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A spatial interaction model for agricultural uses - An application to understand the historical evolution of land use on a small island

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45th Congress of the European Regional Science Association

**"Land Use and Water Management in a Sustainable Network
Society"**

Vrije Universiteit Amsterdam
23-27 August 2005

**A spatial interaction model for agricultural uses. An application to understand
the historical evolution of land use on a small island**

(not assigned)

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Abstract

The agenda is to explain the historical evolution of land uses in small islands. First we assess the capacity of the island territory for different uses based on agronomic analysis and transform these capacities in attractiveness coefficients. Then we design a spatial interaction model with five different sectors which employment can be closely related with surface area, first to five zones in the island and within those zones to small plots of 1 hectare each. Finally we use historical data on population and main export crops in order to calibrate the model for each historical period. Therefore, based on data on the export crop and on the population it is possible to estimate the different land use of the island for all the sectors and to assess the carrying capacity of the island.

Keywords: Planning, Land Use,

1. Introduction

The popular idea of sustainable development (Beckerman, 1992, Arrow, 1995; Stern,1996, Campell, 1996; Drakakis, 1995,1996, Maclaren,1996) within the fuzzy concept of development (Myrdal, 1957; Sen, 1988,1992) has put new pressures on planners. Apart from all misunderstandings it is no more possible to detach physical planning from development strategies and vice-versa.

The aim of this paper is to explain the historical evolution of land uses in small islands, through the analysis of an economic and environmental spatial interaction model, calibrated to a small insular community with historical data about the population and the export sector.

First we assess the capacity of the island territory for different uses based on agronomic analysis and transform these capacities in attraction coefficients (2). Then we design a spatial interaction model with five different sectors which employment can be closely related with surface area, first to five zones in the island and, within those zones, to small plots of 1 hectare each (3). In point (4) we use historical data on population and main export crops in order to calibrate the model for each historical period. Finally, it is possible to estimate historical land uses and identify the causes of past environmental disruptions connected with the lack of food, fire or water.

2. The smallest region: Corvo

Corvo is the most north-western island of the Azores group, laying half the way between the Iberian Peninsula and Newfoundland. With an area of 17 km², it is the smallest of the nine inhabited Azorean islands. The land is constituted by a single volcanic cone, ending in a large crater. Although the cone was once symmetrical, erosion in its west and northern faces, caused by the prevailing winds blow, led to the formation of high cliffs (more than 600 m high) and gave the island a pear like shape (Figure 1).

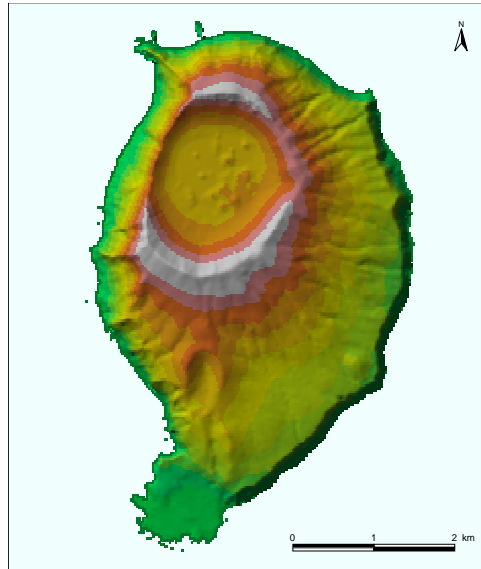


Figure 1: Corvo Island

Situated far away from any large land masses, Corvo is subject to the full force of North Atlantic gales, having a climate characterised by plentiful rain, frequent fogs, almost permanent winds and high air humidity.

The sea around the island is very deep (more than 3 000 m at 5 km from shore) and, due to a branch of the Gulf stream, rather warm (17° C in winter and 21° C in summer). The island is covered with grass, with occasional peat bogs and wind stunted shrubs, giving it a rather high latitude outlook.

Today Corvo is one of the 19 Azorean municipalities, and constitutes also an electoral circle for the Azorean Parliament. Since the electoral law prescribes the Hondt method for mandate assignment and requires each circle to elect a minimum of two representatives, Corvo, despite its small population, elects two Parliament members. Despite its population of only 440, due to its status as a municipality, and its condition as an island, Corvo has all the services one would expect in an urban area: a mayor, a town hall and all the municipal services, including water and sanitation; two banking offices; an airport with an airline office and its part-time fire department; a health centre with attending doctor and nurse; a border and customs police office; postal service office; telecommunications exchange; a harbour and a harbour master; a fiscal delegation, and representative officers of several Azorean government agencies.

