Combined disaggregation of agricultural land uses, livestock numbers and crops' production: an entropy approach

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Abstract: -This paper presents several combined agricultural data disaggregation models in order to recover the farms' land uses, the livestock numbers and main crops' productions. The proposed approach estimates incomplete information at disaggregated level through entropy, using an information prior, and generating information for a combined calculation use of data in the estimation of other variables. The models were applied to the region of Algarve, to some rural pilot areas (Salir-Ameixial-Cachopo and Alcoutim) for livestock data, since this data in some Algarve's inland areas is needed for a European forest fire prevention project, and to the agrarian zones in a more complex framework. The results are promising. They were validated, in cross reference to real data, having proven to be valid and reliable. The total error was small and a considerable level of information heterogeneity was recovered. The total error was about 27,9% for the counties' land uses and 21% for the agrarian zones, and for the livestock it was also acceptable. The level of heterogeneity recovered was always higher than 50%, revealing some improvements regarding previous studies.

Key-Words: -data disaggregation, maximum entropy, livestock, land uses, agricultural production, Algarve.

1 Introduction

At a global level, there is a lack of agricultural data at sub-national adequate levels with the desired regularity, which is a problem both worldwide [18, 20], Europe [1] and in Portugal [2], many times considered as having not an appropriate and valid solution.

To solve these problems, data disaggregation models, were developed by authors such as Chakir [1], Fragoso et al. [2], Martins et al. [13, 14, 15] Howitt and Reynaud [6 ,7], You and Wood [17, 18] You et al. [19, 20, 21, 22] or Xavier et al [23].

These models provided disaggregated data to support decision making in an inexpensive way. However, and in spite of the efforts, a combined dynamic model that could provide a sequence of disaggregated data regarding land uses, livestock and the main crops' productions was not developed. Also, in Portugal, the models proposed by Howitt and Reynaud [6, 7] weren't developed and validated in several years of the calculated sequence, considering their full framework. Validation with real data was only made with the 1999 Agricultural Census.

The model proposed is inspired in Martins et al. [14, 15] Fragoso et al. [2] Howitt and Reynaud [6, 7] and You and Wood [17,18] and it estimates agricultural land use at a disaggregated level using aggregated data and a generalized maximum entropy (GME). This data is then used to calculate the livestock in an extensive regime and to help disaggregating the crops' production statistics, considered essential for the investigation on agricultural and rural development policies [20].

This model is applied to the Algarve Region. Here several studies regarding the European project PROTECT (An Integrated European Model to Protect MEDiterranean Forests from Fire) are being carried out. In this project it is intended to develop a sustainable ecological and economical forest management model that will be tested in several forest intervention zones (FIZs) located in the Algarve's inland.

For implementing these models up-to-date data regarding the farms characteristics is needed such as land uses and livestock. Knowing the values of the livestock raised in an extensive way it's relevant since it may be used in forest fires prevention.

Therefore, since the model must have a strong empirical application, the land use disaggregation model was applied to all counties and also to agrarian zones in order to obtain validation from other years; the production calculation was applied to all counties, but the livestock estimation model was only applied to Alcoutim and a unit in the inland composed by the parishes of Cachopo, Ameixial and Salir (SAM zone), considered relevant for the PROTECT project..

This article is organized as follows: in section 2 the problem formulation is presented; section 3 presents the methodology; in section 4 the results are presented and in section 5 the data validation is made. Finally section 6 presents the main conclusions of this work.

2 Problem Formulation

The disaggregation problem being studied must consider 5 key aspects: 1) there is available data at aggregated level for **t** periods that should be considered (t, t+1…T); 2) there is disaggregated data for the first periods (1989 and 1999); 3) some co-variables or restrictions can be incorporated; 4) the livestock is raised mainly in an extensive way in some areas of the Algarve's inland and for the rest there is not a direct link between land uses and livestock; 5) The total aggregated values for the variables (land uses, livestock and production) must be respected. Therefore, the disaggregation problem can be formulated for agricultural land use as:

$$S_K^x(t) = \sum_{B_i \subset A_x} S_k^i(t) \qquad (1)$$

The aim is to obtain through the known variable $S_K^x(t)$ $S^x_k(t)$, the data for S_k^i (t), which represents the target variable **k** at disaggregated level **i**.

