Geographic information systems as a new tool and methodology proposed for modelling mammal/helminth postfire regeneration. The example of Parc Natural de la Serra Calderona (Comunitat Valenciana, Spain).

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Al Prof. Dr. Ignacio Navarrete López-Cózar, gran maestro, buen compañero, mejor amigo.
To Prof. Dr. Ignacio Navarrete López-Cózar, a great mentor, colleague, and friend.

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Abstract: As part of a multidisciplinary project on the dynamics of postfire recolonization concerning small mammals (insectivores and rodents) in Serra Calderona Natural Park (Valencian Country, Spain) and the use of their helminth parasites as biological tags in the postfire regeneration process, the fundamentals and the preliminary results of a Geographic Information System (GIS) are presented. This GIS aims to fill the knowledge gap regarding the process of the population dynamics of small mammals and their helminth parasites in the burnt area using climatic and remote sensing data. Moreover, this GIS project constitutes the basis of future programmes capable of delivering a complete model of the postfire recovery process, both at small mammal and at helminth level, the mammal/helminth model. The GIS project is created using the data from the multidisciplinary database which includes data on hosts and their helminths parasites, climate data, remote sensing data originating from satellite images etc. corresponding to the postfire years. A complete analysis carried out at various levels using the data from various layers of the GIS project make it possible to model the postfire regeneration process.

Key words: Helminths, Small Mammals, Postfire Regeneration, GIS, Climate Data, Remote Sensing Data.

Resumen: Formando parte de un proyecto multidisciplinar sobre la dinámica de recolonización postincendio de micromamíferos (Insectívoros y Roedores) de la Serra Calderona (Comunitat Valenciana), y de la utilización de sus helmintos parásitos como bioindicadores del proceso de recuperación postincendio, se presentan las bases de aplicación y los primeros resultados de un Sistema de Información Geográfica (SIG). Este SIG tiene como objetivo inicial contribuir al conocimiento de los procesos de dinámica poblacional de los micromamíferos y sus helmintos parásitos en la zona quemada a través de la utilización de datos climáticos y tipo "Remote Sensing". Además, este proyecto SIG constituye la base de futuros programas encaminados a la modelización conjunta del proceso de cicatrización postincendio, tanto a nivel de los micromamíferos como de sus helmintos parásitos, modelo mamífero/helminto. La confección del proyecto SIG se lleva a cabo a partir de los datos recogidos en la base de datos multidisciplinar que incluye datos de los hospedadores y sus helmintos parásitos, datos climáticos, datos "remote sensing" procedentes de imágenes satelitales etc. correspondientes a todos los años de evolución postincendio. Un análisis completo y a diferentes niveles de los datos contenidos en las diferentes capas del SIG permitirá la modelización del proceso de regeneración postincendio.

Palabras Clave: Helmintos, Micromamíferos, Regeneración Postincendio, SIG, Datos Climáticos, Datos Satelitales.

1. Introduction

Helminth parasites faced with environmental changes might respond in many different ways, which makes it difficult to predict what might happen in the helminth community and their hosts after, for example, a devastating wildfire. Mediterranean ecosystems possess their own regeneration capacity

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after the occurrence of a wildfire which allows the small mammal recolonization –with individuals originating from non-burnt areas– as well as the reestablishment of the biological cycles of their helminth parasites. Consequently, these multi-layered biological cycles are likely to be re-established depending on the virulence of the fire, the degree of the ecosystem regeneration, and the follow-up climatic conditions.

In 1994, as a consequence of a devastating wildfire which destroyed Parc Natural de la Serra Calderona (Valencian Community, Spain) in 1992, the PAF (Parasites and Fire) research team of Valencia University initiated a multidisciplinary project concerning the dynamics of small mammal postfire regeneration and the role of their helminth parasites as biological tags in this Mediterranean ecosystem enclave. In the course of eleven research years the initial targets have been reached. First, shedding light on the different ways of recolonization used by the various small mammal species returning to the burnt area. Second, the confirmation of the wood mouse, *Apodemus sylvaticus* (Linnaeus, 1758), as the most important rodent species involved in the recolonization process. Third, proposing the study methodology of postfire regeneration processes and the usage of helminths as biological tags herein. And, last but not least, modelling and monitoring the recuperation processes in Mediterranean ecosystems after a wildfire or a similar environmental catastrophe. However, it is often difficult to understand whether fluctuations in population dynamics of the small mammals concerned as well as those of their helminth parasites result solely from the postfire regeneration process itself or if they are influenced by other biotic or abiotic factors which may be difficult to appreciate by means of this type of conventional study. Nevertheless, the creation of a Geographic Information System (GIS) makes it possible to carry out a spatial and temporal analysis retrospectively with respect to the changing dynamics of biotic and abiotic factors in the burnt areas and in the non-burnt areas (used as control) along the study period.

