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# Mathematical Model of Reproductive Behaviour of Mediterranean Bushes: *Cistus albidus L* Case

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**Abstract** The bushes constitute a basic species of the ground Mediterranean ecosystems. Their role in the contribution of organic matter on the soil and prevention of erosion is well known. MARIOLA model was developed to study the behaviour of Mediterranean shrubs species from a predictable climatic change. This paper presents a model, inside the context of the MARIOLA, which deals with the reproductive phenomena of the phanerogam plants germination, flowering, fructification and dispersion of seeds. In this paper, it has presented a population submodel for the *Cistus albidus L* of the above mentioned process and its validation.

***Keywords:*** *ecological model, flow equations, Mediterranean ecosystem, reproductive model, state equations*

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## 1. Introduction

Erosion and the process of turning the land into a desert as one of its obvious consequences, is one of the main environmental problems of Mediterranean countries. Vast areas of primitive forest have become areas of shrublands, considered the final phase of the degradation process, mostly caused by anthropic action. However, the Mediterranean shrub lands play an important role in protecting the soil from the hydride erosion processes, especially in orographic areas characterized by their steep slopes, greatly harmed by irregular precipitation that quite often are local and very intense. Being able to predict the behaviour of shrub ecosystem caused by climatic variations has become a powerful weapon in adopting policies of territorial organization and planning.

The behaviour of *Cistus albidus L*, in first instance *Thymus vulgaris* and *Rosmarinus officinalis* subsequently was studied [19]. Interactions between Mediterranean shrubs in the context of MARIOLA model was exactly studied in Mateu, Usó and Montes [11].

The authors consider the basic procedures of reproductive biology as they were defined by Font Quer [4] and Strasburger et al. [14].

**Germination** is defined as the development of the germ for the production of a branch, leaf or flower.

**Flowering** is the development of the flowers, from the very moment of the anthesis of most precocious to the withering of the latest ones.

**Fruiting** is the transformation of a flower into a fruit.

The dispersion of the seeds is accomplished by several causes being the ones generally by wind, animals (birds, insects) and fall by gravity and the water.

In this paper a simple model is presented and a more evolved version of model should include the biomasses behaviour and decomposition process in the soil. It is a deductive model but not necessarily lineal nor invariable in time. The input-output flows of every level are calculated by non-lineal regression methods. Besides it is considered the action produced by the animals in the flowers and fruit destruction, and seed pollination and dispersion. It is considered as measurement unit the week and as exogenous variables the temperature, environmental moisture, wind speed and the precipitation intensity.

The MARIOLA model [11,18,20,21,22,23,24], so called for having taken as the base the mountainous terrestrial ecosystem of the Sierra de Mariola (Alicante, Spain), is a dynamic model based on the Dynamic of Systems [5], in which differential equations (state equations) are set up hypothetically, and flow variables are obtained from field observations using multiple regression equations [19,20,24]. The development of the MARIOLA model can predict the effect that the climatic changes of several variables produce on others.

## 2. Reproductive Population Model of *cistus albidus L*

The flower submodel has as goal to know the development of the buds, flowers, fruits and production and dispersion of seeds of the *Cistus albidus L* after an alteration of the environment conditions. It has been developed from the fact that *Cistus albidus L* has an easy counting and detecting flower-bud, ground flowers and moreover the ground fallen flowers are as well easy to detect. Reproductive phenomena depend on the characteristics of the climate where the vegetal specie is located and certain peadological phenomena, specially the amount of nitrogen and magnesium. Even though these elements are conceptually considered in this model, it is not possible to dispose the numerical values of these variables. If has been adopted as a novel criterion the influence of the variable NHS (sun hours average) since the authors suppose that reproductive processes respond a own genetic program of every specie, being the sun hours average what is used as indicator to the specie just both to indicate or end the process. It has been observed that there is an out of phase in the flowering from one to two weeks depending if the plant is on shade or in sunny place, but generally, in a temporal rank, the dependence of the number of hours of sun is held, so that the hypothesis is held too.