These disaggregated and aggregated values may also be represented as a percent value, a probability, as follows:

$$Y_k^i(t) = \frac{s_k^i(t)}{\sum_k s_k^i(t)}, \forall k, t = 1, \ldots K \qquad (2)$$

3 The methodology

3.1 The land use disaggregation model

To define the dynamic process of soil occupation for a county in a given year **t**, it must be considered that each agro-forestry activity occupation depends only on its occupation at the previous year **t-1**. As the variables levels depend only on their values for precedent years the inter-temporal existing relations can be characterized by a first degree Markov process, which allows the use of all the existing information.

Assuming a second order Markov process, the probability of passing from any state of decision $j \in \{1,...,K^r\}$ in the year t-1 to a state of decision $j' \in \{1,...,K^r\}$ in year t can be given by $y_k^i(t-1) \times y_k^i(t)$. This probabilities product can be associated to a matrix $T_{jj'}^i$ which dimension is ($K^r \times K^r$) and is the transition probabilities matrix.

The dynamic process of agro-forestry activities distribution at aggregated level is obtained based on the estimation of the transition probabilities matrix at aggregated level $T_{jj'}$, using the maximum entropy theory (ME). It is a problem of information recovering which also estimates the distribution error ($e_{j'}(t)$) [2, 6, 7, 14]:

$$\underset{T,e}{Max}\, H(T,e) = -\sum_{j=1}^{J} \sum_{j'=1}^{J} \sum_{m=1}^{M} T_{jj'm}.\log(T_{jj'm}) - \sum_{j'=1}^{J} \sum_{n=1}^{N} \sum_{t=r}^{T-1} e_{j'n}(t).\log(e_{j'n}(t)) \qquad (3)$$

Subject to:

$$Q_{j'}(t+1) = \sum_{j=1}^{J} \sum_{m=1}^{M} Q_j(t).w_m.T_{jj'm} + \sum_{n=1}^{N} y_n.e_{j'n}(t), \quad \forall j' \text{ and } t \qquad (4)$$

$$\sum_{j'=1}^{J} \sum_{m=1}^{M} w_m.T_{jj'm} = 1 \quad \forall j \qquad (5)$$

$$\sum_{m=1}^{M} T_{jj'm} = 1 \quad \text{and } Tjj' \in [0,1] \quad \forall j \text{ and } j' \qquad (6)$$

$$\sum_{n=1}^{N} e_{j'n}(t) = 1 \quad \text{and } e_{j'n} \in [0,1] \quad \forall j' \text{ and } t \tag{7}$$

This optimization problem maximizes the entropy of the probabilities distribution $\{T_{jj'1},...,T_{jj'M}\}$ $\forall$j and j' and $\{e_{j'1},...,e_{j'N}\}$ $\forall$j' and t, considering the conditions imposed by restrictions. Equation (4) defines the dynamic process of soil occupation. Equation (5) determines that the sum of the transition probabilities in any Markov state is equal to 1. Equations (6) and (7) guaranty that the variables values $\{T_{jj'1},...,T_{jj'M}\}$ and $\{e_{j'1},...,e_{j'N}\}$ are defined between 0 and 1 and that its sum is 1.

3.2 The disaggregation process

To restore the agro-forestry distributions at counties' level, the transition probabilities matrix at disaggregated level should be estimated each year, by solving a generalized cross entropy (GCE) minimization problem concerning the estimated prior at aggregated level (transition matrixes) and using the transition probabilities estimates for land use at disaggregated levels.

