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Land Use Change and Socio- Economic Evaluation in São Jorge Island (Between 15th and 20th Century)

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Abstract

This paper tries to explain the historical evolution of land uses in São Jorge Island (Azores- Portugal) between 15th-20th centuries. 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 exports in order to estimate the land use for each century. Therefore, based on historical 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: Spatial Interaction Modelling, Land Use, History, GIS.

Introduction

The aim of this paper is to explain the historical evolution of land use in small islands, through the simulation of an economic and environmental spatial interaction model, calibrated to a small, insular community based on historical data about the island's population and the export sector.

We start by introducing the study area in the Portuguese Azores archipelago-São Jorge Island. Then we design a spatial interaction model with five different sectors in which employment is related to surface area. After the assessment of the attractiveness are describes for the island territory for different agricultural uses based on agronomic analysis. Then we present model simulations based on historical data on population and main export crops for the 16th till the 20th centuries. From these simulations it is possible to estimate historical land uses and identify the causes of past environmental disruptions connected with the lack of food, floods, volcanic activity or earthquakes as will be discussed in the conclusion.

Study area

S. Jorge Island (Azores Archipelago) is located at about 180 Km East of the Mid – Atlantic Ridge and presents as a volcanic ridge, 56 Km long and about 2000 meters above the surrounding sea bottom. As an elongated shape with a WNW- ESSE trend strongly reflects the tectonic control in the area of the Azores Plateau. S.Jorge Island has a longitudinal shape with no indented coastline and the highest point is Pico da Esperança at 1,053 meters (Figure 1). São Jorge has an area of 246.25 km^2 and a current population around 10500 inhabitants.

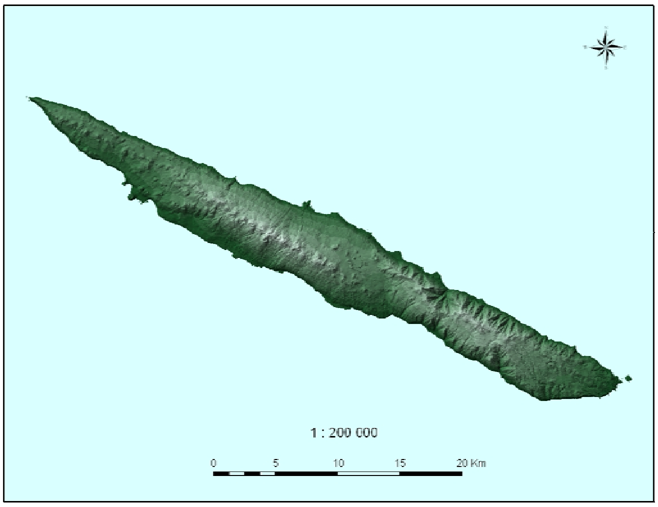

Figure 1. Shaded relief map of São Jorge Island (Azores).

São Jorge has a temperate climate all year round, practically with no significant temperature changes. The temperatures vary between 14°C and 25°C. The annual median precipitation is approximately 914 mm, with high air humidity and frequent fogs above the 500-600 meters. The sea water average temperature varies between 15°C and 23°C all over the year, under the influence of the Gulf Stream.

The first settlement of São Jorge dates from 1439 and it is known that in about 1470, there were already small groups of settlers on the western and southern coasts and the locality of Velas had already been founded. The Flemish nobleman, Wilhelm van der Haegen, came to the island and established a settlement at Topo (Cunha,1981).

The island must have been settled with people from the north of Portugal, and prosperity must have come quickly. The rule of the island was given to João Corte Real, captain of Angra on Terceira island, in 1483, but Velas received its town charter by the end of the 15th century. Topo became the seat of a municipally in 1510 and the same happened to Calheta in 1534, demonstrating the vitality of the economy (Maciel, 2001). Currently São Jorge is divided into two municipalities, Calheta in the east with five parishes and Velas in the west with six parish.

