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An approximation to the prediction of the summery emergence of *Ochlerotatus caspius* (Diptera: Culicidae) based on the relationship between degree-days accumulations and adult captures

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Resumen

Predicción de la emergencia estival de Ochlerotatus caspius *(Diptera: Culicidae) basada en la relación entre la acumulación de días-grado y la captura de adultos.*

Ochlerotatus caspius (Pallas) (Diptera, Culicidae) es el culícido más abundante durante el verano en las marismas de Huelva. Este estudio demuestra que la relación entre capturas de adultos, convertidas en probit, y la acumulación de temperatura o número de días-grado, convenientemente adaptada mediante a una transformación logarítmica, muestra ser significativamente lineal para cada generación de este mosquito a lo largo de cada verano. Además, si se procesan todos los datos disponibles de todos los años considerados en el estudio se obtiene una alta correlación lineal y, en consecuencia, las ecuaciones resultantes poseen valor predictivo. Los resultados de la validación de los pronósticos que se extraen de las rectas de regresión log-probit, permiten que se puedan considerar estas rectas como una herramienta más de cara a aumentar la eficacia de los programas de control integrado que se llevan a cabo en esta zona.

Palabras clave: *Ochlerotatus caspius*, Días-grado, Modelo predictivo, Culicidae, Mosquito.

Abstract

Ochlerotatus caspius (Pallas) (Diptera, Culicidae) is the most abundant culicidae during the summer in the Huelva Marshes (SW of Spain). This study proves that the relationship between adult captures, turned to probit indexes, and temperature accumulations or degree-days, conveniently modified by a logarithmic transformation, shows to be significantly linear for each generation of this mosquito throughout the year. Jointly processing all data of the available years also results in a high linear correlation, statistically significant, and, consequently, the proposed equations have predictive value. The reliability of the forecast based on the resulting log-probit have shown to be acceptable in order to be considered as an useful tool to improve the effectiveness of the integrated pest management in the area.

Key words: *Ochlerotatus caspius*, Degree-days, Log-probit linear regression, Forecasting model, Marshes, Culicidae, Mosquito.

Introduction

Ochlerotatus caspius (Pallas) is a well-known, prominent pest widely distributed in the Paleartic Region. Its larvae are primarily halophilic, with occasional occurrences in fresh water. The biological characteristics of this insect have been extensively studied due to its potential as a disease vector.

The Marches of Huelva is an area of special attention for mosquitoes control. It is an area of river and sea floods corresponding to the mouths of the rivers Guadiana, Carreras, Piedras, Odiel and Tinto, with a remarkable geographical and ecological interest. The natural drainage of the marches has been long affected by new settlements and industrial estates, resulting in new areas susceptible of larvae focuses. As a consequence, several population explosions of mosquitoes have taken place since 1960, worsened by the important increment of human population in the area. Both local and national authorities had to implement countryside preservation measures as well as pest control strategies, still in progress. Among other culicidae common in the area, *Oc. caspius* is the most problematic species due to its persistent summer population explosion (López 1989).

In this context, this paper presents the application of a classical, simple forecasting tool to the emergence of the adults of *Oc. caspius*, aiming at improving the control programmes in use in the area. The objective is to characterise the relationship that exists between the catches of adults using light traps and the temperature accumulations or degree-days.

The proposed technique is based on the computation of temperature accumulations in order to obtain the correlation with trap catches of adults of *Oc. caspius*. In spite of the limitations of the used traps, a direct relationship between the number of catches of adults and their rate of emergence, the latter being directly influenced by the heat that the insect received during developmental stages, has been assumed. This correlation has been reported by several authors, mainly differing in the way that temperature accumulations are computed. The relationship between temperature accumulations and trap catches, conveniently transformed, has also been demonstrated to be highly linear when obtained for other insects, especially Lepidoptera, and has been used to make predictions about the development of the insects whose development is mainly influenced by temperature, and to make decisions regarding pest control (Potter & Timmons 1983, Ahmad & Ali 1995, Judd & Gardiner 1997, Del Tío et al. 2001).

Material and Methods

Area of Study:

The study was carried out over the Aljaraque Municipality (PB760273, PB762271, PB761269). This area of the marshes suffers from a strong seasonality, with humid winters and dry summers in which the water only persists in the largest ponds. Seasonal rhythms become fortnightly during spring and autumn due to the influence of strong tides that produce progressive floods. Despite the building of several roads in the area, the natural drainage has been preserved.

Capture data compilation:

Data ranging from 1994 to 1996, provided by regional government (Diputación de Huelva), have been used in this study. Nine actinic light (6 w) traps with adhesive, transparent sheets were used to capture adult specimens. Traps were inspected daily during the three years.