According to Golan et al.[4], Howitt and Reynaud [6, 7], Fragoso et al. [2], Martins et. al [14, 15] and Xavier et al. [23], the first step of this disaggregation process can be translated by the following cross entropy minimization problem:

$$\underset{T^i,e}{Min} H(T^i,e) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{j'=1}^{J} T^i_{jj'}.\log(T^i_{jj'}/\hat{T}_{jj'}) + \sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{t=r+1}^{T} e_{kn}(t).\log(e_{kn}(t)) \tag{8}$$

Subject to:

$$S_k(t+1) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t).s^i + \sum_{n=1}^{N}\zeta_n.e_{kn}(t) \forall k = 1,\ldots K \tag{9}$$

$$\sum_{j'=1}^{J} T^i_{jj'} = 1 \text{ and } T^i_{jj'}{}' \in [0,1] \quad \forall j \text{ and } j' \tag{10}$$

$$\sum_{n=1}^{N} e_{kn}(t) = 1 \quad \text{and } e_{kn}(t) \in [0,1] \quad \forall j' \text{ and } t \tag{11}$$

$$y\text{hlim}^i_k \geq \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t) \forall i \text{ and } k = 1,\ldots K \tag{12}$$

And/ or

$$y\text{hmin}^i_k \geq \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t) \forall i \text{ and } k = 1,\ldots K \tag{13}$$

And

$$y\,\text{slim}^i_k \geq \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t) \forall i \text{ and } k = 1,\ldots K \tag{14}$$

Or

$$B^i_k \geq \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t).S^i \forall i \text{ and } k = 1,\ldots K \tag{15}$$

where $\{\zeta_1,...,\zeta_N\}$ with N ≥ 2 points is the support vector associated to the probabilities $\{e_{k1},...,e_{KN}\}$.

The objective is to minimize the cross entropy of the transition probabilities distribution and the entropy of the errors probabilities distribution (8) subjected to several restrictions.

Equation (9) guarantees information compatibility between aggregated and disaggregated levels. Equations 10 and 11 ensure that $T^i_{jj'}$ and e_{kn} sum is equal to 1.

The equations (12) and (14) refer to the percent value in relation to the total area of the farm and imply that the occupation probabilities must not exceed the historical maximum limits of the probability of each occupation k in each unit i ($y\text{hlim}^i_k$) or the biophysical limits for each occupation ($y\,\text{slim}^i_k$), when the data complemented with experts' opinions does not allow the establishment of the first restriction. It is also possible to insert minimum historical limits (13).

The equation (15) reports to situations, where we have a biophysical area of a unit i (referring to a county or parish), and so that unit is larger than the farms total land use. Therefore, we do have not specific information about its distribution in the farm's area.

If there isn't available data for all units one may also choose a direct disaggregation of data regarding the referred pilot areas [14], by rewriting equation (9) in the following way:

$$y_k(t+1) = \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'} + \sum_{n=1}^{N}\zeta_n.e_{kn}(t) \;\forall k \text{ and } t \tag{16}$$

After this minimization problem, one may simply use the $\hat{T}^i_{jj'}$ to calculate $\hat{y}^i_k(t+1)$, and $\hat{S}^i_k(t+1)$:

$$\hat{y}^i_k(t+1) = \sum_{j=1}^{J}\sum_{j'\in\psi} q^i_j(t).T^i_{jj'}(t) \quad \hat{S}^i_k(t+1) = \hat{y}^i_k(t+1).s^i \tag{17}$$

3.3 The livestock's numbers estimation

The livestock are taken as a function of land uses if they are raised in an extensive way or of other explanatory variables, if the previous situation doesn't verify. Since we only intend to obtain data on livestock raised on an extensive regime, focus will be placed there.

3.4 The breeding livestock estimation

In order to calculate the breeding livestock in an extensive regime a relation between land uses and livestock must be made. To do so the conversion in Normal Heads (NH) is useful. Normal Head is a livestock measure that relates the livestock converted to normal heads in function of the species and ages, based on a legal table of conversion. As an example, a sheep over 1 year will equal 0.15 NH, while a bovine over 2 years will equal 1 NH.

