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Modelling of the Total Number of Monthly Mosquito Outbreaks (Diptera: Culicidae) Using the Objective Regressive Regression Methodology in Villa Clara, Cuba

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ABSTRACT

The objective of the study was to determine the possible incidence of the ROR methodology in the modelling of the total number of monthly mosquito outbreaks in Villa Clara province, Cuba. The research covered the 13 municipalities of the province, as well as the number of outbreaks reported in the different months of the period analyzed (2010-2020). A descriptive, ecological, retrospective and statistical study was carried out, for which all the information on the work cycles established for surveillance and vector control was collected. The data were organized in the Windows Excel application, by years and months. The forecast of the outbreaks was modelled employing the Objective Regressive Regression Methodology (ROR), with the use of dichotomous variables DS, DI, and NoC. Forty-five mosquito species distributed in 13 genera were identified, with the best represented and distributed species being Anopheles albimanus, Aedes aegypti, Ae. albopictus, Ae. scapularis, Culex quinquefasciatus, Cx. nigripalpus and Psorophora confines. The summary of the ROR model for the total monthly foci in Villa Clara explained 91% of the variance, with a low error for the focal point, where the analysis of variance corroborated that the model was valid and significant at 100%. The model parameters, SD, DI, and trend were significant, with a tendency to increase the number of foci per month. We conclude that it is possible to model mosquito outbreaks in a given geographical area, however large it may be, and even to predict the behaviour of the outbreaks in the short, medium, and long term.

Keywords: Foci, Methodology, Modeling, Mosquitoes, Objective Regressive Regression, Villa Clara

INTRODUCTION

Since the dawn of civilization infectious diseases have affected humans [1-3]. The early history of infectious diseases has been characterized by sudden and unpredictable outbreaks, often of epidemic proportions [3,4].

Emerging and re-emerging infectious diseases are one of the health problems that have aroused the most interest in different countries around the world in recent years, as many of them are considered national catastrophes, due to the high morbidity they generate, a large number of lives they cost and the cost they represent from the economic point of view for the country [1,3,5]. They cease to be health problems to become economic problems, due to their impact on tourism, industry, and product exports, in addition to the resources that the health sector must contribute to control the disease [2,3,6].

Millions of people suffer from infections transmitted by arthropod vectors; among them, culicines are undoubtedly the most important hygienic-sanitary ones, because they constitute one of the priority health problems in almost all tropical and subtropical regions [7-9] and are responsible for the maintenance and transmission of pathogens that cause Dengue, Yellow Fever, West Nile Fever, Chikungunya, Zika, Malaria, Lymphatic Filariasis, among other deadly and debilitating infections [10-12].

In Latin America, Yellow Fever remains a persistent threat [13]. Between 1980 and 2012, 150 outbreaks of this entity have been reported in 26 African countries, with more than 200 000 cases occurring globally [14,15]. From December to February 2017, an outbreak of Yellow Fever affected Brazil, with 1345 suspected cases, 295 confirmed cases, and 215 deaths [16].

Dengue has spread in recent decades and continues to be the main arbovirosis and emerged, with Chikungunya and Zika in recent years. Malaria remains the leading health problem of parasitic aetiology in the world [17-25] (WHO, 2014b, 2015). An estimated 4,29,000 deaths were recorded in 2015. About 90% of malaria-related deaths globally occur in Africa, with 70% of these deaths occurring in children under five years of age [26].

In Cuba, the incidence of these entities, both parasitic and viral, is undoubtedly a health problem [27], with a tendency to increase the number of cases, as well as the populations of vector organisms [8,28,29].

Seasonality and interannual variation in disease incidence is more pronounced for arboviral diseases, as reservoir vectors are susceptible to seasonal changes [28,30,31]. Climatic conditions and the transmission dynamics of these diseases are interlinked, and as more is known today about meteorological parameters, the impact of climate change can and should be mitigated [31-33].

Over the past 50 years or more, models of emerging arboviral diseases have changed significantly [34,35]. Climate is the major factor in determining the temporal and geographic distribution of arthropods, the characteristics of their life cycles, the consequent dispersal patterns of associated arboviruses, the evolution of arboviruses, and the efficiency with which they are transmitted from arthropods to vertebrate hosts [8,28,36].