## 2.1. Ecological Characteristics

The *Cistus* species are native to the Mediterranean basin. These deep-rooted, evergreen shrubs occur widely as components of the Mediterranean *macchia* (maquis) and garrigue plant association [3,6,7,8,9,25]. In according to Arianoutsou-Farag-Gitaki and Margaris [1], the *Cistus* species fill about 13% of the burned areas in their colonization time. Despite the interest in *Cistus* for erosion control and fire hazard reduction, little attention has been given to the ecology and ultimate fate of these plants. Given enough time, fire would eliminate plantings of *Cistus* or any other shrubs unless the species possesses adaptations to enable it to survive and recover after burning. Stands of *Cistus* destroyed by fire in the Mediterranean Basin regenerate very rapidly, and the species are well adapted to frequent burning [8]. They regenerate after fire by new growth from dormant buds in the root crown of the burned plants as well as from seed [13]. It has also been shown that *Cistus* seed germination increases after fire. *Cistus* species are classified as active pyrophites and are often encountered as pure stands in areas where frequency of fire is particularly high [12].

*Cistus albidus L* is a dense shrub with opposite white-felted fleshy, leaves with 3 parallel prominent veins on the underside. The petals are pink to red (sometimes white) and 2-3cm long. The leaves have traditionally been used as an abrasive to clean cooking pots. Rockroses are often parasitized by *Cytinus*. *Cistus albidus L.* is placed abundantly along all the Valencia Region (Spain). The biological type corresponds to a Nanophaneriphita with mean size in between 40-120 cm. Its flowering period in mainly from April to June, although it could be appear a first flowering in March and the lates one at the end of July [2,10,15,16]

## 2.2. The Study Area

To carry out the experimentation and validation we had to choose two different zones with similar characteristics, which are considered to be representative of bush ecosystems in the Mediterranean mountain zone. The parameterization plot is located in the proximity of the village of Agres, in the Serra de Mariola (Province of Alicante, Spain) UTM = 30SYH19, height 850 m, with the following climatic characteristics based on 16 years of observation, mean annual temperature 14.1 ºC, temperature of the coldest month (January) 6.5 ºC, temperature of the warmest month (August) 23.1 ºC, pluviometer annual mean 600 mm, mean of potential evapotranspiration 757 mm. The geological substratum is of the cretaceous limestone, over which calcareous platforms are situated of the regololithic type with a reforestation of *Pinus halepensis.*

The Serra de Mariola is located within the community of Valencia, north of Alicante and south of Valencia, last Betic reliefs. It includes the municipalities of Banyeres de Mariola, Bocairent, Alfafara, Agres, Muro del Comtat, Cocentaina, Alcoi, Onil and Biar. The mountain is one of the last foothills of the Baetic Mountains (Gualda-Gomez, 1988). It has a quadrangular form and an alignment from southwest to northeast. The predominant material is limestone, although the intense tectonic activity has caused the existence of very varied landscapes. The maximum height of the mountain is the Montcabrer, with 1390 m, the third in the province of Alicante. Besides this, there are numerous mountains over a thousand meters, as the Alto de Mariola (1.158 m), el Contador (1,232 m) and El Portín (1,081 m). This mountain has a Mediterranean climate with a slight continental shade due to the relative existing medium altitude. It has cold winters where temperatures can drop to -15°C in the highest areas (1000 meters or more). Summers are hot, with temperatures that can exceed 35 and even 40. Rainfall varies between 350 mm and 900 mm per year respectively (very irregular). This mountain is remarkably rich in vegetable varieties. Among them is the presence of yew. In microreserve of Teixeira d'Agres we can see the forest of Europe's southernmost yew, but is currently not as abundant as in the past. Most of the mountain is covered by a forest formation where the pine is predominant along with various shrubs such as gorse, rosemary and rockrose. However, it is also possible to find Mediterranean mixed forest, where species such as oak intermingle with much less common deciduous trees in Valencia such as ash, maple or gall as tree species and the presence of butcher's broom and honeysuckle shrubs. But undoubtedly the true wealth of the mountain is located in the floristic diversity. They have come to identify 1,200 species, many of them endemic to Valencia or saw it. Among them they could note Mariola sage, cat's tail, the edge chamomile, piperela, lavender, santonica, hypericum tea or rock. Due to the variety of environments the mountains has a rich fauna. Among the reptiles are highlighting the Iberian lizard or ashen lizard, the eyed lizard, snake or a viper vipers. Among the birds can be found Granivorous as partridge, or Serin Finch; insectivorous as the robin, tit or woodpecker or prey such as the golden eagle, goshawk, sparrow hawks, kestrels, owls, long-eared owl, the tawny owl, the griffon vulture and the red kite. Mammals are also abundant highlighting the rabbit, marten, weasel, genet, badger, fox and wild boar. It also highlights some insects like water fleas and mosquitoes.