We consider that the number of effective livestock intended for breeding p (in NH) in unit i, at the moment t can be calculated in the following way:

$$ENH_p^i(t) = E_p^i(t) \times INH_{\text{p}} \quad (18)$$

where INH is the conversion index from livestock p into NH (the NH equivalent).

If there is valuable data about all the previous disaggregated land uses, we may establish other coefficients in order to have a more complete relation. To do so there are several processes of areal weighting from other scientific areas such as Gallego and Peedell [3]. If it's not possible, the relation between livestock numbers in NH and agricultural and forest occupation is determined by [15]:

$$\text{R}_{\text{pk}}^{\text{i}} = (\sum_{p=1}^{P} ENH_p^i(t)) \div S_k^i \quad (19)$$

in which R is the relation between total livestock numbers p and k agricultural and forest occupation in territorial unit i.

These values can then be transferred to a period t+1 according to the following formula:

$$ENH^i(t+1) = \text{R}_{\text{pk}}^{\text{i}} \times S_k^i(\text{t}+1) \quad (20)$$

Until this point, the methodology proposed allowed us to estimate the total number of breeding livestock (NH), but it does not allow us to calculate the percentage weight of each category.

Therefore, we have to convert the data of each livestock breeding categories into NH; from a database created at aggregate level, based on the theory of maximum entropy calculate the livestock weight in t+1…T; and finally redistributing the NH. Afterwards, the number of NH can easily be converted into real number of animals' by means of the inverted use of each conversion index. So:

$$E_p^i(t+1) = ENH_p^i(t+1) / INH_p \quad (21)$$

3.5 Total livestock's numbers estimation

To estimate total livestock numbers, the data conversition in NH cannot be made due to the NH coeficients limits. If a set of explanatory variables is available it can be used and will solve this problem. If not, one may suppose, as refferred by Martins et al. [15] that the year variation rate follows the livestock intended for breeding rate (or the aggregate if that data is not liable), and so:

$$\vec{\nabla} Et_p^i = \left(\left(\frac{E_p^i(t+x)}{E_p^i}\right)^{(\frac{1}{x})} \right) - 1 \quad (22)$$

in which $\vec{\nabla} Et_p^i$ is the year variation rate of total livestock p, x the number of years.

3.6 The production data disaggregation

To convert the allocated crop areas into production, we need to consider, both the broader production systems, and the spatial variation within them [18].

In order to calculate the several different crops' productions the following formulae, proposed by You and Wood [18], may be used:

$$\overline{\text{Pr}}_{kl} = \frac{\sum_i Suit_{kl}^i . S_{kl}^i}{\sum_i S_{kl}^i} \quad (23)$$

where S_{kl}^i and Suit are the allocated crop areas and potential yields determined by biophysical conditions. Then estimate the actual crop yield of crop k in production system l and unit i (Pr_{kl}^i) as:

$$\text{Pr}^i{}_{kl} = \frac{Suit_{kl}^i . pr_{kl}}{\overline{\text{Pr}}_{kl}} \quad (24)$$

Finally the production for each crop k in unit i will be calculated:

$$\text{Prod}^{\text{i}}{}_{\text{kl}} = S_{kl}^i \times (\text{cropintens}) \times \text{Pr}^{\text{i}}{}_{\text{kl}} \quad (25)$$

If data is not available, it's recommended to use all the reference disaggregated yield of existing productivities and the biophysical determinants and, if possible, the climatic determinants. Also, areal weighting techniques may be another choice.

4. Results

The proposed model was applied to recover: 1) The main land uses and crops' area of counties using the complete restrictions dataset presented and a simultaneous disaggregation procedure; 2) A complete sequence of data using the agrarian zones in a more complex framework, with restrictions only in the first two years; 3) The disaggregation of the main crops using a direct disaggregation procedure for the SAM area; 4) The disaggregation of total livestock numbers for the two pilot areas presented before, as well as the extensive raised livestock intended for breeding; 5) the disaggregation by county of some of the existing crops' production.

A sequence of data for the years of 1993, 1995, 1997, 1999, 2003, and 2005 was obtained, for all the variants with the exception of the productions, for which the results were only presented for the years 2003 and 2005. These results are presented next.