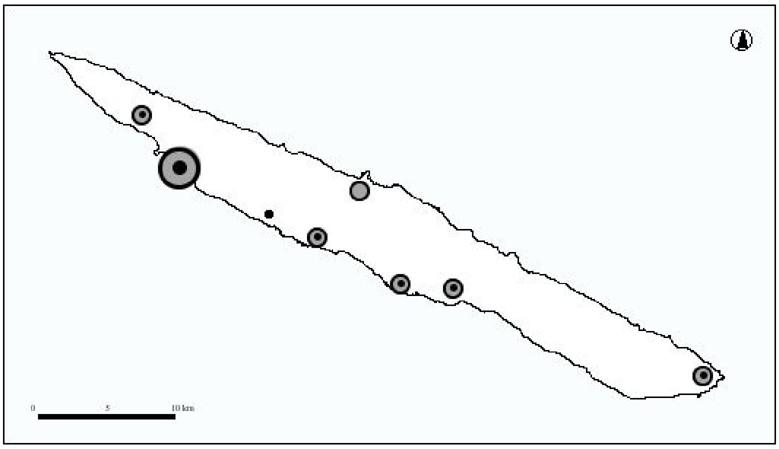

Figure 2. Population clusters in São Jorge (Azores) between 16th and 17th Centuries (adapted from Pereira, 1995).

Today, the economy of São Jorge, as the rest of the Azores, is dominated by cattle production for beef and milk, and external public support from the Portuguese Government and the European Union (Dentinho and Meneses, 1996). In the past the island exports various productions in different periods. The main exports were wood (exported to main land for naval construction), wheat, oranges (exported to England) and woad (exported to Flanders and other European countries where they were used in dyeing).

The population of São Jorge (Figure 3) evolved from 16th century to 19th century generally with a positive growth rate. In this period several natural events occurred: two eruptions have been disastrous, first in 1580 eruption and other in 1808. In both eruptions small glowing clouds were reported. The earthquakes that affected most the Island were the earthquake of 1757 and 1964. From then until today the growth rate became negative generally with a few oscillations (SREA, 2004). The only increase in the number of inhabitants were due difficulties in the emigration to the New World. From 1950, there is a strong decrease in population, explained by the emigration and by a specialization of the economy in the products of the agro livestock farming. During the 60th decade, the emigration transforms-itself in a true exodus, namely for the United States of America and Canada. The earthquake of 1964, that affected in particular Velas municipality, including movements of the population ftor Angola (Africa). In the third phase, from 1981, the population continues to diminish, although not so accentuated as previously, what can be justified by the external public support to the regional economy, including the support to reconstruction associated to the earthquake of 1980 (Serpa, 2005).

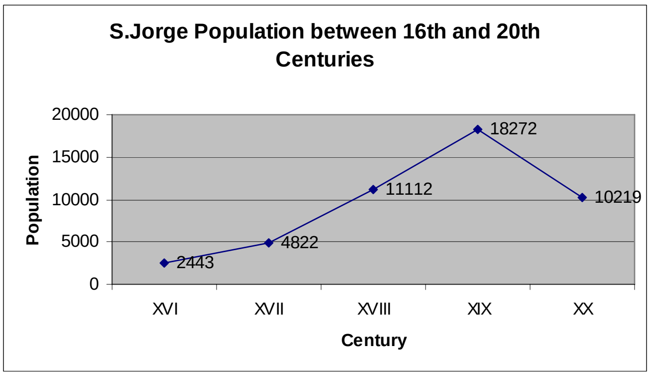

Figure 3. Population of São Jorge (Azores) from 15th to 20th centuries (source: Cunha, 1981;Pereira 1995; SREA 2004)

During these centuries, land use also varied, influenced by the main exports and by the demands of the local population. The past isolation of the island has been overcome by the works carried out in the two main ports in each municipality, and by the construction of an airport in Velas in the middle eighties.

Model definition

A spatial interaction model distributes employment and residents by different zones of the region taking into account the distances between those zones and their attractiveness (Dentinho and Meneses, 1996). In the application described in this chapter, it is assumed that residents and each type of employment generate land-use patterns based on coefficients of land use for each activity. The relationships 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.

- **Mathematical formulation**

The model is composed of the Eqs. (1)-(4). The population that lives in each zone is dependent on the employment, basic and non basic, which is established in all the other zones within a commuting range:

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

and

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

Where:

T_{ij} is the population that lives in j and depends on the activity k in zone i;

E_{ki} is the employment in sector k in zone i;

r is the inverse of the activity rate, thus the ratio of population over employment;

W_j is the residential attractiveness of j;

α is the parameter that defines the friction produced by distance for the commuters;

d_{ij} is the distance between i and j and

P_j are all the 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:

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

and

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

Where:

S_{ikj} is the activity generated in sector k in zone j that serves the population in i;

V_{kj} is the activity attractiveness of sector k in zone j;

sk is the ratio of employment of non-basic activity k over population;

β is the parameter that defines the friction produced by distance for the people that look for activity services;

d_{ij} is the distance between i and j;

