Using GRASS and Spatial Explicit Population Dynamics Modelling as a Conservation Tool to Manage Grey Squirrel (*Sciurus carolinensis*) in Northern Italy

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Abstract

Grey squirrel, an invasive alien species, is currently replacing the native Eurasian red squirrel in British Isles and north-west Italy. Grey squirrel has recently been reported in Parco Lombardo della Valle del Ticino (NW Italy) and the species is likely to spread in the woodlands connecting Italy to other European countries. We used GRASS GIS and Spatially Explicit Population dynamics Models as a conservation tool to predict the spread of grey squirrels and to test different management options in the Ticino Regional Park and surrounding areas in a 40 years time frame. GRASS GIS has been used in two phases of the work: at first to build the habitat and the squirrel distribution maps to be processed by the model and then to map the model output. Scripting in a Bourne-shell environment allowed us to integrate the GIS capabilities with the population dynamics program, written in C programming language, and assured the data stream from GRASS to the model and back. The integrated approach of SEPM and GIS allowed us to suggest public administration a cost effective action plan to stop the invasion process.

1. Introduction

The introduction of species from a different ecosystem in another environment is claimed to be the second most important reason for loss of biodiversity, after the destruction and fragmentation of natural habitats, leading to extinction or decline of native species (Vitousek et al., 1996; Williamson, 1996; IUCN, 2000). Alien species interfere with the native fauna by different ecological processes: predation, inter-specific competition or acting as vector or reservoir of diseases (Sainsbury et al., 2000; Gurnell et al., 2004). Many introduced species can also cause direct economic damage to human activities (impact on farming, forestry, animal husbandry; disease risk), and socio-economical problems sum with the ecological one (Shine et al., 2000). A well documented case of competition by an invasive alien species is the wide-scale replacement of the native Eurasian red squirrel *(Sciurus vulgaris)* by the

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introduced western grey squirrel *(Sciurus carolinensis)* in the British Isles and in parts of northern Italy. The rapid increase of grey squirrel's distribution, coincided with a dramatic decline of the range of the native red squirrel (Wauters et al., 1997a), at the point that greys has now almost replaced reds in Great Britain and Ireland (Gurnell and Pepper, 1993) and in a small region in Piedmont (northern Italy) (Bertolino and Genovesi, 2003). Recently, other grey squirrel populations have been discovered in mixed deciduous woodland belts along the Ticino river (Fornasari et al., 2002). The competition of red and grey squirrels in northern Italy has serious implications for red squirrel conservation in Europe (Genovesi and Bertolino, 2001b; Genovesi and Bertolino, 2001a), because of the vicinity of France and Switzerland as shown in Figure 1. Political concern about the lack of action in many countries has been expressed by the Permanent Commission of the Bern Convention, which has produced several recommendations (n. 57, 77 and 78 of 1997) urging countries to eradicate alien invasive species where possible. In order to assess the risk of extinction of red squirrel populations, and to plan effective management strategies for controlling the invasive species, it is necessary to know the rate at which replacement will occur, which mainly depends on landscape structure (connectivity between good habitats) and abundant food supplies (Wauters et al., 1997b). We used an integrated approach of GRASS GIS with SEPM (Spatially Explicit Population dynamics Models) that has been tested on grey squirrels in Britain and Piedmont, Italy (Rushton et al., 1997; Lurz et al., 2001). The aims of the work are: (1) evaluate grey squirrel expansion in the Ticino Regional Park and surrounding areas; (2) test the effect of different control strategies.

2. Material and Methods

2.1 Study Area and Data Collection

The Ticino Regional Park in Lombardy, North-Italy, extends for about 908 km^2 along the east-side of the Ticino river (Figure 1). Our study area extended for 40 km in all directions from the park boundaries. The current distribution of grey and red squirrels in the park was investigated using 315 hair-tubes (Gurnell et al., 2001) placed in the park and inspected during a three year campaign (1999 - 2001) (Fornasari et al., 2002). An initial population size of 150 grey squirrels, present in nine habitat blocks (sub-populations, see Figure 2), was estimated from the cited study, and used as the starting point for the SEPM model.