The simultaneous land use disaggregation model was applied in the Algarve region considering 12 land uses in order to obtain disaggregated data for the several agrarian zones and counties. The results were considerable and are presented in table 1 (annex) for the year 2005.

For livestock data disaggregation was only considered in the two pilot areas (Alcoutim and the SAM zone). Here a series of the main livestock intended for breeding, namely Bovines, Sheep and Goats evolution was recovered, and a more detailed data set in proportions for the whole animals which also includes Swines, and that was converted to animals in the last two years of the sequence (as exemplified in table 2-annex).

For the crops' production, data it was only recovered for some specific crops, since the yields, provided by the Regional Direction of Agriculture, only referred to some crops (figure 1-annex presents some sample results).

5 Validation

The validation is made for year 1999 (exception for the agrarian zones) because of the lack of statistical data [2] and was based in the analysis of several deviation indicators, such as:

$$PAD_k = \left| \frac{Y_k - \hat{Y}_k}{Y_k} \right| \times 100 \qquad (26)$$

$$\text{WPAD}_k^i = y_k^i \left| \frac{y_k^i - \hat{y}_k^i}{y_k^i} \right| \quad \text{and} \quad \text{WPAD}^i = \sum_{k=1}^{K} \text{WPAD}_k^i \qquad (27)$$

and, at the aggregated level:

$$\text{WPAD} = \sum_{i=1}^{I} \frac{S^i}{S}.\text{WPAD}^i \qquad (28)$$

The data regarding the simultaneous disaggregation procedures revealed a total error of 27,9% for the counties in 1999.

For the agrarian zones, the results were a little better since the WPAD was of 20,9% in 1999. However, it was of 38% in 2003 and 29,3% in 2005.

These more relevant errors may be caused by the impact of forest fires in territorial occupation.

For the SAM zone the error was about 30% for the main land uses.

The total livestock percentage estimation process revealed a WPAD^i of 23,7% for Alcoutim and 21% for the SAM zone. On the other hand the WPAD^i for the historical breeding livestock recovery was of 33% for Alcoutim and 28% for the SAM zone.

To measure the information gains of these procedures the Disaggregation Informational Gain (DIG) was used [6,7]. DIG is based in the cross entropy between the observed values for land use at aggregated level y_k and at disaggregated level y_k^i and in the cross entropy between the land uses estimated by the disaggregation process $\hat{y}_k^i$ and the observed at disaggregated level y_k^i.

The level of recovered information was very satisfactory over passing the levels obtained by Fragoso et al. [2] for the Alentejo area. About 67% of the information heterogeneity was recovered in the land use disaggregation model in 1999. Also, for the land uses, in the agrarian zones, the following DIGs were obtained: 55% in 1999, 52% in 2003 and 56% in 2005.

6 Conclusion

The models were able to recover all the necessary information and to give a good contribute for the availability of data in the Algarve Region area. This data may be useful for better understanding the tendencies and solving rural development problems..

However, these models may still be improved and namely for the production disaggregation processes a more complex framework may be developed. The rapid changes that take place, such as forest fires, and don't allow the models adaptation [6, 7] are still an aspect that is only solved with the inclusion of prior information.

Also, if the recollection of several explanatory variables of the livestock number (e.g. meat produced by territorial unit, quantity of feeding stuffs sold) could be done it may be applied to all the existing livestock.

Therefore, we intend in the future to optimize this model and solve this and other facts that may be points of improvement.