Figure 4 explains how the spatial interaction model works. The term basic employment is related to the employment oriented at or supported by external markets and/or instituitions. The non-basic employment is related to the local population. In the first instance, it is possible to estimate the population of the different zones dependent on the basic activity (exports and external supports) of various zones by multiplying its amount by the proportion of those dependent on the activity of zone i living in zone j following Eq. (1). Secondly, the existing population for each zone i induces the creation of non-basic activity (services to the population) in different zones following Eq. (3). Thirdly, the non-basic activity in the various zones generates more dependent population across the region, again taking into account Eq. (1). The second and third stages are repeated iteratively until the total employment and total population derived from the model both converge to actual levels. The endogenous variables ($P_{i,}$ E_{kj}) can be obtained from the exogenous variable basic employment (Eb_{ik}) through the use of matrices [A] and [B].

$[E_{ik}] = \{I- [A] [B]\} [Eb_{ik}] ; [P_i] = \{I- [A] [B]\} [Eb_{ik}] [A]$ (5)

Where:

$[A] = [\{r.W_j \exp (- \alpha d_{ij}) / \Sigma_j[r.W_j \exp (- \alpha d_{ij})]\}]$ (6)

and

$[B] = [\{sk.V_{kj} \exp (- \beta d_{ij}) / \Sigma_j [sk.V_{kj} \exp (-\beta d_{ij})]\}]$ (7)

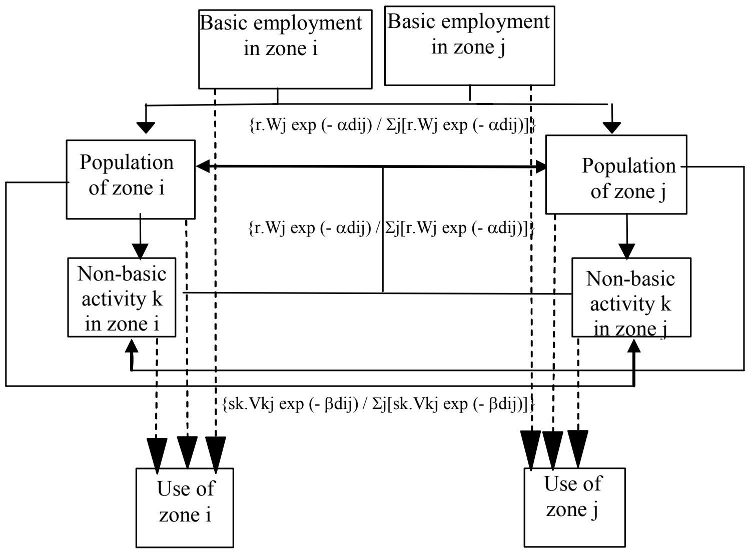

Figure 4. Spatial interaction model with land use patterns

However, there are also area constraints that must be fulfilled. The area ocupied by the different activities (basic, non-basic, and residential) in each zone should not exceed the total area of that zone Eq. (8), Furthermore, the area occupied by the different activities for each suitability class and zone should not exceed the total area of that suitability class and zone Eq. (9).

$\Sigma_k[\sigma_{ik} S_{ik}] + \rho_i P_i + \Sigma_{ik}[\sigma_{ik} Eb_{ik}] \leq A_i$ (for all zones i)(8)

$\Sigma_k[\sigma_{ik} S_{ik}] + \Sigma_{ik}[\sigma_{ik} Eb_{ik}] \leq A_{ik}$ (for all zones i and activities k) (9)

Where:

σ_{ik} is the area occupied by one employee of sector k in zone i;

ρ_i is the area occupied by one resident in zone i;

A_{ik} is the area available for sector k in zone i.

The general structure of the system can be represented, in a simple way, by a model with three interrelated blocks (as shown in Figure 4). Firstly, there are the exports and external flows of money that are considered as the basic employment or the engine of small economies (Dommen and Hein, 1985). These are assumed to set the initial dimension of the five sectors considered. Secondly, there is the internal economic system that describes the relations between the local population and the various activities (k) that fulfil the demand of that population. This is the non-basic employment and includes also five sectors: urban, horticulture, agriculture, pasture and forest production. The third block focuses the use of natural resources, here represented by the use of surface area, which is crucial to analyze the sustainability of the whole system. Actually, when some demand cannot be fulfilled by the local supply, it must be fulfilled by external production which reveals the dependence of local population on external fundamental supplies from horticulture and agriculture, cattle productions and forest services.

- **Model calibration**

Population and the exportations were the quantitative data used to calibrate the model. Using the population data for different years of the island's history, the model simulated the basic employment – for "pasture", "agriculture" and "urban" sectors – and for the non-basic activity for each of the five sectors in each zone.