With all these, Corvo is indeed one of the smallest humanised ecosystems. Today, the economy of Corvo, as the rest of the Azores, is dominated by cattle production for beef (Corvo) and external public support (Dentinho & Meneses, 1996)

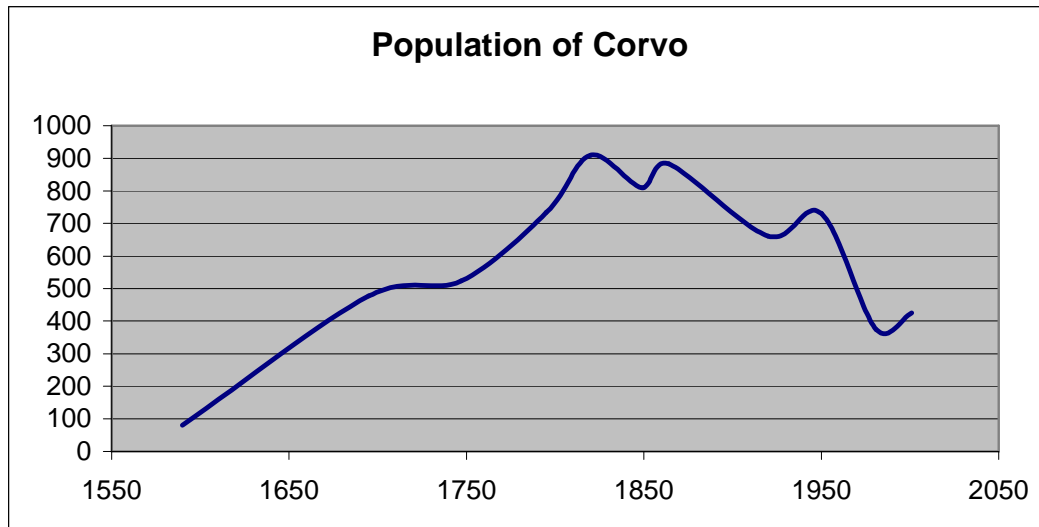


Figure 2: Population of Corvo from 1590 to 2001

The population of Corvo Island has evolved since 1590 to 1820 generally with a positive growth rate. From then on and until today it became generally negative with few oscillations (Madeira, 1998). The population in 2001 represents half of the population in 1820 (425 in 2001 and 910 in 1820), when the population of Corvo population achieved its maximum. The first population records found are from the end of XVI century, when Corvo had about eighty inhabitants.

During these centuries land use also varied influenced by the main exports and by the demand of the local population. The aim of this paper is to estimate the patterns of land use with the results from an interaction spatial model.

3 - The Model

A spatial interaction model distributes employment and residents by the different areas of the region taking into account the distances between those areas and their attractiveness (Dentinho, 2002). In the adaptation made in this paper it is assumed that residents and each type of employment generate a land use patterns based on coefficients of land use for each activity. The relations between and within the external and the internal economic systems can be explained using the structure of a basic model (Hoyt, 1939; North, 1955; and Tiebout, 1956) according to which exports, or basic activities, are the propulsive factors of the economy, demarcating not only its dimension but also the pattern of local production.

The model is explained by expressions (1) to (4). The population that lives in each zone is dependent on the employment that is established in all the other zones within a commuting range.

$$(1) \quad T_{ij} = E_{ki} \{r.W_j \exp(-\alpha d_{ij}) / \sum_j [r.W_j \exp(-\alpha d_{ij})]\}$$

$$(2) \quad P_j = \sum_i T_{ij}$$

Where: T_{ij} = population that lives in j and depend on the activity k in i ; E_{ki} = employment in sector k in area i ; W_j = residential attractiveness of j ; r = inverse of the activity rate; α = parameter that defines the attraction produced by distance for the commuters; d_{ij} = distance between i and j ; and P_j = residents in j .

On the other hand the activities generated for each zone serve the population that lives in all the other zones within a service range.

$$(3) \quad S_{ikj} = P_i \{s_k.V_{kj} \exp(-\beta d_{ij}) / \sum_j [s_k.V_{kj} \exp(-\beta d_{ij})]\}$$

$$(4) \quad E_{kj} = \sum_i S_{ikj}$$

Where: S_{kj} = activity generated in sector k in zone j that serves the population in i ; E_{kj} = activity in sector k for zone j ; V_{kj} = activity attractiveness of sector k in zone j ; s_k = amount of activity k per population; β = parameter that defines the attraction produced by distance for the people that look for activity services; d_{ij} = distance between i and j ; and E_{kj} = employment in sector k in zone j .