The possibility of making high-quality forecasts using the ROR methodology, which due to its simplicity and accuracy can open an important window to know the future of climate variables or daily data, years in advance [37-39]; this cycle can be extended to the 11 years of the solar cycle, or to higher cycles, which are known in nature; in particular, Culicidae [40-42].

The objective of the research was to determine the possible incidence of the ROR methodology in the modelling of the total number of monthly mosquito outbreaks in Villa Clara province, Cuba.

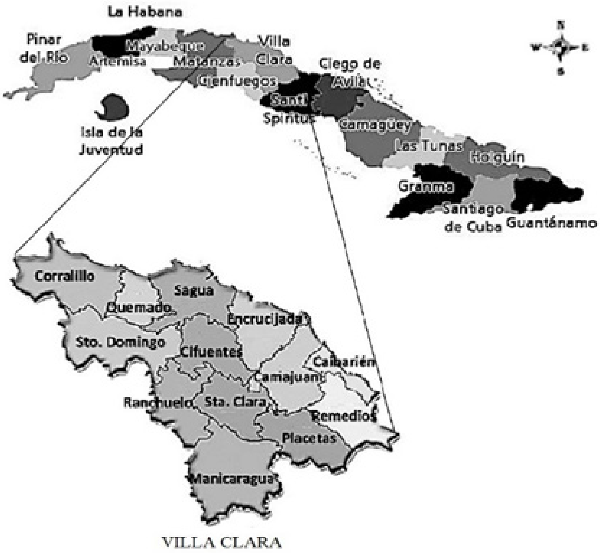
MATERIALS AND METHODS

Type of Study

Observational, descriptive, ecological, retrospective, and statistical study, in the period from 2010 to 2020.

Study area

The research was carried out in Villa Clara province, Cuba, whose provincial capital is Santa Clara municipality, and covered the 13



Source: Provincial Meteorological Center of Villa Clara

Figure 1. Administrative map of Villa Clara province.

municipalities that comprise it. This province is located in the central region of the island of Cuba (Latitude: 22° 29'40" N, Longitude: 79°28'30" W), and has the following geographical limits; to the west, with Matanzas province, to the east, with Sancti Spíritus province, and to the south, with Cienfuegos province (Figure 1).

In Villa Clara province, the specialists of the Provincial Unit for Surveillance and Antivectorial Control (UPVLA) have registered 316 370 dwellings and/or premises in the general universe, of which 236 391 belong to the urban universe (74.7%) and an average of approximately 1 581 850 water storage tanks in these dwellings or premises, with ideal conditions for the breeding, proliferation, and dissemination of Culicidae in the 13 municipalities.

Sample

It included the 13 municipalities of the province, as well as the number of outbreaks reported by them in the different months of the period analyzed (2010 to 2020).

Methods and techniques for collecting information

The documentary review of the records and statistical files existing in the Provincial Unit of Surveillance and Antivectorial Control (UPVLA) and in the Provincial Department of Health Statistics of Villa Clara, where the entire entomological history of the work cycles conceived in the 13 municipalities of the province is compiled, which is periodically reported in statistical tables established for such purposes by the National Directorate of Surveillance and Antivectorial Control (DNVLA) and the Department of Health Statistics of the Ministry of Public Health (MINSAP).

The information was collected based on the work cycles established for surveillance and vector control, aimed at focal work in the universe of dwellings and premises in urban and rural areas of the 13 municipalities of the province, where the periodicity of the cycles is monthly, in the case of the urban universe.

Procedures for information processing

The data were organized in the Windows Excel application by years and months; that is, 11 columns are placed: the first one with the municipalities and the provincial accumulated, the remaining ones with the years and their respective focal points.

The second, with a total of 14 columns; the first with the years and the average focal point, while the following 12 represent the months with their respective focal point, and the last, the total by years, in each of the municipalities of the province. After organizing the data, we proceeded to obtain the time series and trend for each of the aforementioned variables.

Mathematical modelling

For the development of the predictive model, the methodology of Regressive Objective Regression (ROR) was used, which made possible the prediction of the foci utilizing the ROR methodology [43,44], for which, in the first step, dichotomous variables DS, DI, and NoC are created, where:

NoC: Number of Cases in the base,

DS=1, if NoC is odd; DI=0, if NoC is even, when DI=1, DS=0 and vice versa.

Subsequently, the module corresponding to the Regression analysis of the statistical package SPSS version 19.0 (IBM Company) will be executed, specifically, the ENTER method where the predicted variable and the ERROR are obtained.