The second step was to distribute spatially the activities within each zone; this was done using the attractiveness coefficients for each activity and using a hierarchy relating to the five sectors. This hierarchy was given assuming the following order of land use allocation; this assumption is consistent with the fact that: first urban use, second horticulture, third agriculture, fourth pasture and finally forest are located closest to the residences.

The estimates for the distance inertia parameters, α and β, were obtained from available data on work-residence movements on Dentinho, 1994 *in* Oliveira *et al*,1994.

The coefficients (sk) and the inverse of the activity rate (r) were derived from the official statistics of São Jorge relating to the year 2001 The general formula used is expressed as follows:

Table 1. Population, Production Areas (ha) and Exportations (kg/year) between the XVI- XX Centuries.

	Century	**XVI**	**XVII**	**XVIII**	**XIX**	**XX**
	Populations (inhabitants)	2443	4822	11112	18272	10219
ORANGE	**Production Area (ha)**	-	-	-	916	80
	Exportation (kg/year)	-	-	-	-	-
WHEAT	**Production Area (ha)**	750	1125	1133	1500	10
	Exportation (kg/year)	756701	-	-	231000	-
WOOD	**Production Area (ha)**	-	-	-	132	1159
	Exportation (kg/year)	-	-	-	-	-
MEAT	**Production Area (ha)**	-	-	-	2400	10538
	Exportation (kg/year)	264000	-	-	-	1241550

Sk = Employment in sector k / Population

Sk = ρ x(σ / τ)

Where:

σ=Employment k/Hectare; τ=Production k/Hectare ; and ρ = Consumption k / person

We assumed that all these parameters were stable throughout the centuries.

Assessment of attractiveness

The attractiveness was determined through the assessment of the environmental conditions of each zone (Figure 5) for five sectors: urban, horticulture, arable farming, pasture and forest.

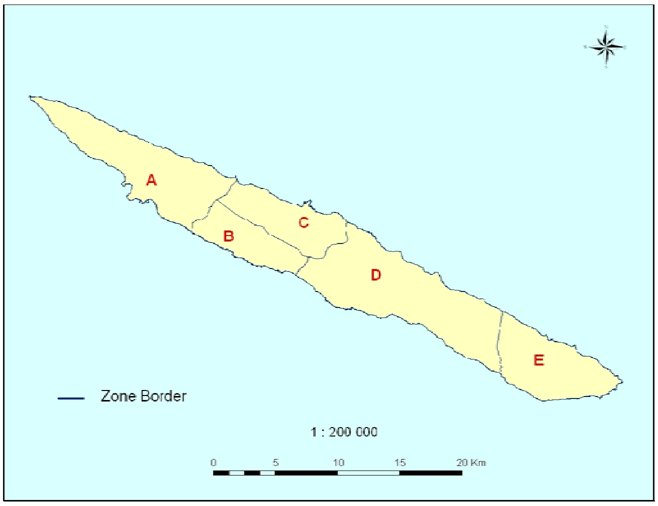

Figure 5. Zonal borders

(Zone A = Velas, Santo Amaro and Rosais; Zone B = Manadas and Urzelina; Zone C = Norte Grande; Zone D = Calheta, Ribeira Seca and Norte Pequeno; Zone E = Santo Antão and Topo and Zone F = External area)

The environmental features considered were: temperature, moistness, precipitation, slope, soil quality and exposure. The spatial climate data was obtained by the model CIELO (Azevedo, 1996).

Table 2.

		Temperature (ºC)	Precipitation (mm)	Exposure (ºC/day)	Humidity (%)	Slope (º)	Soil quality*
Urban Use	Apt	<35	-	-	<95	<25	All Class
	No Apt	<13	-	-	>95º	>25	-
Horticulture Use	Apt		>1000	-	-	< 15º	Class I-VI
	No Apt	<10	-	<2400	-	> 15º	Class VII
Arable farming Use	Apt	-	-	1200-1600	-	< 15º	Class I-IV
	No Apt	-	-	-	-	> 15º	Class V-VII
Pasture Use	Apt	-		-	-	<30º	Class I-IV
	No Apt	<12,5		-	-	>30º	Class VII
Forest Use	Apt	-	-	-	-	-	All Class
	No Apt	<12,5	-	-	-	-	-

*adapted from Soil Classes of Pinheiro *et al* (1987)

The analysis of the attractiveness for horticulture considered the culture of citruses (Gonçalves and Medeiros, 2005). The climatic conditions analyzed were temperature (accumulated temperature and medium temperature in the coldest months), precipitation (total precipitation and percentage occurring in the summer months), slope and soil quality.