Figure 2 explains the functioning of the spatial interaction model. In the first moment it is possible to estimate the population of the different areas dependent on the basic activity of

various areas just by multiplying its amount by the proportion of dependents on activity of area i which lives in area j $\{r.W_j \exp(-\alpha d_{ij}) / \sum_j [r.W_j \exp(-\alpha d_{ij})]\}$. In the second moment the existing population for each area i induces the development of non basic activity in the different areas which estimate is obtained by multiplying the population of area i by $\{s_k.V_{kj} \exp(-\beta d_{ij}) / \sum_j [s_k.V_{kj} \exp(-\beta d_{ij})]\}$. In a third moment the non basic activity in the various areas is associated with more dependend population across the various areas. The second and third moment are repeated iteratively until the Total Employment and Total Population derived from the model converges to the to levels consistent of total population and employment.

Nevertheless there are also area constraints that must be fulfilled.

$$(5) \quad \sum_{ik} \sigma_{ik} S_{ikj} + \rho_j P_j + \sum_{ik} \sigma_{ik} E_{b_{ikj}} \leq A_j \quad (\text{for all zones } j).$$

Where σ_{ik} = area occupied by one employment of sector (k) in zone (i); and ρ_j = area occupied by one resident in zone j.

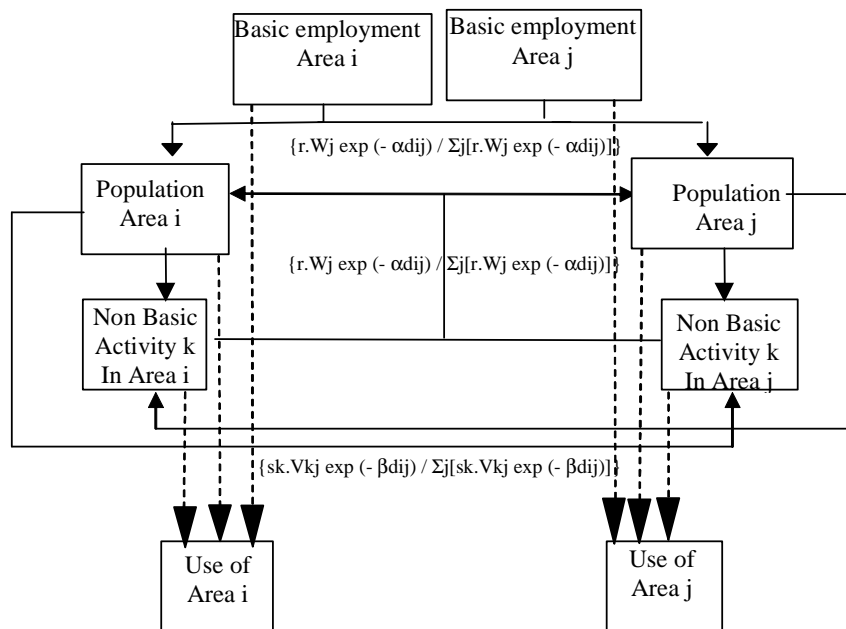


Figure 3: Spatial Interaction Model with Land Use Patterns

The general structure of the system can be represented, in a simple way, by a model with three interrelated blocks (Figure 3):

- First, the external economic system that integrates exports and the world markets - the engine of small economies (Dommen & Hein,1985);

- Second, the internal economic system that describes the relations between the local demand and the various activities (k) that fulfil that demand: urbe, hortus, ager, saltus and silvae.
- The third block focuses the use of natural resources, or zones, which are crucial to analyse the sustainability of the whole system.

3. Data

3.1. Attractiveness for sectors and zones.

The attractiveness (V_{kj}) was determined through the assessment of the environmental conditions of each zone for five sectors (k): urban, forest, pasture, agriculture and horticulture. The environmental features considered were (q): temperature, precipitation, elevation, slope, soil and exposure. The formula used is expressed in (6).

$$(6) \quad V_{kj} = \sum_m (\prod_{qm} C_{jkqm}^{(1/Q)})/M$$

where V_{kj} = the attractivity of sector k for zone j; and C_{jkqm} = normalized value of factor (q) for sector (k) in spot (m) of zone (j); Q = the number of factors (q) considered; and M_j = number of spots (m) in zone j. Due to lack of data it was not possible to assess the relative importance of each factor and therefore all the factors took the same weight.

