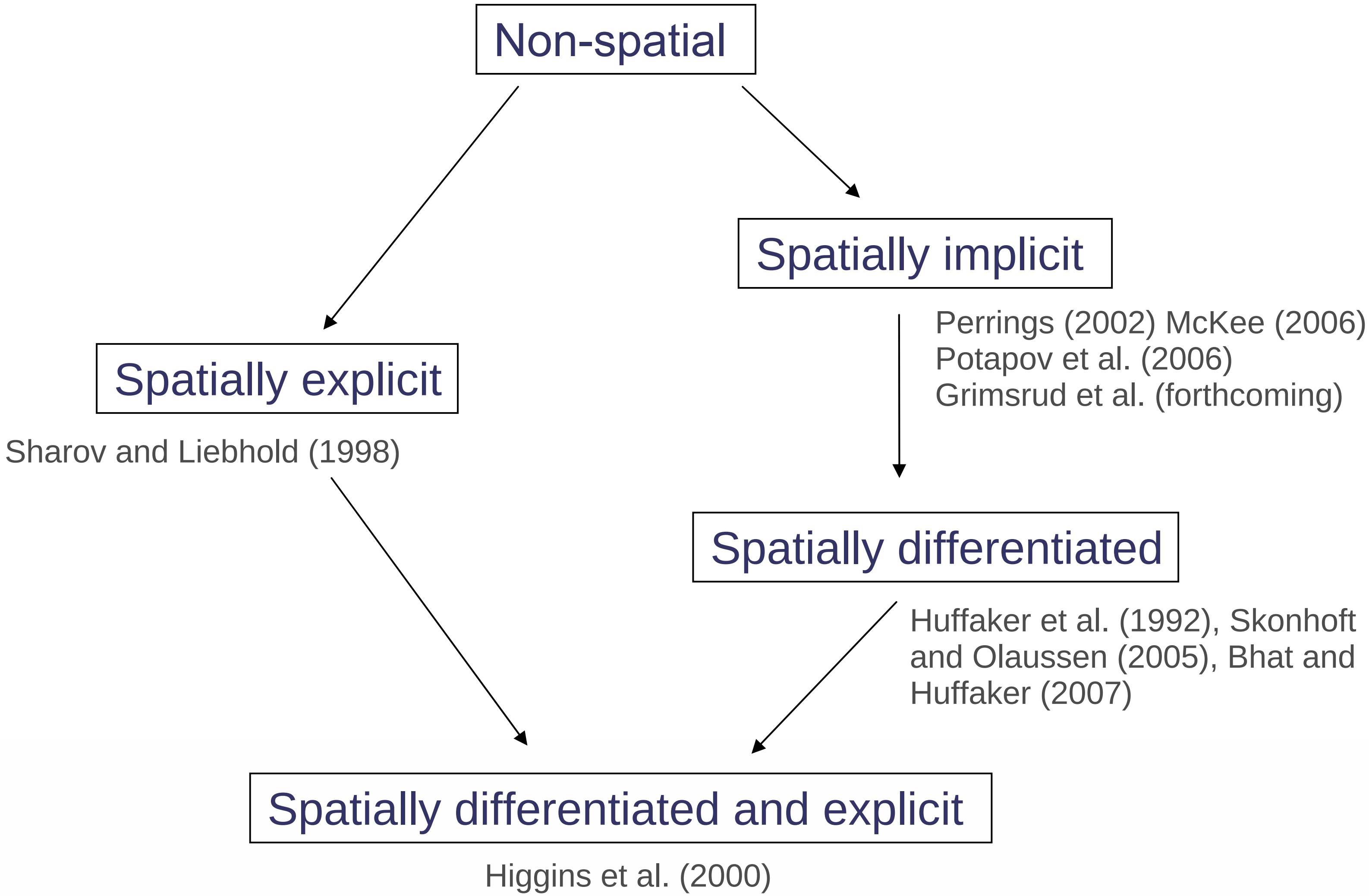
Higgins et al. (2000): Computer-based simulation of clearing strategies for alien plants in a fynbos in Cape Peninsula

Integrates demography of alien plant populations with spatial structure of invaded system

Cost-effectiveness: Start clearing low-density stands of juvenile plants, then higher density stands of juvenile plants and leave high density stand of adult plants last

Threat to native species: Prioritize high biodiversity

Economics of BI: spatial aspects



Economics of BI: spatial aspects

Non-spatial

Most of the studies have ignored spatial heterogeneity (they are either spatial implicit, or not spatial differentiated)

Or considered simple landscape (two areas)

Huffaker et al. (1992), Skonhoft and Olaussen (2005), Bhat and Huffaker (2007)

Spatially differentiated and explicit

Higgins et al. (2000)

Numerical Illustration

Explore the effect of spatial heterogeneity in a complex landscape

Simulate the spread of an organism through a complex network of habitats

Maximise the expected time to invade the whole network (T) for a given budget

Compare the cost-effectiveness of spatially homogeneous and heterogeneous control strategies

Numerical Illustration

Stochastic metapopulation model (Drechsler and Wissel 1998, Frank and Wissel 2002)