Then the autocorrelograms of the variable ERROR are obtained, paying attention to the maximums of the significant partial autocorrelations PACF. The new variables were then calculated taking into account the significant Lag of the PACF. Finally, these regressed variables were included in the new regression in a process of successive approximations until a white noise in the regression errors was obtained. For the case of atmospheric pressure, lags of 1 year in advance can be used, as other authors have done for the climatic indexes, although it is unlikely that 11 years in advance results will be obtained since we only have 11 years of data in the base, nevertheless, in the monthly data we will try to use the results for the meteorological variable atmospheric pressure.

RESULTS AND DISCUSSION

To date, 45 species of mosquitoes distributed in 13 genera have been identified in the province of Villa Clara, the best represented and distributed species in this province being *Anopheles albimanus*, *Aedes aegypti*, *Ae. albopictus*, *Ae. scapularis*, *Culex quinquefasciatus*, *Cx. nigripalpus* and *Psorophora confines* (present in all 13 municipalities of this province), followed by *Culex corniger* and *Psorophora ciliata* (in 12 of the 13 municipalities), as shown in Table 1.

Of the 71 mosquito species recorded for Cuba [45], in Villa Clara, the number of species identified (45/63.38%), so that species was collected in all the river ecosystems sampled, where they appeared with relatively high abundance, a fact that agrees with the results obtained by Marquetti (2006) [46], specifically for Cx. quinquefasciatus in the urban ecosystem; this result also confirms the criteria of different authors [47-49] concerning the extraordinary adaptive capacity and high ecological plasticity of Cx. quinquefasciatus in the most diverse and possible habitats provided by man. Thus, the great ecological plasticity of the entomofauna of Culicidae existing in Cuba was also evidenced, despite being an archipelago, which corroborates the results obtained by García (1977) [50] and González (1985) [51].

It is notorious and relevant to the fact that Ae. aegypti and Ae. albopictus have gained ground and space in Villa Clara province, species of high entomoepidemiological risk, due to their involvement in the transmission of several infectious entities [52-54], among which Dengue, Yellow Fever, West Nile virus, Chikungunya, and Zika virus stand out; but reality has shown us, that at present, these two species are practically present throughout the length and breadth of the national geography, expanding increasingly and colonizing an important number of breeding sites generated by human activity together with environmental variables [2], thus showing their high ecological plasticity and high capacity to adapt to the most dissimilar ecological niches [8,46].

The statistical description of the number of outbreaks per month

Regarding the descriptive statistics for the number of outbreaks by municipality (Table 2), it can be observed that both the highest mean value and the standard deviation are higher in the municipality of Santa Clara and lower in Encrucijada. The lengths of the series are 14 years of monthly data, where the maximum value reached was 972 in Santa Clara and the minimum was zero in several municipalities, with Santa Clara being the municipality with the highest standard deviation and Encrucijada the lowest. The great vari-

Table 1. Distribution of identified mosquito species by the municipality.

Mosquito species	Authors	Municipalities	Total
Aedeomyia squamipennis	(Lynch Arribálzaga,1878)	9, 12	2
Anopheles albimanus	(Wiedemann, 1821)	1, 2, 3, 4, 5, 6, 7, 8,9,10,11,12,13	13
An. Atropos	(Dyar & Knab, 1906)	5,6,9	3
An. grabhamii	(Theobald, 1901)	5,6,11	3
An. vestitipennis	(Dyar & Knab, 1906)	3,5,6,7,8,9,11	7
An. crucians	(Wiedemann, 1828)	5,8,12	3
Aedes aegypti	(Linnaeus, 1762)	1, 2, 3, 4, 5, 6, 7, 8,9,10,11,12,13	13
Ae. albopictus	(Skuse, 1894)	1, 2, 3, 4, 5, 6, 7, 8,9,10,11,12,13	13
Ae. mediovittatus	(Coquillett, 1906)	1, 2, 3, 4, 5, 6, 7, 8,9,10,11,12,13	13
Ae. scapularis	(Rondan, 1848)	1, 2, 3, 4, 5, 6, 7, 8,9,10,11,12,13	13
Ae. sollicitans	(Walker, 1856)	1,3,4,5,6,7,10,11,12	9
Ae. taeniorhynchus	(Wiedemann, 1821)	1, 2, 3, 4, 5, 6, 7, 10,11	9
Ae. tortilis	(Theobald, 1903)	3,4,5,7,9	5
Ae. vittatus	(Bigot, 1861)	4,8	2
Ae. walkeri	(Theobald, 1901)	2, 6,11,12	4
Coquillettidia nigricans	(Coquillett, 1904)	9,11	2
Culex americanus	(Neveu-Lemaire, 1902)	6,9	2
Cx. atratus	(Theobald,1901)	4,5,6,8,9,10	6
Cx. bahamensis	(Dyar & Knab, 1906)	6,8	2
Cx. cancer	(Theobald,1901)	1,5,6	3
Cx. chidesteri	(Dyar, 1921)	1,2,6,8,9,11,12	7
Cx. corniger	(Theobald, 1903)	1, 2, 3, 4, 5, 6, 7, 8,9,10,12,13	12
Cx. erraticus	(Dyar & Knab, 1906)	4, 5, 6, 7, 8,9,10,12,13	9
Cx. iolambdis	(Dyar, 1918)	8,9	2