Urban attractiveness

The attractiveness for urban use was achieved through the analysis of three parameters: slope, exposure and altitude (Gonçalves and Dentinho, 2005). Slope was divided into three classes 0-7, 7-25 and >25%. Slopes higher than 25% have no aptitude for construction, and the interval between 0 and 7 was preferable. The north and west exposures were excluded because of the low temperatures due to the low radiation and strong winds. South exposure was considered preferable. It was considered that urban implementation would only occur until 300m and close with close access to the sea. The high slopes between the East area and the sea turn this area less attractive to urban use.

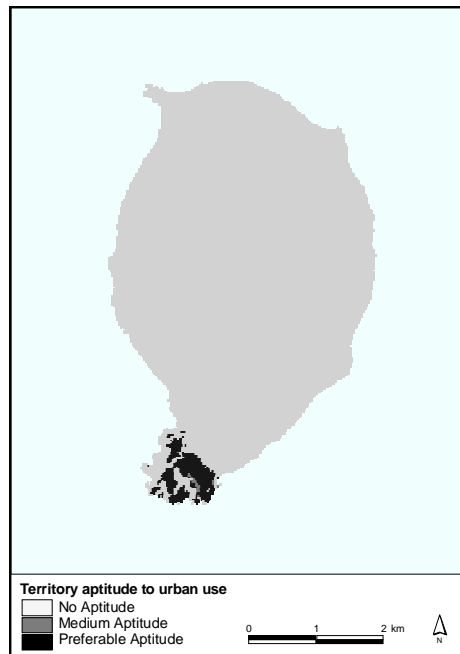


Figure 4: Attractiveness for urban use

Horticulture

The analysis of the attractiveness for horticulture and fruit production considered the culture of citruses (Gonçalves and Medeiros, 2005). The climatic conditions analysed were the temperature (accumulated temperature and medium temperature in the coldest months), the precipitation (total precipitation and percentage occurring in the summer months) and soil use capacity. Each one of the three criteria was given the same importance in determining the aptitude. Although the result shows three classes of aptitude the class of best aptitude is almost non-existent in Corvo island. Notice that although the territory of Corvo has a great area with alleged aptitude for horticulture and fruit production, this is relatively reduced aptitude because the optimum climatic and soil conditions are hardly present together in the same part of the territory.

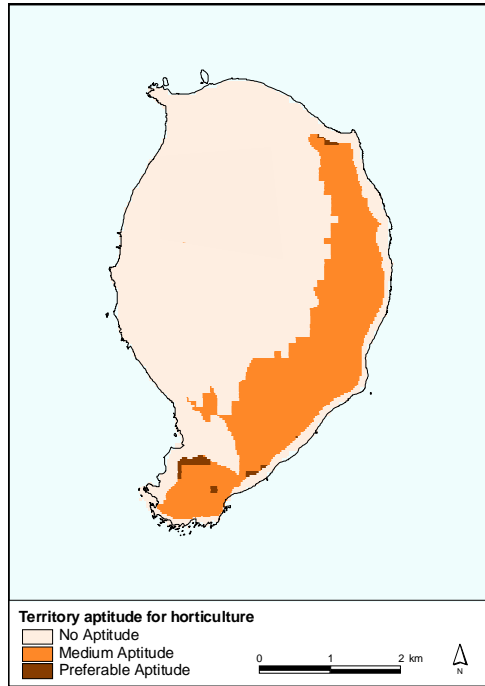


Figure 5: Attractiveness for horticulture and fruit production (oranges).

Agriculture

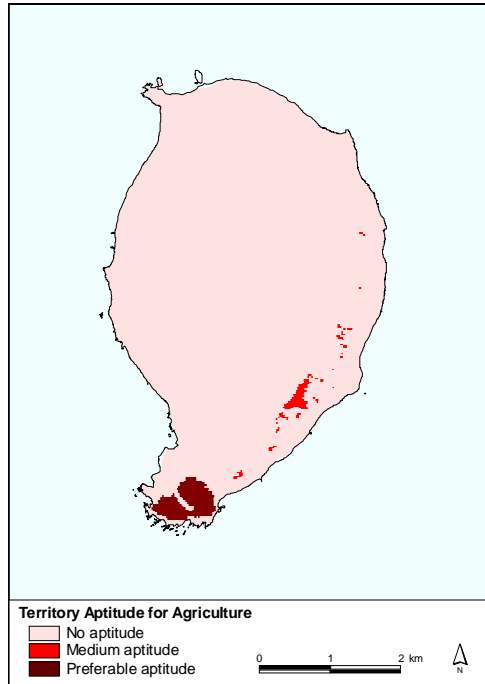


Figure 6: Attractiveness for agriculture (maize).