In this way, and as a part of this multidisciplinary project, the basis of the application of a GIS having the initial objective to serve as a new valid tool capable of completing the understanding of the population dynamics of small mammals and their helminth parasites in a burnt area using climate and remote sensing data is presented. Moreover, this GIS constitutes the methodological basis to design future models such as the mammal/helminth model proposed by Galán-Puchades and Fuentes (1996) and Galán-Puchades *et al.* (1999).

2. Proposed methodology

The methodology presented here complements the proposal of Galán-Puchades *et al.* (1999). The steps to be followed in order to create a GIS project using the postfire regeneration process of Parc Natural de la Serra Calderona as a blueprint are detailed here. A GIS is a computerized information system which makes it possible to capture, store, handle, analyse, visualize and present georeferenced data. The geographic information system is organised in various thematic layers with their own spatial and temporal attributes corresponding to i) the data of the study area, hosts, helminth parasites, climate data etc. originating from previously created databases; ii) digital data derived from external digitalised information of existing maps or remote sensing data from aerial pictures and satellite images.

2.1. Study area

The study area is a Spanish Mediterranean ecosystem located in Parc Natural de la Serra Calderona (39º35'-39º51'N, 0º15'-0º43'W), a mountain-range constituting one of the easternmost foothills of the Iberian System which descends towards the Mediterranean sea. This natural park is situated in Comunitat Valenciana covering parts of the provinces of València and Castelló with a surface of 52,000 ha. Its general orientation is NW-SE separating the valleys of the rivers Túria and Palància. The average altitude is approximately 500 m. This natural park suffered a devastating wildfire at the end of the summer of 1992 affecting a total of 9,500 ha including forests and cultivated land which had been left untended.

In the study, initiated in 1994 (second postfire year), several enclaves situated in the burnt area as well as in the control area have been surveyed and

studied seasonally for both host and helminth data and occasionally for helminth data only. Each of these prospected enclaves was marked geographically with its geographic coordinates and its altitude using a GPS (Global Positioning System) and a barometric altimeter. The geographic information has been compiled for each of the points considered in the study: burnt area, control area, different kinds of enclaves. Moreover, each enclave has been ecologically characterized (landcover, type of vegetation, hydrology, fauna etc.) coinciding with its respective survey aiming to detect possible changes that might have occurred in this area as a consequence of the regeneration process.

2.2. Host data

The host material has been obtained in trapping sessions using the capture-recapture method, seasonal/annual collection of data in the burnt area as well as in the non-burnt area used as control according to the methodology described by Fuentes *et al.* (1998, 2000) and Galán-Puchades *et al.* (1999).

Three species have been studied: one insectivore, the common shrew, *Crocidura russula* (Hermann, 1780), and two rodents, the wood mouse, *A. sylvaticus*, and the Mediterranean mouse, *Mus spretus* Lataste, 1883.

Population dynamics of each host have been analysed by means of the study of data corresponding to capture/recapture, sex, age, weight, sexual activity of each of the captured individuals in the seasonally surveyed areas, i.e. in the burnt as well as in the non-burnt area, after the second year after fire (1994) until to date (2005, thirteenth year after fire).

2.3. Helminth data

The helminthological study of the insectivores and rodents has been carried out using individual hosts found dead in the enclaves surveyed seasonally and/or using the whole set of hosts captured in the enclaves surveyed occasionally. The latter enclaves, which have been surveyed only once, infrequently, twice or more often, leaving the recuperation process of these areas undisturbed, have been considered in the follow-up small mammal population analysis. However, additional surveys of these enclaves have been carried out after a carefully considered interval in case outstanding zoological and/or parastiological results were detected. In order to complete the parasitological study, the faeces found in the traps of the hosts captured alive were also collected to carry out coproparasitological studies using the Kato-Katz® technique, in order to obtain helminthological data of the released animals. At the same time, the specificity and the sensibility of this technique were certified comparing the results obtained from faeces of released animals with those of dissected animals (100% sensibility and 100% specificity after helminth identification)

The parasitological postmortem study carried out in the laboratory followed the usual helminthological techniques (Fuentes *et al.*, 2000).