The dynamics of the invasive species follows a spatially explicit Markov process

Extinction of a local invasive species population: $e_i = \varepsilon A_0^{-y}$

y large	Species with weak fluctuation in growth rate e_i responds strongly to changes in A_i
y small	Species with strong fluctuation in growth rate e_i responds weakly to changes in A_i

Colonisation of a non-invaded patch: $\lambda_{ij} = c(1-x_j)\exp(-\alpha d_{ij})$

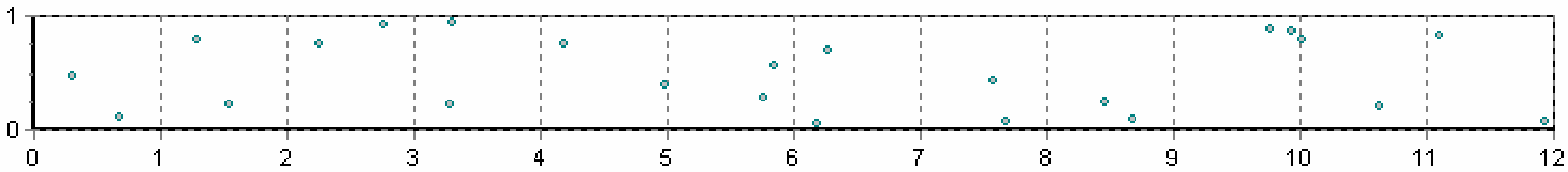
Numerical Illustration

Our landscape: rectangular shape with 12 strips, and each strip has the same number of patches

First strip is assumed invaded, and we calculate the expected time until a patch of the final strip is invaded (T)

Policy: Control measures over 10 strips (homogeneous/heterogeneous)

Each scenario is simulated 1000 times, and we compute the average T



Numerical Illustration

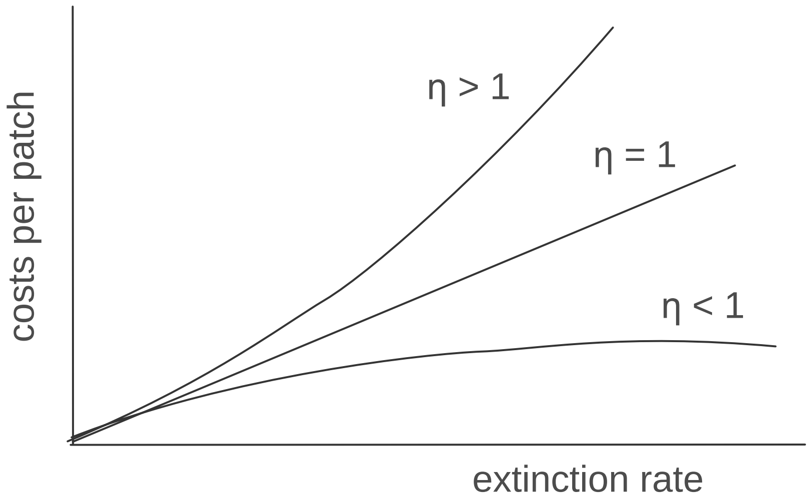
Under management

$$e_k = e_0(1+b_k)^{1/\eta}$$

$$b_k = (e_k/e_o)^{\eta}$$

Costs of increasing the local extinction rate increase more (less) strongly than linear with e_k, if $\eta > 1$ ($\eta<1$)

$\eta = g/y$



g economic parameter

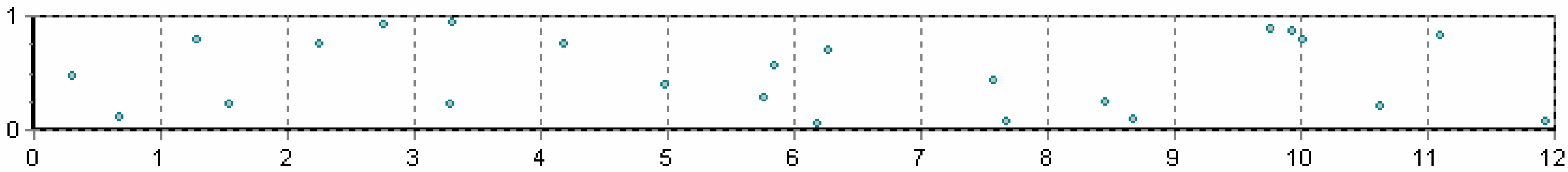
g>1 decreases in A are less than proportional with effort costs – increasing marginal costs

g<1 decreases in A are more than proportional with effort costs – decreasing marginal costs

Numerical Illustration

Different management options, which differ by the level of spatial heterogeneity:

1. all strips b (financial control efforts) Homogeneous management
2. strips 1,3,5,7,9 2b // strips 2,4,6,8,10 nothing
3. strips 1,3,5,7,9 1.5b // strips 2,4,6,8,10 0.5b
4. strips 1,3,5,7,9 0.5b // strips 2,4,6,8,10 1.5b
5. strips 1,3,5,7,9 nothing // strips 2,4,6,8,10 2b