Data processing:

Using the capture data from all the traps, a flight curve was obtained for every year (Fig. 1). Before computing the temperature accumulations, the analysis of capture data and flight curves revealed that, in practice, annual captures correspond to the emergences of three different generations, taking also into account the available information about the life cycle of this species in the area.

A program based on the work of Allen (1976) was used in order to compute temperature accumulations. This program considers the evolution of the temperature of the air as a sinusoidal function throughout the day.

Temperature data were provided by the Meteorological Service of Western Andalusia (Centro Meteorológico de Andalucía Occidental y Ceuta, Instituto Nacional de Meteorología, Spain). Degree-days were computed using a lower threshold of 4°C and an upper threshold of 32°C, according to the life cycle of this species in these latitudes (López 1989). Computation of degree-days corresponding to the first emergence starts from the 1st of January. For the rest of considered emergences, computations always start from the date when 50% of captures from the previous emergence are registered. In fact, the period required for the captures to amount to 50% is approximately the same as the period between the appearance of the first adults and the laying of eggs which begins the

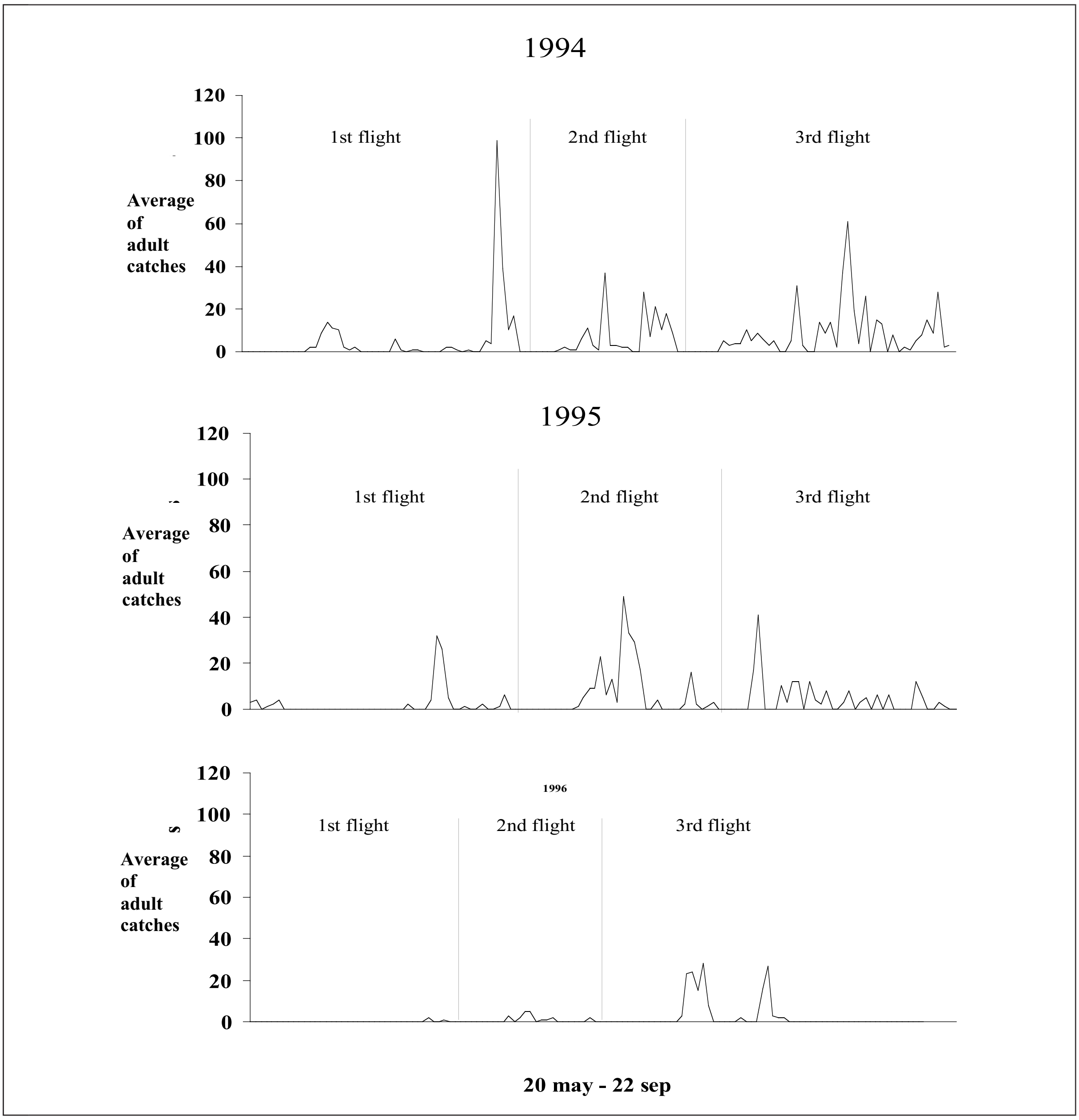

Figure 1. Summery captures of *Oc. caspius* in the target area during 1994, 1995 and 1996. The estimated separation of the three flights considered is also shown

Figura 1. Capturas estivales de *Oc. caspius* durante 1994, 1995 y 1996. También se muestra la parte del vuelo correspondiente a cada generación considerada.

next generation, as shown by the life cycle of this culicidae in the area (Sinegre 1974, Gabinaud 1975, López 1989).