Table 2: Descriptive statistics of the number of monthly light bulbs

Descriptives statistics					
Municipalities	**N**	**Minimum**	**Maximum**	**Media**	**Standard deviation**
Corralillo	126	0	61	6,22	10,292
Quemado	129	0	67	8,41	13,985
Sagua	150	1	1567	113,50	209,832
Encrucijada	144	0	45	2,58	5,859
Camajuaní	154	0	221	18,49	36,579
Caibarien	143	0	331	29,06	56,656
Remedios	131	0	251	24,04	43,191
Placetas	153	0	674	44,68	92,174
Santa Clara	167	33	8083	972,49	1,560,339
Cifuentes	148	0	139	11,28	21,448
Santo Domingo	143	0	285	21,12	38,824
Ranchuelo	165	0	522	42,46	78,824
Manicaragua	146	0	604	57,60	107,183
N válido (por lista)	120				

ability of data per municipality was found, which could be due to the physical-geographical characteristics of the municipalities, and to factors inherent to the campaign operators themselves, at the time of collecting the mosquito foci, since this human quality is not always optimal [8,33,55].

Description of a ROR model for the number of outbreaks

The following are the results of the models by the municipality, where the values obtained for explained variance R were high, while the standard deviation was small. To better illustrate the above, the municipality of Camajuaní was chosen, since it turned out to be the municipality with the highest variance explained for the number of outbreaks. It can be seen how 90.1% of the variance is explained, with a standard error of 25.3 foci (Table 3).

The analysis of the variance of the model indicates that Fisher's F is 53.85, significant at 100% (Table 4).

The summary of the ROR model for the total monthly outbreaks in Villa Clara explains 91% of the variance, with an error of 1,233 outbreaks, where the Durbin Watson statistic was small, so the model allows for the existence of other predictive variables (Table 5).

The analysis of variance explains that the model is valid and significant at 100% (Table 6).

Table 3: Summary of the ROR Model for the municipality of Camajuaní.

Model Summary[c,d]					
Model	**R**	**R square[b]**	**Adjusted R-squared**	**Standard error of estimation**	**Durbin-Watson**
1	.901[a]	0.812	0.797	25.325	0.94
a. Predictors: Lag73Focos, Lag13Focos, DI, DS, Lag25Focos, NoC.					
b. For regression through the origin (the model without intercept), R-squared measures the proportion of the variability in the dependent variable about the origin explained by the regression. This CANNOT be compared to R-squared for models that include intercept.					
c. Dependent variable: Camajuaní					
d. Linear regression through the origin					

Table 4: Analysis of Variance for outbreaks in the municipality of Camajuaní

ANOVA[a,b]						
Model		**Sum of squares**	**gl**	**Quadratic mean**	**F**	**Sig.**
1	Regresión	207225.72	6	34537.62	53.851	.000[c]
	Residuo	48101.281	75	641.35		
	Total	255327.000[d]	81			
a. Dependent variable: Camajuaní						
b. Linear regression through the origin						
c. Predictors: Lag73Focos, Lag13Focos, DI, DS, Lag25Focos, NoC						
d. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.						

Table 5: Summary of the ROR model for monthly outbreaks in Villa Clara.