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Table 1-The land uses probabilities in 2005 for the Algarve's counties

	ALBUFEIRA	ALCOUTIM	ALJEZUR	C. ARIM	FARO	LAGOA	LAGOS	LOULE	MONCHIQUE	OLHAO	PORTIMAO	S B ALPORTEL	SILVES	TAVIRA	VILA DO BISPO	VRSA
CC	0,006	0,011	0,014	0,021	0,002	0,003	0,022	0,007	0,001	0,002	0,006	0,007	0,01	0,025	0,034	0,018
OCT	0,078	0,038	0,121	0,082	0,193	0,076	0,212	0,059	0,067	0,164	0,105	0,046	0,033	0,066	0,078	0,162
PO	0,191	0,173	0,274	0,18	0,075	0,096	0,187	0,056	0,009	0,083	0,066	0,054	0,122	0,112	0,246	0,318
CT	0,134	0,00	0,001	0,015	0,264	0,152	0,028	0,051	0,021	0,26	0,072	0,018	0,197	0,065	0	0,077
OFF	0,025	0,00	2,32E+02	0,007	0,006	0,024	0,01	0,005	0,001	0,012	0,034	0,004	0,004	0,008	0,00E+00	0,012
OL	0,079	0,006	0	0,027	0,074	0,061	0,01	0,068	0,007	0,061	0,067	0,072	0,03	0,04	0	0,019
AM	0,121	0,042	0	0,089	0,058	0,121	0,033	0,044	6,34E+02	0,08	0,055	0,02	0,016	0,043	0,001	0,016
OCP	0,256	0,005	0,023	0,071	0,177	0,213	0,034	0,134	0,004	0,171	0,149	0,076	0,058	0,075	0,003	0,113
PP	0,005	0,176	0,152	0,127	0,011	0,009	0,135	0,03	0,019	0,002	0,124	0	0,084	0,007	0,431	0,119
MF	0,014	0,254	0,277	0,043	0,062	0,101	0,244	0,352	0,736	0,093	0,226	0,531	0,218	0,154	0,106	0,009
SNT	0,073	0,146	0,103	0,201	0,095	0,089	0,069	0,11	0,05	0,075	0,061	0,091	0,127	0,23	0,079	0,124
OO	0,019	0,004	0,03	0,011	0,027	0,024	0,018	0,013	0,016	0,018	0,017	0,02	0,012	0,017	0,048	0,009

(source: model results)

CC-cereals; OCT- other temporary crops; PO-Fallows; CT-citrines; OFF- other fresh fruits; OL-olive trees; AM-almond trees; OCP-Other permanent crops; PP-permanent pastures; MF –Shrubs and forest without crops; SNT-non used agricultural area; OO- other occupations

Figure 2- The percentages/probabilities and total number of livestock-Alcoutim

Anim/years	t1993	t1995	t1997	t1999	t2003		t2005	
BO	0,018	0,02	0,017	0,017	0,019	381	0,02	293
OV	0,651	0,659	0,655	0,671	0,681	13639	0,683	10017
CAP	0,257	0,254	0,251	0,228	0,228	4566	0,229	3358
SU	0,074	0,067	0,077	0,084	0,072	1442	0,068	997

(source: model results)

County	prod. (ton)
ALBUFEIRA	163
ALCOUTIM	58
ALJEZUR	0
CASTRO MARIM	142
FARO	154
LAGOA	50
LAGOS	22
LOULE	751
MONCHIQUE	30
OLHAO	105
PORTIMAO	139
S B ALPORTEL	123
SILVES	327
TAVIRA	439
VILA DO BISPO	0
VRSA	16

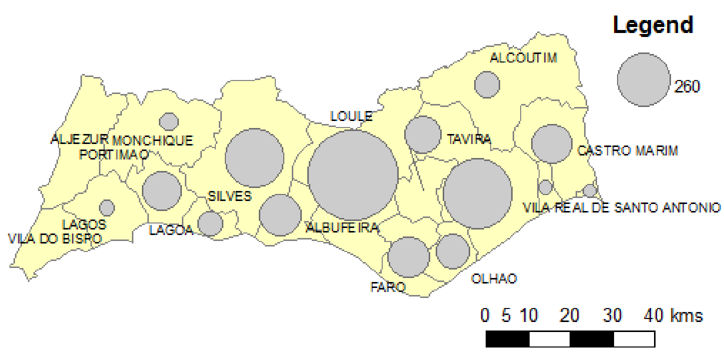

Figure 1- The disaggregated olive production by county
(source: model results)