The validation zone corresponds to the Font Roja Natural Park, in Alcoi, situated in the Serra del Menejador (Province of Alicante, Spain), UTM = 30 SYH 18, height 800 m. The climate characteristics obtained from 18n years of observations are the following: mean annual temperature 14.7°C, mean temperature of the coldest month (January) 7.6°C, mean temperature of the warmest month (August) 27.8°C, pluviometer annual mean 449 mm, mean of potential evapotranspiration 771 mm. Geologically the material of the sub-soil are marls of the Keuper type, over which calcareous platforms of the regolithic type are situated with an artificial repopulation of *Pinus halepensis* mixed with fragments of potential *Quercus rotundifolia* forest.

10 shrubs differing in size, shape and structure were selected as representative of Mediterranean ecosystem: Bupleurum frucicescens L., Ulex parviflorus Pourret, Helychrysum stoechas (L.) Moench, Rosmarinus officinalis L., Lavandula latifolia Miller, Sedum sediforme (Jacq.) Pau, Genista scorpius (L.) DC, in Lam.&DC, Marrubium vulgaris L., Thymus vulgaris L, and Cistus albidus L.

They are common plants [2,10,15,16,17] which play an important role in the shrub communities of the Western Mediterranean region, especially during the first ten years after a forest fire.

The experimental and validations zones were of 100 square meters.

### 2.3. Model Characteristics

Besides it is considered the action produced by the animals in the flowers and fruit destruction, and seed pollination and dispersion. It is considered as measurement unit the week and as exogenous variables the temperature, environmental moisture, wind speed and the precipitation intensity. The reproductive phenomena depend on climate characteristics where the vegetable species are located. It will also depend on the determinate edaphological factors as nitrogen and magnesium which can be very important.

The variables are the following:

**EXOGENOUS VARIABLES**

H = moisture (%)
T = temperature (ºC)
Plu = precipitation (l)
NHS = sun hour average (hour/day)
VEVI = win speed (km/h)

**AUXILIAR VARIABLES**

BT = total biomass of plant

**STATE VARIABLES**

NGEM = number of flower buds
NFLOR = number of flowers
NFRUT = fruit number

**FLOW VARIABLES**

CRGEM = growth of the flower buds
DGEM = destruction of the flower buds
CRFLOR = flower growth
DFLOR = flower destruction
CRFRUT = fruit growth
DFRUT = fruit destruction
FRUTGERM = fruits germination.

**STATE EQUATIONS**

$$\frac{dNGEM}{dt} = CRGEM - DGEM - CRFLOR$$

$$\frac{dNFLOR}{dT} = CRFLOR - DFLOR - CRFRUT$$

$$\frac{dNFRUT}{dT} = CRFRUT - DFRUT + FRUTGER$$

**FLOW EQUATIONS**

The formula of flow equations are deduced from experimental data by means of multiple regressions of variables (SELEGO program). The test of normality have been also been carried out on all distribution of data, all of them resulting significant to 95%.