2.2 Habitat Map

In order to predict grey squirrel range expansion, we obtained CORINE Land Cover data for the regions of Piedmont and Lombardy

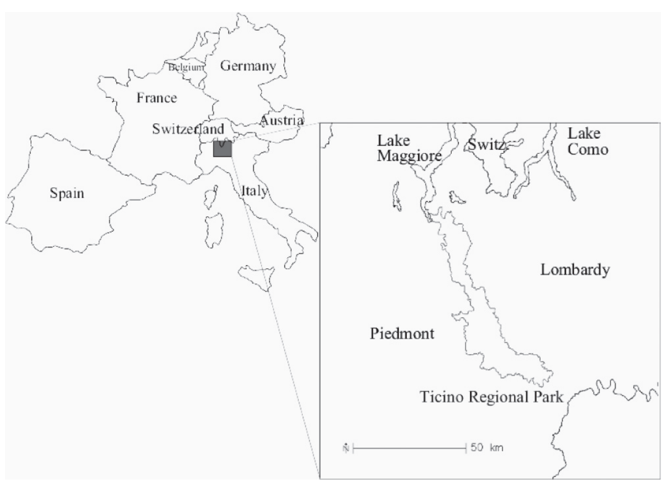


Figure 1: Study area location: Parco Lombardo della Valle del Ticino, northern Italy, Europe

in digital format at 250 m spatial resolution (Commission of the European Communities, 1993), and added further detail using two other land cover/land use sources: the Ticino Regional Park forestry map (10 m spatial resolution) for areas inside the park that are not in the Varese province (Lombardy), and the vegetation map of the Varese province (10 m spatial resolution, Tosi and Zilio, 2002).

All habitat types were classified using CORINE-biotopes, and land cover and vegetation type data were harmonised in a single habitat map, with a 250 m resolution, produced with the aid of the GRASS module r.mapcalc (GRASS Devel. Team, 2002). Each 250 m by 250 m cell has a single habitat type.

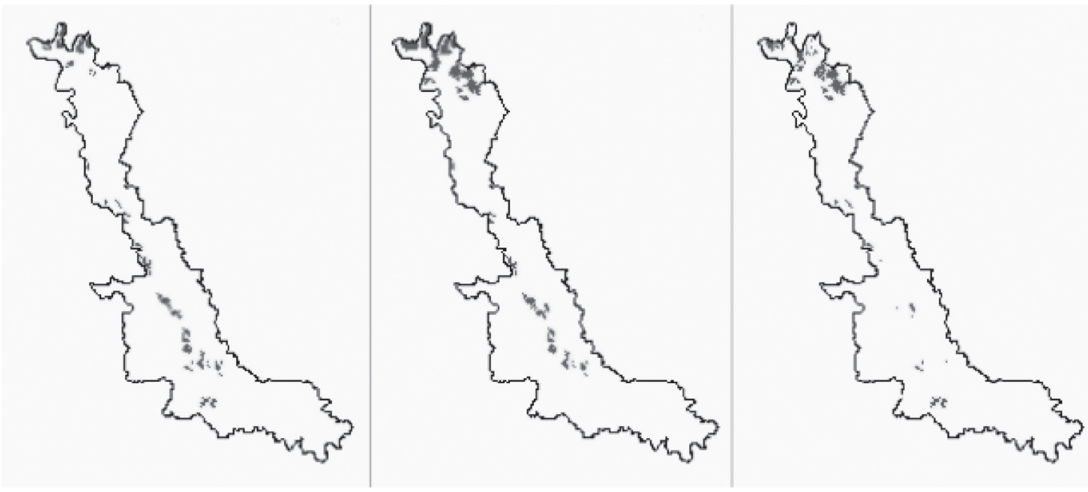
2.3 Control Maps

We assumed that the grey squirrel population would be managed using the dispersal control technique: a fixed rate of individuals would be removed each year while the population was still small and spreading. We tested different schemes in the attempt to make a compromise between the effectiveness and the (logistic) feasibility of control. In all the runs squirrels were removed inside the park area and only in blocks covered by woodland, since these were more likely to host a squirrel population. We used GIS to create three different control scenarios selecting different numbers of woodland blocks in which to trap grey squirrels according to different combinations of block size and woodland type (see Figure 3), as we judged it impossible to trap squirrels in all 20 km^2 woodlots.