The helminthological dataset was ecologically analysed by means of calculus of parametric and non-parametric tests, diversity indices, similarity indices, frequency distribution of helminths etc. which make it possible to characterize both the helminth community of each small mammal species and its particular populations determined by burnt or non-burnt areas, host sex, host age, capture season etc. following the protocols established by Fuentes *et al.* (2000, 2004a, 2005a).

2.4. Climatic database

The climate data of 7 meteorological stations of Instituto Nacional de Meteorología located within the study area have been collected and processed.

The compiled climate data corresponds to the variables of mean, maximal and minimal temperatures, precipitation, rainy days, potential evaporation and relative humidity. The data of each variable has been compiled on a monthly basis from 1991 (one year before the wildfire) until to date.

Based on this climate data, corresponding climadiagrams have been drawn, which make it possible to show the hydrological equilibrium by means of delimiting the dry and wet seasons in the study area. These climadiagrams can be created for various time series depending on the objective of the study, i.e. postfire year, dry or wet season etc.

2.5. Satellite imagery and digital layers

Remote sensing data is compiled using satellite images of NOAA (National Oceanic and Atmospheric Administration) and Landsat. NOAA satellites, with the AVHRR (Advanced Very High Resolution Radiometer) sensor on board, have been providing images at least every 12 hours with a 1.1 km resolution of the study area since 1979. Landsat satellites have been providing images every 16 days with resolutions of 30 and 120 m for Landsat 4-5 with the Thematic Mapper (TM) sensor since 1984, and resolutions of 15, 30 and 60 m for Landsat 7 with the Enhanced Thematic Mapper Plus (ETM+) sensor. Additional images originating from other satellites with different spatial, spectral and temporal resolutions might be used if required.

Initially NOAA images are grouped by days and later according to seasons of survey aiming to obtain new images with mean values of a complete trapping season. One Landsat image for each season of survey, previously selected according to the image cloud cover and image quality, has also been used.

By means of specialized software processing the entire set of images, originating from these two satellites, the corresponding values of each parameter considered have been extracted for each enclave studied. The extracted parameters of various spectral channels, applied in this kind of study, mainly are: NDVI (Normalized Difference Vegetation Index) values which reflect indirectly the quantity of rainfall by showing the general response of vegetation to rainfall, and the temperature difference between day and night from the AVHRR sensor; and NDVI, Land cover and TasseledCap (a classification which makes it possible to differentiate greenness (various types of vegetation cover), wetness (presence of water or wet lands), and brightness (dry or non vegetated land). ArcView GIS software with the associated Spatial Analyst extension are used to extract the statistical values of various parameters creating buffers of 5 km for each of the enclaves analysed, following conversion of the image raster to a grid file.

Maps and digital photographs corresponding to topography, vegetation, hydrology, climatology, soil type etc. on various scales (e.g. 1:50.000, 1:10.000, 1:5.000) are used as interactive layers which can be overlapped with satellite images.

2.6. Statistical procedures

Non-parametric tests, as well as correlations, lineal, multiple and polynomial regressions, multifactorial analyses –among others–, using biotic and abiotic variables, are the main statistical procedures designated for the statistical analyses, as one of the vital parts to create the mammal/helminth model. The chosen software has to include a conventional statistical package as well as specialized application for GIS procedures, as, for example, Spatial and Geostatistical Analyst extensions.

3. Geographic information system project

The GIS project consists of two clearly different parts, the multidisciplinary database and digital layers.

3.1 Multidisciplinary Database

The multidisciplinary database has been created with data originating from field surveys –hosts and parasites– following the methodology proposed by Fuentes *et al.* (1998, 2004a), from climatic data, their corresponding climadiagrams and other ecological parameters.