Considering the history of the island, the attractiveness for agriculture (Figure 4) was determined assessing the territory capacity for maize and wheat (Gonçalves and Monjardino, 2005), based in temperature, soil use capacity and slope demanded for these two cereals. Because of the similarity between the two cultures, the result for the attractiveness for both cultures is the same. The climatic conditions evaluated for both cultures were related to temperature accumulation and minimum and maximum temperature limits during certain development stages. The slopes considered apt to the culture were only from zero to fifteen percent. The areas with no attractiveness do not have either soil capacity or temperature conditions for the crops. The classes of medium and preferable attractiveness are distinguished based on the climatic conditions that allow the cultivation of latest varieties potentially more productive, assuming that there is no water deficit. This assumption can be made in Azores because of the high precipitation levels during the whole year.

Pastures

The territory aptitude for pasture (Gonçalves and Calado, 2005) was achieved considering both altitude and slope. It was created three classes of aptitude for altitude, 0-300, 300-600 and more then 600m.

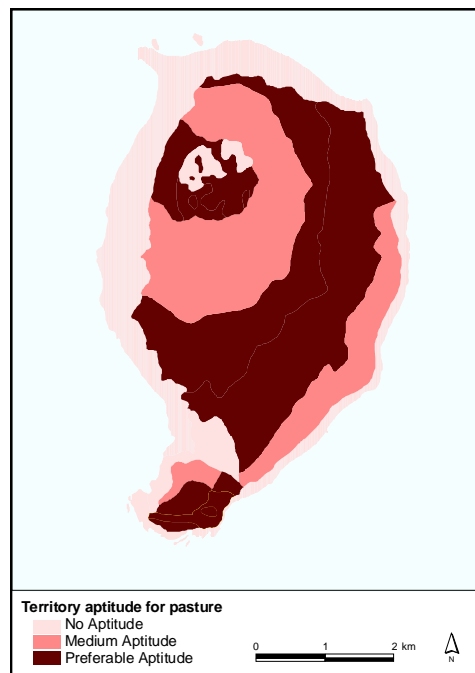


Figure 7: Attractiveness for cattle (pasture)

The slopes were reclassified also in three classes 0-7, 7-25 and $> 25\%$. Slopes higher than 25% were considered totally inapt for this activity. The aptitude for forest was achieved considering that the forest would occupy the territory where the soil and climatic conditions were too severe to any other use. So the classification of the soil use capacity classes was different from the classification of the cereals and citruses, the ones that were preferably apt are now considered as inapt and vice-versa.

Forest

The attractiveness for forest is quite similar to the attractiveness for pasture, except that forest can grow in higher slopes.

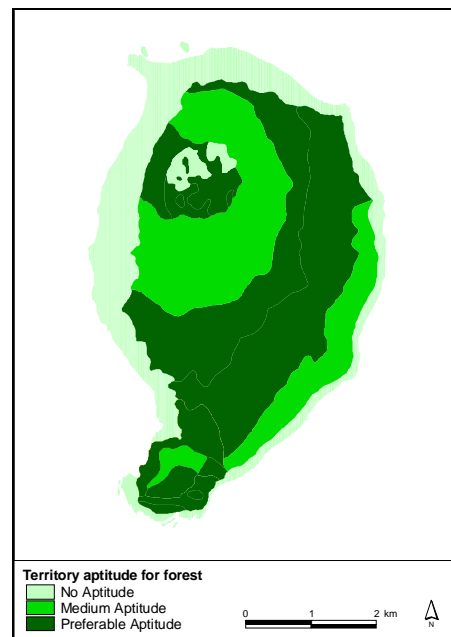


Figure 8: Attractiveness for forest.

4. Results

Using the data population from different years of the island history, the model was simulated to obtain land use patterns for each period and each zone. The second step was to distribute spatially the activities within each zone which was done using the attractiveness coefficients for each activity and considering a hierarchy relating the five sectors. It was given preference for the urban use, then to horticulture, to agriculture, to pasture and finally forest.