Figure 2: Grey squirrel initial distribution: the species is present in grey blocks inside Ticino Park boundaries

2.4 Model Details

The model used for simulating the distribution of grey squirrels in the landscape has two main components. The first is a geographical information system which stores habitat and animal population information. GRASS 4.2 (U.S. Army, 1993) and GRASS 5.0 (GRASS Devel. Team, 2002) were the GIS used to store and retrieve habitat information and the model outputs. The GIS undertakes data manipulation and abstraction and provides input for the second component, which consists of a program simulating the population dynamics of grey squirrels and their interactions and dispersal within the GIS-held landscape. The second component is a population dynamics model that predicts the distribution of squirrels by simulating the life history processes of births, deaths, home range formation and dispersal in yearly time steps. A detailed description of the original model, used for investigating the spread of the grey squirrel and decline of the red squirrel in East Anglia, England, is given by Rushton et al., 1997. The model was applied and fully tested in Piedmont, details are described in Lurz et al., 2001. The population dynamics program was written in the programming language C and integrated with the GIS component in a UNIX-shell environment. GIS capabilities have been used to build the habitat map from different sources, the initial distribution of the species and the patterns for control. Suitable habitats were defined according to type the carrying capacity (CC), i.e. the number of individuals who can be supported by a given area (Odum, 1975): each type of habitat type received a CC value based on published estimates. From the habitat map we created a clump map of 18463 habitat blocks, and for each block area and centroids have been calculated. Species distribution and control raster maps were processed by r.volume



(a) 'Best habitat' scenario: most suitable habitat, 18 blocks, total area 2800 ha

(b) 'Extended control' scenario: 17 patches of average and good habitat for a total trapping area of 4600 ha, larger control blocks in the northern part

(c) 'Target-area control" scenario: average and good habitat, managed area 2600 ha asymmetric distribution within the Park

Figure 3: Habitat blocks where the management of grey squirrel took place in each of three simulated scenarios

using the habitat clump map in order to have all data referred to the same block frame. Clumps are the key to pass data from GRASS to the model and back: a shell script has been used to rearrange the output of GRASS modules r. clump and r.volume in an ASCII file suitable for being processed by the population dynamic model. Each record in this file contains clump number, habitat type, number of squirrels, coordinates of clump centroids, clump size (i.e. number of cells) and a binary value for the control mechanism. The spatial information and the biological parameters have been processed by the SEPM program who then outputs files that can be used for statistical analysis and for creating maps since they contain the clump number and the number of squirrels predicted for each replicate of the simulations. By the aid of another shell script run directly in GRASS, we were able to display density maps for each year of the simulation.

3. Results

All the runs started from the situation known in year 2001 and forecasted squirrel population dynamics for the following 40 years. As the model is a stochastic one, we ran it 10 times for each set of inputs to cover a 40 year time span. So for each scenario we then ran the models 400 times. Results presented are averages of those multiple runs.

3.1 Grey squirrel spread

The landscape in and around Ticino Regional Park is very suitable for squirrels. If the starting population is not managed, our results indicate that grey squirrels are likely to spread over a wide area over the next 40 years. The model predicts approximately 370000 individuals (see also Table 1). The spatial spread of grey squirrel population over the simulation period at ten year intervals is shown in Figure 4. Our predictions suggest that it will take more than twenty years for grey squirrels to start invading the southern part of the Park and to spread outside the Park boundaries reaching Switzerland (Figure 4(c), (d)). Squirrels are predicted to show different patterns of spread: inside the Park dispersion tends to occur along the wooded riverbank of Ticino, while outside the spread has no preferential direction. The model simulations indicate that it will take up to 15 years to reach carrying capacity within Ticino Park. Dispersal beyond park boundaries may therefore be slow and the rapid implementation of control measures is likely to be successful in slowing down or even preventing further spread.

3.2 Grey Squirrel Control Scenarios

For each control scenario, having previously defined different control maps showing the location of control areas, we tested the effect of two different removal rate, namely 50% and 80% of the individuals present at a given time. Squirrel removal starts in 2005 for each scenario, so for the first three years of the simulation no squirrels are removed. A comparison of the surface to be managed in each control scenario is shown in Figure 3 and comparing the simulation outputs we were able to find the best compromise between effective management and number of patches to control. The scenario called "target area control" best fitted those requests: results and comparison with the uncontrolled spread are presented in Table I while the "best habitat" scheme was proved to be ineffective.

4. Discussion

Without control, grey squirrels could invade Switzerland woodlands within the next two decades. Simulating different grey squirrel con-