Model summary[c,d]					
Model	**R**	**R square[b]**	**Adjusted R-squared**	**Standard error of estimation**	**Durbin-Watson**
1	.910[a]	0.829	0.823	1233.2425	0.917
a. Predictors: Step202105, DI, DS, NoC					
b. For regression through the origin (the model without intercept), R-squared measures the proportion of the variability in the dependent variable about the origin explained by the regression. This CANNOT be compared to R-squared for models that include intercept.					
c. Dependent variable: Foci Total VC					
d. Linear regression through the origin					

Table 6: Results of the analysis of variance.

ANOVA[a,b]						
Model		**Sum of squares**	**gl**	**Quadratic mean**	**F**	**Sig.**
1	Regression	854977909	4	213744477	140.539	.000[c]
	Residuo	176422912	116	1520887.2		
	Total	1031400821.000[d]	120			
a. Dependent variable: Focuses-Total-VC.						
b. Linear regression through the origin						
c. Predictors: Step202105, DI, DS, NoC.						
d. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.						

Table 7: Resultados del análisis del modelo según tipos de coeficientes

Coefficients^{a,b}						
Model	**Unstandardized coefficients**			**Standardized coefficients**	**t**	**Sig.**
	B		**Error estándar**	**Beta**		
1	DS	-809.384	408.356	-0.195	-1.982	0.05
	DI	-766.745	411.667	-0.185	-1.863	0.065
	Tendency	17.611	3.604	0.684	4.886	0
	Step202105	7208.483	500.455	0.635	14.404	0
a. Dependent variable: Focuses-Total-VC.						
b. Linear regression through the origin						

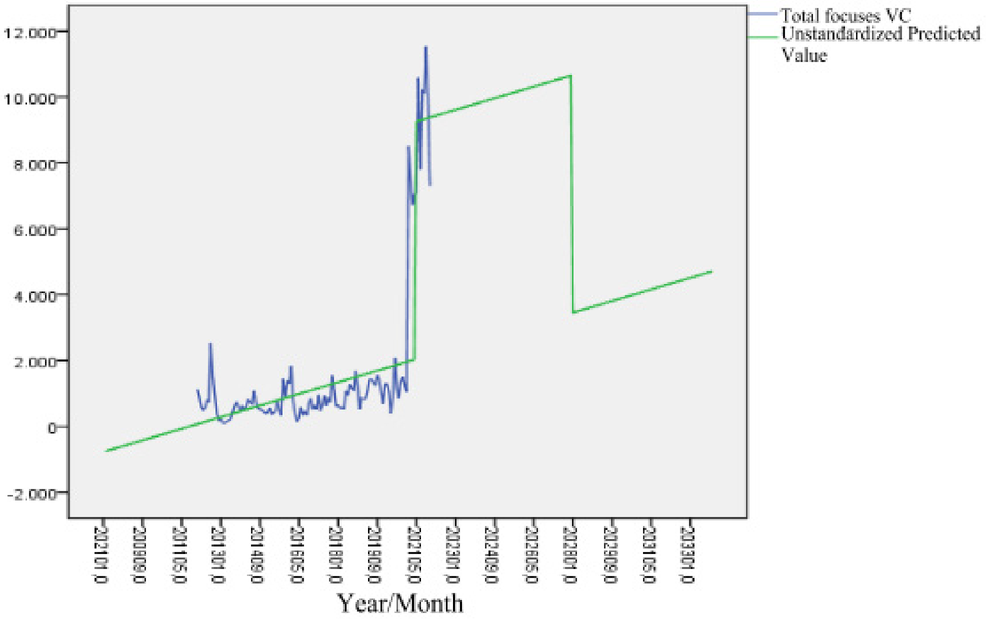


Figure 2. Outbreak forecast to the year 2033, according to ROR methodology

The parameters of the model, SD, DI, and the trend were significant; the latter shows that it is positive and significant to the increase, with a coefficient of 17.6 foci per month (Step202105), a variable that indicates the impact of the series from the year 2021, the month of May onwards, which constitutes an increase of 7,208 cases (Table 7).

Figure 2 shows the very long-term forecast of the number of mosquito outbreaks, showing that there is a tendency to increase until January 2028, where there is a decrease in cases, although the tendency is to increase also after 2028, results very similar to those obtained in research carried out in other provinces of the country [8,56].

CONCLUSION

It is possible to model the focus of mosquitoes in a given geographical area, however large it may be and even predict the behaviour of the focus in the short, medium, and long term.

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