To be suitable the territory must have total precipitation more than 1300 mm/year, with not less of 10% in summer moths, and the accumulated temperature can not be less the 2400ºC/day with the medium temperature in the coldest months less than 10ºC. If the slopes surpass the 15% and the class soil is VII is considered no apt.

Figure 6 shows the resulting attractiveness-map, indicating that the optimal locations are found only in South, namely in Velas, Urzelina and Calheta, in soils with smaller elevation and not displayed to the wind and to the fog. But is also suitable in all Fajãs (flat, low-lying areas leading to the sea on both sides of the island, formed by subsidence of the cliffs, with a micro climate).

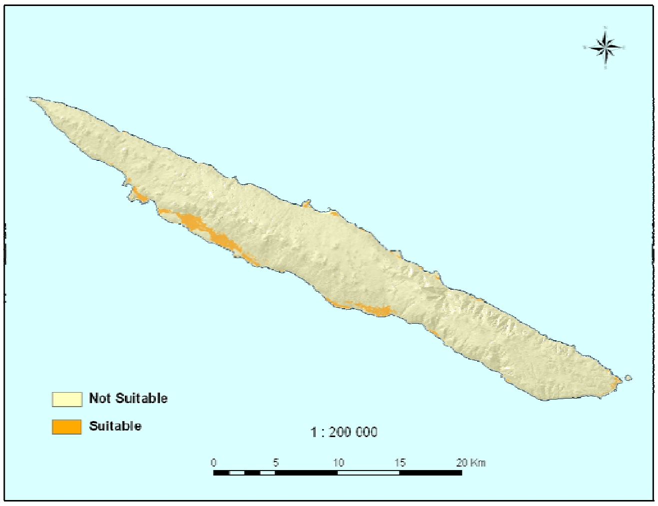

Figure 6. Attractiveness for Horticulture Use in São Jorge Island (Azores).

The attractiveness for urban use was achieved through the analysis of three parameters: slope, temperature and humidity (Gonçalves and Dentinho, 2005). Slopes greater than 25% are not suitable for construction. The annual medium humidity must be less than 95% and the annual medium temperature upper than 13ºC to consider apt to urban use.

Because the climate factors affect the comfort levels the urban use has a bigger concentration in South, and occurs in smaller elevations and close to the only access to the sea (Figure 7).

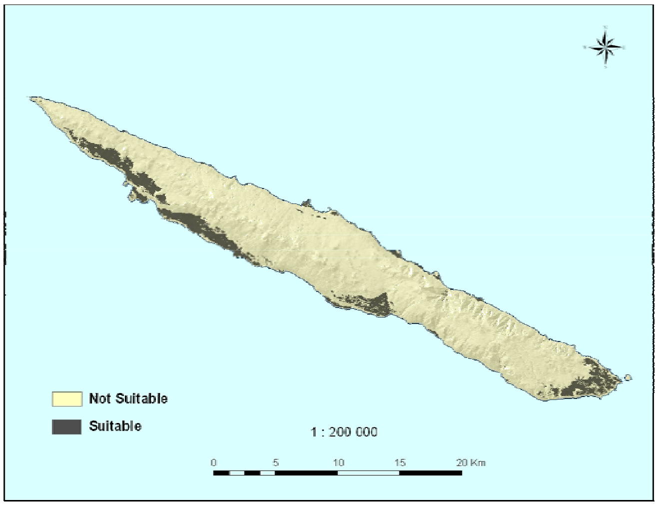

Figure 7. Attractiveness for Urban Use in São Jorge Island (Azores).

The attractiveness for arable farming was determined by assessing the territorial capacity for maize and wheat (Gonçalves and Monjardino, 2005), based on temperature, soil capacity and slope conditions. Because of the similarity between the two crops, the definition of attractiveness is the same for both. The evaluated climatic conditions related to temperature accumulation and minimum and maximum temperature limits during certain development stages. The slope considered suitable for the culture ranged only from 0 to 15%. The areas with no attractiveness do not have either a sufficient soil quality (Class V-VII), slope more than 15º or the right temperature conditions for the crops. We made this assumption to São Jorge Island because of the high precipitation levels during the whole year.