The first simulation was made for 1590, when there were about eighty inhabitants. According to the model in this year there was already the complete occupation of the first two zones of the territory, named A and B. The rest of the territory, the other three zones C, D and E had still 80% of the area with its natural vegetation, which means it was not being explored to support the population. The other interesting result is that pasture and urban activities are the only ones that can sustain the population of Corvo from 80 persons in 1590 to 910 in 1820.

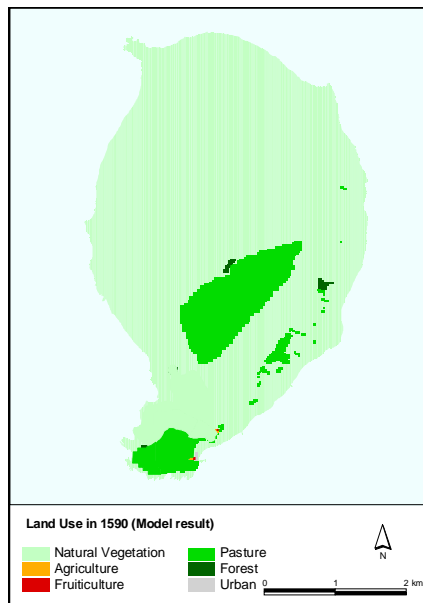


Figure 9: Estimate land use for 1590

The second simulation is made for 1820 when Corvo population achieved its historical maximum (910 inhabitants). In this scenario all the land is completely occupied by the five activities and, similarly to the other years, the most relevant sector is pasture. Actually in 1820 pasture represents ninety seven percent of the area occupied.

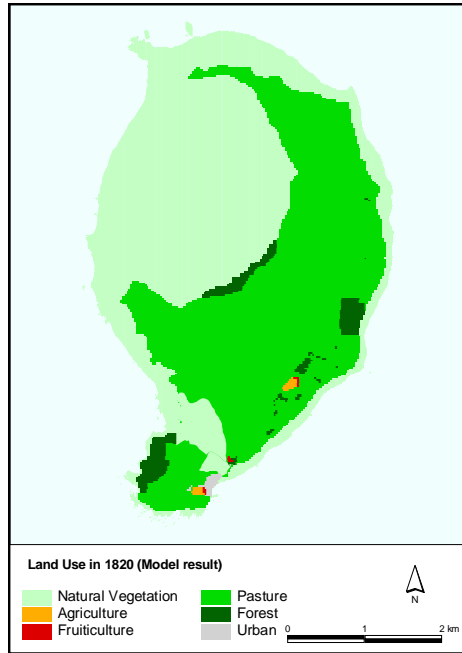


Figure 10: Estimate land use for 1820

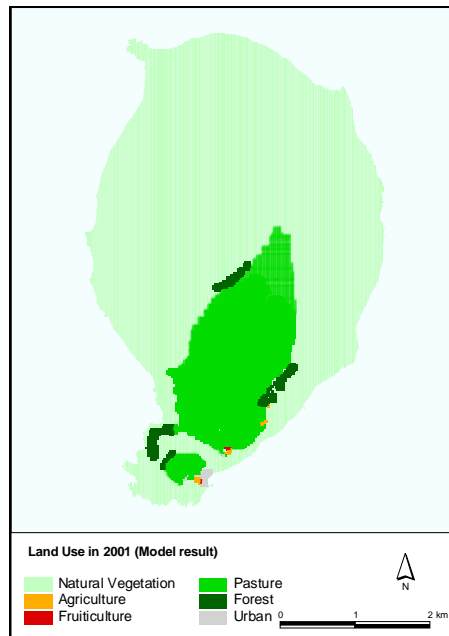


Figure 11: Estimate land use for 2001

This last simulation is supposed to illustrate the actual land use. In 2001 Corvo had 440 inhabitants but the important basic activity was no longer the exports of cattle but the public sector sponsored by external transferences.

5. Conclusion

The integration of the tools of geographical information systems with spatial interaction models has a long way to go, depending on the capacity of the computers and on the data available. In this paper we tried to show one of the uses of this capacity which is to obtain land use patterns along history based on incomplete information on population, productivities and main exports. This is just the first attempt. In following developments we will try to apply the model to other islands of the Azores that, although being bigger, they also have more historical records.

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