$$DFRUT = f\left(H, T, PLU/100, VEVI, NFRUT\right)$$

$$CRFLOR = f\left(H, T, PLU/100, NHS, NGEM\right)$$

$$CRGEM = f\left(H, PLU/100, BT\right)$$

$$DGEM = f\left(H, T, PLU/100, NGEM, VEVI\right)$$

$$DFLOR = f\left(H, T, PLU/100, VEVI, NFLOR\right)$$

$$GERM = f\left(H, T, PLU/100, NFRUT, NHS\right)$$

$$CRFRUT = f\left(H, T, PLU/100, NHS, NFLOR\right)$$

The formulas developed are as follows

$$CRGEM = 11937827736.633297\left(\frac{PLU}{100}\right)^2$$

$$+8887432236.478121\left(\frac{1}{H}\right)$$

$$+25968866013.697624\cos\left(\frac{PLU}{100}\right)$$

$$+8888766569.492008\arctan H - 39931297044$$

$r = 0.814130$

$$DGEM = 12800952588.667847\left(\frac{PLU}{100}\right)^2$$

$$+9529999838.423653\left(\frac{1}{H}\right)$$

$$+27846458313.539825\cos\left(\frac{PLU}{100}\right) - 40.429810\cos VEVI$$

$$+9531439387.324566\arctan\left(\frac{PLU}{100}\right)^2$$

$$+42818396553.492188$$

$r = 0.790951$

$$DFLOR = -2885250093.034542\left(\frac{PLU}{100}\right)^2$$

$$-2148000863.935655\left(\frac{1}{H}\right)$$

$$-6276407624.418370\cos\left(\frac{PLU}{100}\right)^2$$

$$-2148323388.535451\arctan H + 2.059450\sqrt{NFLOR}$$

$$+9650983489.331842$$

$r = 0.923803$

$$GERM = -0.013337(T \cdot NHS)$$

$$+21436656856828.5\left(NFRUT \cdot NHS\right)$$

$$-0.144616\left(NHS\right)^2 - 300113195995598.25 NFRUT$$

$$-2086637.\arctan NFRUT + 45.449667$$

$r = 0.999325$

$$CRFRUT = -18244600898.0214\left(\frac{PLU}{100}\right)^2$$

$$-13582666169.55335\left(\frac{1}{H}\right) - 33.930457 e^{(-0.1 nFLOR)}$$

$$-39688258767.668732\cos\left(\frac{PLU}{100}\right)$$

$$-13584716165.781677\arctan H + 61027064334.445496$$

$r = 0.993230$

$$DFRUT = 0.005002(T \cdot NFRUT)$$
$$+0.017530\left(\frac{PLU}{100} \cdot NFRUT\right)$$
$$-0.016123(VEVI.NFRUT) - 0.000238(NFRUT)^2$$
$$+1.421540e^{(-0.1NFRUT)} - 1.413185$$
$$r = 0.981457$$
$$CRFLOR = 24538061248.274929PLU^2$$
$$+18268010624.317451\left(\frac{1}{H}\right)$$
$$+53378691559.585045\cos PLU$$
$$+18270752691.694279\arctan H - 82078300505.120819$$
$$r = 0.991609.$$

### 2.4. Validation

The model has been parameterized using field data from Agres in experimental zone and was validated with data from Agres and la Font Roja. Comparing the field values taken in a sample of 30 *Cistus albidus* plants from Agres and 30 samples from la Font Roja between March 2013 and September 2013, with the corresponding values simulated in the model, we see that in no case is the difference greater than 10%.

### 2.5. Simulation

Different simulations have been realized under normal climatological conditions for a mountainous Mediterranean ecosystem. Little variations in experimental data lead to similar results that validation. In MARIOLA model, we assume extreme conditions corresponding to climates changes evolving to blighting:

a) High atmospheric temperature.
b) Low environmental humidity.
c) Low precipitation.
d) Moderate wind speed.

We can observe the following:

1) Plants with a woody biomass smaller than 85 g of dry weight perish between the first and the third month.

2) Plants with woody biomass greater than 85 g of dry weight decrease the woody biomass over first months, then grow following an exponential pattern until the come up with greater values than the initial values.

3) Under the same extreme conditions we can observe that buds, flowers and fruits does not exist.

It confirms the expectations of MARIOLA first versions. This model can open perspectives of research upon effects of desertification in the Mediterranean conditions. The populational reproductive submodel confirms this presumption.

## 3. Conclusions

MARIOLA model, being has been operating since 1995, and modeling different shrubs in many places along the Valencian Community. This model, with all its limitations, has replied to the expectations put on it. It has allowed us to calculate with enough credibility a series of variables determining the development and behaviour of bushes in the Mediterranean ecosystems. It not only allows us to follow the mentioned development in the ecosystem level but it can also be used for the pursuit of one sample.

1) BIOSHRUB (Usó-Doménech, Nescolarde-Selva, Lloret-Climent and González-Franco, 2016) program can be considered a closed program. BIOMASS files (Usó-Doménech, Nescolarde-Selva, Lloret-Climent and González-Franco, 2016) can be extraordinary enlarged while experimental work increases the information of the taxons. However, parameter b needs a more adequate interpretation of its meaning from a vegetable edaphophysiological point of view. It is possible that the step (now of 0.1) has to be enlarged to 0.01 to be able to reduce the mistake margins of the biological interpretation of such a parameter.

2) Mathematically, all flow equations (SELEGO program (Usó-Doménech, Nescolarde-Selva, Lloret-Climent and González-Franco, 2016)) are a combination of transformed functions of variables by multiple regressions. They are the input and outputs of ordinary differential equations (and partial derivatives differential equations also). It is not a normal way of building a model. Stability and semantic problems are opened (Usó-Doménech, Nescolarde-Selva and Lloret-Climent, 2015). The differential equations are integrated with a “noise” and uncertainty that derives from the same nature of the data of the real and of the real methods for building the flow equations.

3) MARIOLA model is flexible. Its structure allows the addition of new goals and relationships. Its enlargement depend on the aggregation level desired, which is at the same time a function of the objectives of the model itself.

MARIOLA can open perspectives of research upon the effects of erosion and desertification in the Mediterranean ecosystems.

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