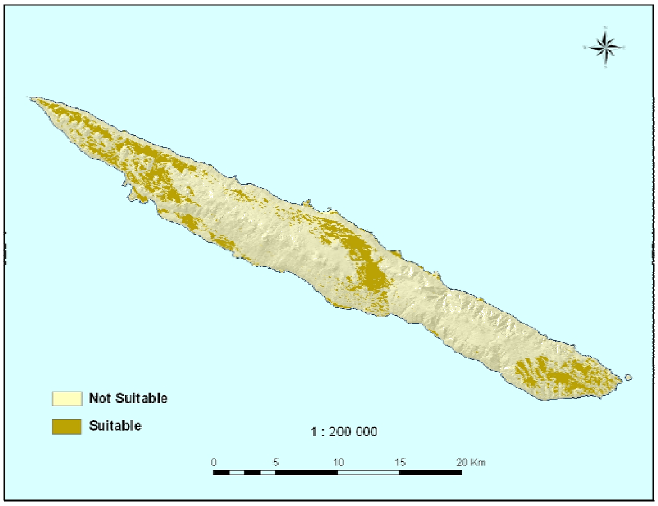

Figure 8. Attractiveness for Arable Farming in São Jorge Island (Azores).

We observe in Figure 8, the areas of good aptitude to the culture of the corn are limited because the elevated values of slope and that correspond many of the times to the localities of wheat culture. It happens because the demands of soil are identical as the values of temperature, even though the climatic demands will be distinct.

In the attractiveness for forest we only considered the annual medium temperature parameter (Figure 9). The territory where the annual medium temperature were less then 12,5 ºC were considered not suitable, what corresponds to the more elevated localities (Peaks of Arieiro, Caldeirinhasm, Carvão and Esperança, and Topo mountain rage)

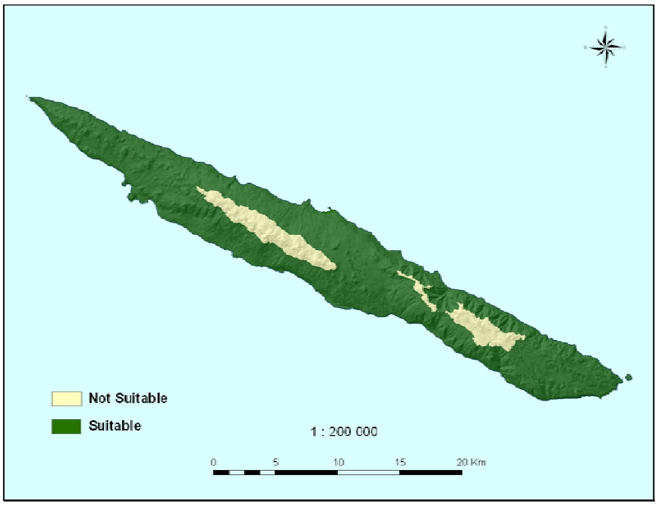

Figure 9. Attractiveness for Forest in São Jorge Island (Azores).

The territory suitable for pasture was achieved considering soil quality, temperature, precipitation and slope (Gonçalves and Calado, 2005). The annual medium temperature can not be less than 12,5ºC and the total precipitation less than 1300mm to consider apt to pasture use. Steeper slopes than 30º and soil class VII were considered totally unsuitable for this activity.

Practically all the territory is suitable to pasture, only excluded part of the western side of the Island because the slope, also the zones of bigger elevation and soil class VII are considered as not apt (Figure 10).

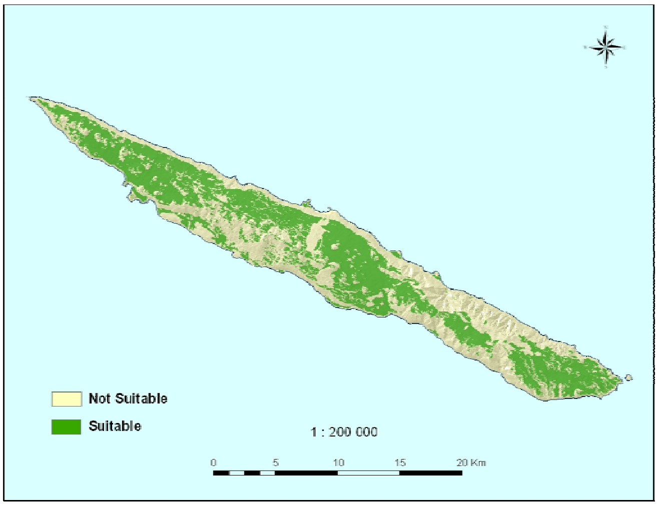

Figure 10. Attractiveness for Pasture in São Jorge Island (Azores).