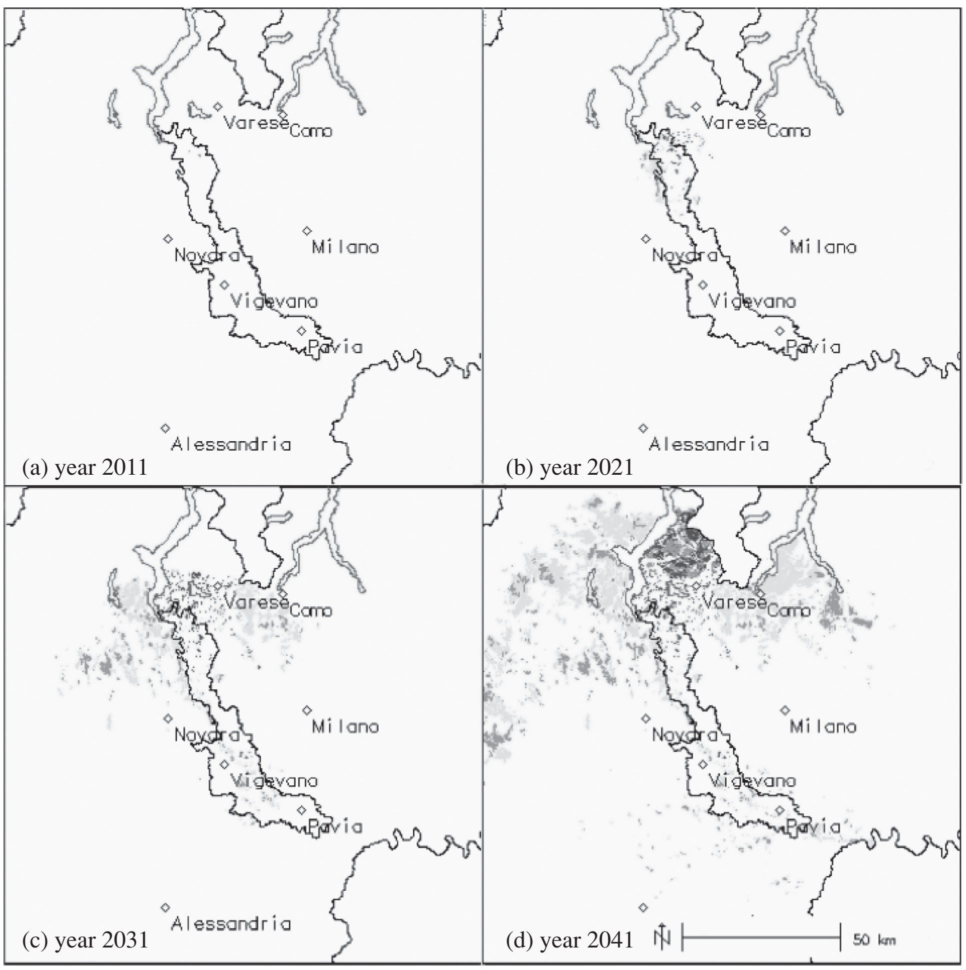


Figure 4: Simulation results for the spread scenario. Habitat blocks occupied by grey squirrels are evidenced in greyscale. Different shades represent the different densities (individuals per hectare) according to the legend below

Table 1: Average predicted grey squirrel population size in the 'no control' and in the 'target area control' scenarios. Results are presented at five years intervals. SD: standard deviation

Individuals		Removed							
Year	No control	Control 50%	SD	Control 80 %	SD	Control 50%	SD	Control 80 %	SD
2001	150	150	-	150	-	-	-	-	-
2006	115	60	14	46	6	34	7	36	6
2011	247	73	16	41	11	31	8	26	5
2016	1639	58	9	14	9	33	7	20	9
2021	19311	125	38	10	13	48	10	9	10
2026	58485	200	72	8	12	107	37	7	10
2031	109720	145	52	2	5	102	47	2	4
2036	201521	200	114	0	0	91	61	0	0
2041	370237	205	171	0	0	64	37	0	0

trol or removal scenarios suggests that: (i) efficient control is possible and mainly determined by the spatial distribution and woodland patch size of the "target" control areas; and (ii) immediate actions must be taken, since delay in grey squirrel control will result in the population increasing and spreading, which makes the problems of successful containment more difficult. The coupled use of SEPM and GIS proved to be a useful tool in conservation as it allowed us to test the effectiveness of different strategies, including a "no action" option, proiding wildlife managers with maps showing the consequences of each strategy. Control maps analysis allowed us to identify the best cost-effective action control plan to prevent the spread of the invasive grey squirrels. Those maps, theoretically, could already be used on the field to place traps. However, caution must be used, as model scenarios were based on surveys that may underestimate the real distribution range and current population size of grey squirrels. In addition, no information was available on the presence of the species outside the park boundaries, and so we assumed it was absent. For all these reasons our predictions can be considered as conservative and we suggest a combination of grey squirrel monitoring and public participation survey to map grey squirrel presence, which may also help increase public awareness. Moreover, future surveys can be used to improve model performance and to test the reliability of our predictions. Successful containment of further grey squirrel spread will require local co-operation between Italian and Swiss authorities involved in wildlife management.

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