3.2. Digital Layers

Various digital layers provide static data and/or dynamic data, while thematic digital maps provide only static information as they do not take into account the changes occurring during the postfire regeneration process which are keys in understanding this evolutionary process. However, these layers are of great importance as they reflect the characteristics of each biotope before the environmental impact, as well as particular points of their evolution, always taking into account the precise moment of data collection.

On the other hand, satellite images (every 12 hours from AVHRR and every 16 days from Landsat) provide dynamic data which correspond to the evolutionary phases along the entire postfire regeneration process.

3.3. The GIS Project

The GIS project relies on specialized Arc View GIS software. Georeferenced ortophotos on a scale of 1:5,000 are used to situate geographically each of the prospected points. Each of these georeferenced points has been allocated its own multidisciplinary database, which makes it possible to visualize and analyse the compiled information for each of the studied enclaves:

- geographic and field data: coordinates, soil type, soil use, hydrology, vegetation, landcover, degree of forest regeneration etc.
- climatic data: monthly/annual evolution of all considered variables;
- climadiagrams
- remote sensing data: seasonal/annual and/or biannual evolution of parameters such as NDVI and temperature differences;
- zoological data: seasonal data of the captured species (population dynamics, sex, age etc.)
- helminthological data: species data, biological cycles, frequency distribution, diversity/uniformity/similarity of the host communities/populations etc.

Once the GIS project has been completed, using statistical analysis results, the mammal/helminth model can be proposed.

4. Mammal/helminth postfire regeneration model

Using the GIS project as a starting point, the various models concerning the recolonization of small mammals in Mediterranean forest areas affected by a wildfire, as well as the recuperation process can be designed. At the same time, a mammal/helminth model is designed using the parasite species which best reflects the postfire regeneration process of one or more hosts, i.e. the selection of one or more helminth species as biological tags of the regeneration and recuperation process.

The first findings which have led to the design of this model have already been presented in several scientific gatherings, both, on a national (Fuentes & Galán-Puchades, 1999; Fuentes *et al.*, 2005b; Sainz-Elipe *et al.*, 2005a) as well as on an international level (Fuentes *et al.*, 2004b; Sainz-Elipe *et al.*, 2005b). The following postulates as the basis of the mammal/helminth postfire regeneration model stand out:

- in the burnt area the variables taken along the study year, relative humidity and maximum temperature, have been correlated positively with *A. sylvaticus* and negatively with *C. russula*, respectively;
- the influence of climate on *A. sylvaticus* and *C. russula* in the burnt areas shows the greater sensitivity of an area undergoing a postfire regeneration process;
- the climatology analysis reflects positive correlations in the burnt area between the prevalence of helminths with an indirect cycle and prevalences of the nematode *Heligmosomides polygyrus* with mean and maximum temperatures of the study year;
- the nematode species of the genus *Syphacia* show a positive correlation with the capture percentage of the wood mouse in the burnt as well as in the non-burnt area;
- the great influence of interannual climate changes in the burnt area on helminths with an indirect cycle and on the nematode *H. polygyrus* (the only species with free living stages), reflects –because of the postfire regeneration process– the greater susceptibility of invertebrate populations;
- the correlation between the capture percentage of the wood mouse in both areas and the prevalences of the *Syphacia* species confirms that their transmission rate depends on the density of the host population;
- clear correlations between population dynamics of each small mammal species and the different biological cycles of the helminths, on the one hand, with the NDVI values, on the other hand, have been demonstrated;
- the analysis of the influence of climatological conditions shows that an ecosystem which has been affected by a wildfire suffers more profoundly from the effects of climate changes as it undergoes a process of permanent evolution and is, therefore, more vulnerable.

Thus, after the analysis of these preliminary results, the use of GIS in general, and these climatic and remote sensing data in particular, can be proposed as a new tool to complete the understanding and modelling of the mammal/helminth postfire regeneration process.

The present as well as future results of the model have to be ratified in the study area in question. Thereafter the model can be extrapolated to other Mediterranean forest areas that have been affected by wildfires and/or other environmental catastrophes. Moreover, as Galán-Puchades *et al.* (2002) proposed, this model can be adapted and extrapolated to human populations affected by environmental catastrophes and disasters having devastating effects on conglomerations with the aim to be used epidemiologically by the public health sector in general and concerning parasitic diseases in particular.

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