Simulations

The first simulation was made for 16th Century, when there were about 2443 inhabitants (Figure 11). The population, due to climate and geographical influences sets-itself in South preferential. The exploitation of the territory was concentrated next to those population clusters. Later extend for Rosais and Beira, Topo, Calheta and Ribeira Seca (Mendonça, 1998). The exceptions in the north coast are the plains and fertile lands. (Fajãs, Toledo and Norte Grande). The area occupied by the cereals is very over the area occupied by the pasture, due to the fact the diet feed be constituted essentially by the starchy foods (Avellar,1902). The rest of the island had still 48,10% of the area with natural vegetation, which means it was not being very much explored to support the population. Unfortunately no complete records of land use exist from the time of the first settlers.

Figure 11. Simulated land use for 16th Century in São Jorge Island (Azores).

To second simulation corresponds to the 17th Century (Figure 12) shows a decline of the wheat culture although had a demography growth. That is explained by the introduction of the woad culture, what caused a lack of the cereal in this century, and possibly was fought by the increase of the livestock farming production (Mendonça, 1998). Observes an increase of the south coast exploitation, namely in Urzelina, because in this century was elevated to parish (Pereira, 1995).

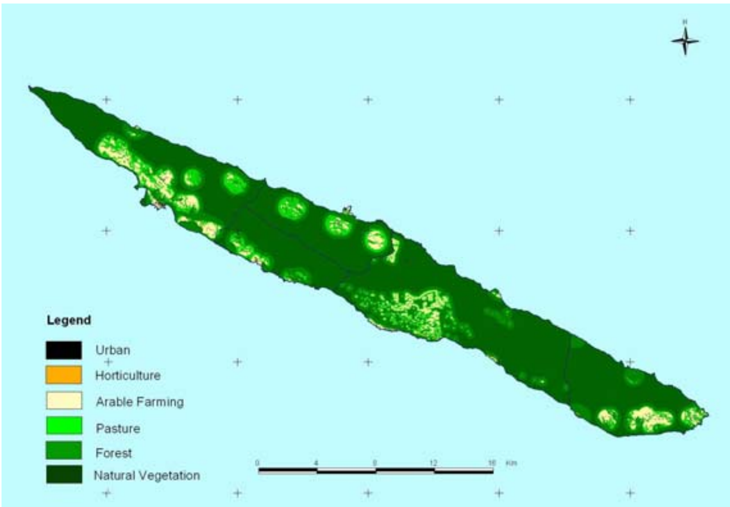

Figure 12. Simulated land use for 17th Century in São Jorge Island (Azores).

Regarding the simulation of 18th Century (Figure 13) we observe a big productive specialization in arable farming, namely with the introduction of the corn that is going to exceed the wheat culture, for the reason that offer bigger guarantees to the population (Mendonça,1998). The diminished forest area occurs because grows the wood exportation and is also occupied by pasture (Cordeyro, 1981).

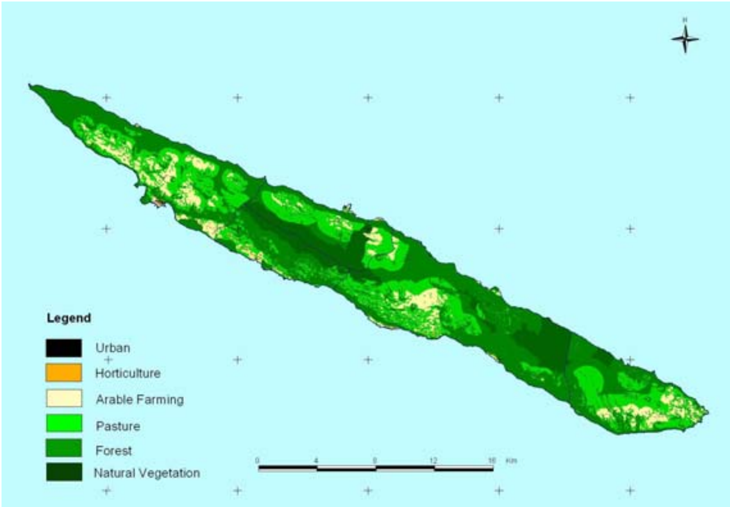

Figure 13. Simulated land use for 18th Century in São Jorge Island (Azores).

This simulation is made for 19th century, when São Jorge population achieved its historical maximum (18273 inhabitants). In this scenario (Figure 14), all the land is completely occupied by the five activities with exception for the localities without aptitude and worse access. It's possible to observe a considerable increase of cereals culture of the cereals, namely in the regions more western and oriental of the Island, possibly due the soil and climate characteristics. This production growth leads to the exportation of the wheat for the main land and of the corn for other islands (Avellar, 1902).