Simulations Results

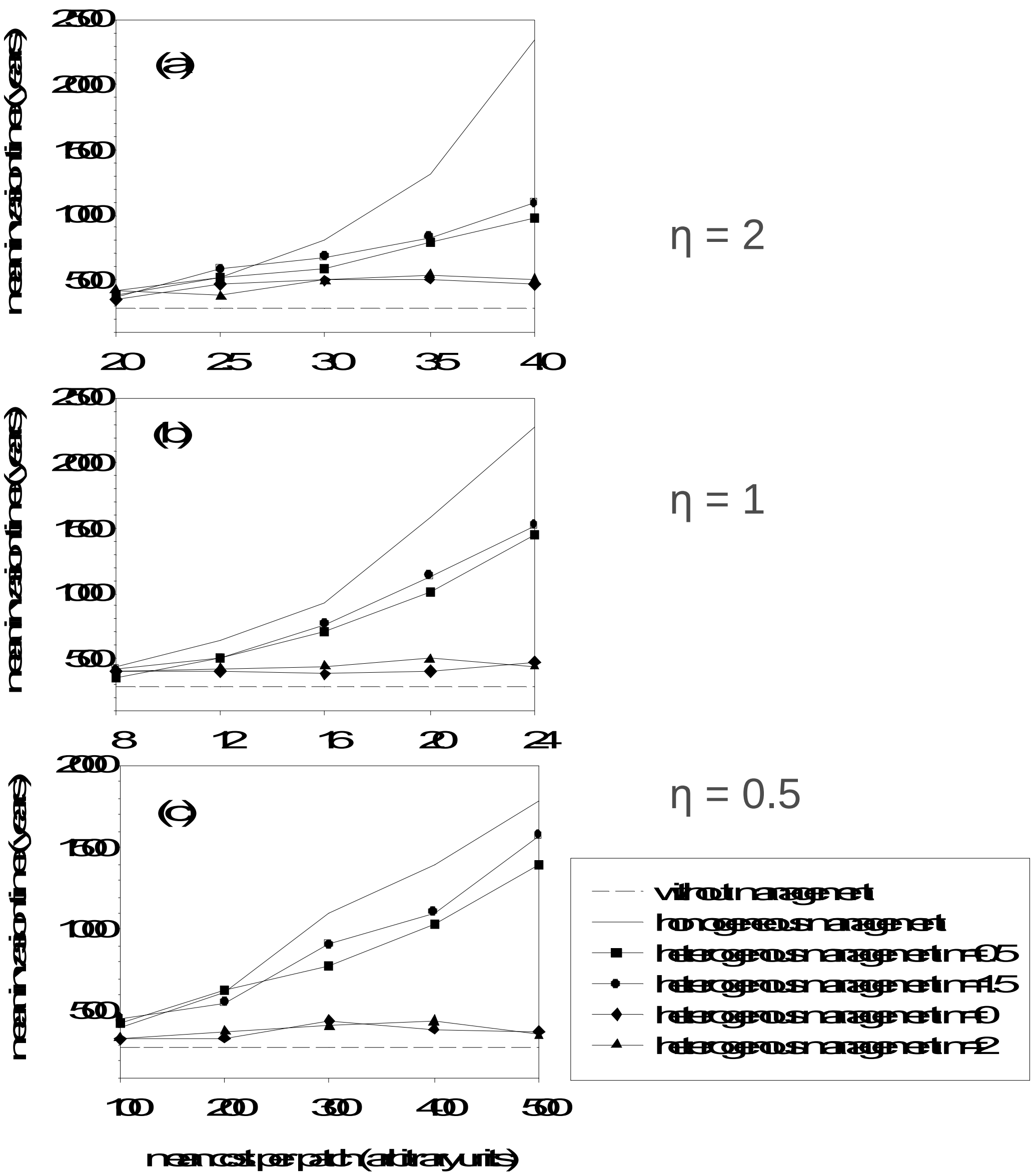
Sequence of management effort does not have a strong influence

The higher the level of heterogeneity, the shorter the invasion time

Homogeneous management leads to the highest invasion time.

It is the most cost-effective for all η

Decreasing η (y increases or g decreases), the advantage of homogeneous management decreases



Simulations Results

Dominance of homogeneous control effort, why?

"*The life time of a metapopulation can be approximated by a function that contains only the geometric means of e and c/e of local patches*" (Frank and Wissel 2002)

Time to invasion T depends on the geometric mean of the local extinction rates:

$$E=(e_k * e_{k+1})^{1/2}$$

When will we have a "break-even"?

If extinction rate increases exponentially with control efforts

Heterogeneous control outperform homogeneous control only if e_k increases with b_k more strongly than exponentially (i.e. marginal costs decrease extremely fast)

Conclusions

Heterogeneity & complexity should be considered in policy analysis

Most of the economic studies of invasive species are non-spatial or spatially implicit

Studies that incorporate heterogeneity consider simple landscapes

Illustration of the effects of spatial heterogeneity in complex landscape:

- Invasion time depends on the heterogeneity of control efforts
- Homogeneous control outperforms heterogeneous control for a large class of costs functions
- This depends on the shape of the costs, and temporal variation of alien species growth rate