However what does more reflect in this simulation are the horticulture areas, namely in: Velas, Urzelina, Calheta and all Fajãs. In parallel to this culture exists a wood search because would be utilized in boxes manufacture that drove the fruit for the external market.

The introduction of installations for by-products of the milk manufacture maintains the pastures areas and increases the exportation (Matos, 1994 in Oliveira *et al.*, 1994).

Figure 14. Simulated land use for 19th Century in São Jorge Island (Azores).

The last simulation represents an estimation of the 20th century, where registered a considerable population decrease due to the emigration.

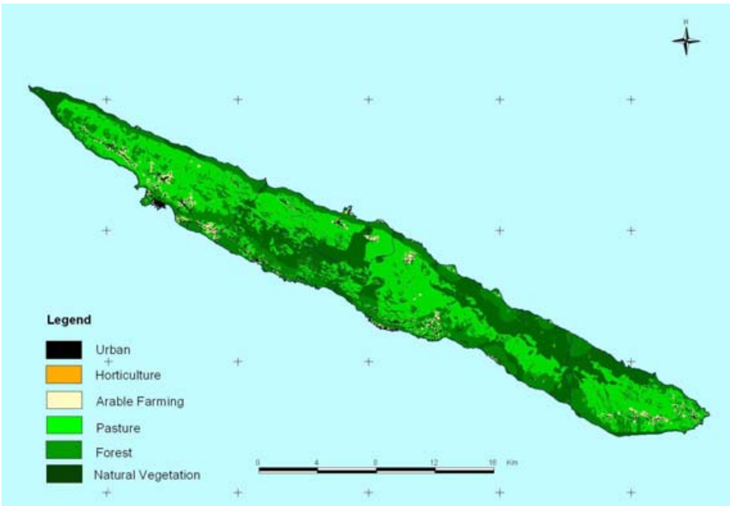

Figure 15. Simulated land use for 20th Century in São Jorge Island (Azores).

Figure 15 a big stretch of pasture use, because occurs a increase of cattle, being in this century the more value of the Island economy. These use go to occupy the areas that before produced the wheat and the corn, what leads in compensation to the increase of the importing of those cereals.

A drastic reduction occurs in the area that before was occupied by the horticulture, due to the pest that ruined a big number of farms and to the competition in the sales with others countries (Mendonça, 1998), and these regions are now are occupied by firewood.

If we will have in count the occupation of the territory estimated for the 20th Century (Figure 15) and the observed land use (Figure 16) we verify that the first does not differ substantially of the second one, despite of treat of a probabilistic model. The increase that is verified in arable farming can be attributed to a considerable improvement in accessibility and because the fact of not include the corn for silage, but only the corn grain in the model.

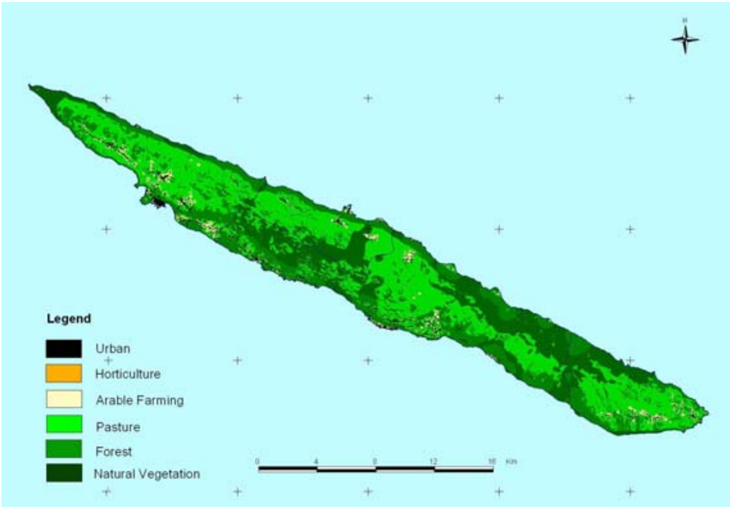

Figure 15. Observed land use in São Jorge Island (Azores).

Conclusion

This paper described the application of a spatial interaction model to simulate past land-uses based on population, employment, productivities and main exports data for São Jorge Island.

Spatial interaction models are interesting tools to analyze the relations between man and the environment. In combination with an assessment of land attractiveness this allowed for the reconstruction of historic land-use configurations.

This work also highlights the importance of agriculture, in Sao Jorge Island history, not alone as generator of sustenance for family's survival but essentially like spring of resources for industry and employment.

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