Finally, annual linear equations corresponding to a weighted-least-square correlation between the percentages of total catches throughout the corresponding period, turned into probit indexes, and the logarithms of temperature accumulations (i.e., degree-days), were obtained to avoid the sigmoidal distribution of the data. The characteristic emergence equations of the area, computed by processing all available data for each emergence, have also been determined.

Results

Table 1 presents the log-probit linear equations that express, for each of the three main emergences considered, and for the 3 years, temperature accumulations versus adult captures with traps.

Flight	Year	Regression line	d. f.	F	C.I.		r	SE
					Y Intercept	Slope		
1º	1994	y=16,3639x - 48,8210	21	26,41	-59,204 to -38,438	13,180 – 19,548	0,7464	0,8560
	1995	y=19,3222x - 57,9480	12	30,53	-69,365 to -46,532	15,825 – 22,819	0,8473	0,8901
2º	1994	y=10,5859x - 22,9845	17	93,68	-25,819 to -20,130	9,492 – 11,679	0,9200	0,6009
	1995	y=16,3072x - 40,5682	16	300,99	-43,213 to -37,924	15,367 – 16,960	0,9744	0,3857
	1996	y=15,9312x - 36,0021	6	146,66	-39,445 to -32,559	14,616 – 17,247	0,9802	0,3158
3º	1994	y=7,4638x - 15,8830	32	202,25	-17,352 to -14,410	6,939 – 7,989	0,9292	0,5175
	1995	y=9,4443x - 21,4325	18	97,13	-24,190 to -18,675	8,486 – 10,403	0,9185	0,4535
	1996	y=17,7081x - 45,0920	10	51,04	-52,197 to -37,987	15,229 – 20,187	0,9144	0,6612

Table 1. Log-probit linear equations showing temperature accumulations versus adult captures. (**d.f.** = degrees of freedom; **F** = F value; **r** = correlation coefficient; **SE** = standard error; **C.I.** = confidence intervals; **x** = log degree-days; **y** = probit).

Tabla 1.- Ecuaciones lineales (log-probit) de la relación obtenida entre las capturas de adultos y la acumulación de días-grado (d.f. = grados de libertad; F = valor de F; r = coeficiente de correlación; SE = error standard; C.I. = intervalo de confianza; x = log días-grado; y = probit).

Flight	Regression line	d. f.	F	C.I.		r	SE
				Y Intercept	Slope		
1º	y=17,8781x-53,5598	35	55,63	-61,379 to -45,740	15,4812-20,2750	0,7835	0,8877
2º	y=7,9388x-16,2871	43	52,79	-19,233 to -13,341	6,8460-9,0314	0,7424	1,0679
3º	y=8,4572x-18,6249	64	261,41	-20,108 to -17,142	7,9341-8,9802	0,8963	0,6122

Table 2. Regression equations (temperature accumulations-adult captures) obtained by processing all available data. (**d.f.** = degrees of freedom; **F** = F value; **r** = correlation coefficient; **SE** = standard error; **C.I.** = confidence intervals; **x** = log degree-days; **y** = probit).

Tabla 2. Rectas de regresión lineal entre las capturas de adultos y la acumulación de días-grado realizadas con los datos anuales para cada vuelo (d.f. = grados de libertad; F = valor de F; r = coeficiente de correlación; SE = error standard; C.I. = intervalo de confianza; x = log días-grado; y = probit).

In all cases, linear correlations were statistically significant, with a 5% confidence level, presenting F values much higher than the confidence threshold. Note that, due to the extremely low number of captures corresponding to the first flight of 1996 (Fig. 1), the regression has not been performed, although these data have used as the starting point of successive flights.

Correlation coefficients, *r*, are quite high, specially in the regressions of the second and third flights, with values over 0.9 in all cases. Furthermore, standard errors are very low and confidence intervals are quite small, specially for the second and third flights.

Consequently, the statistical significance of the correlations shows that the relationship between the catches of adults turned to probit and the logarithms of temperature accumulations proves to be highly linear.

In order to increase the reliability of the average levels of temperature accumulations when the emergences took place, all available data were then reprocessed, except for the first emergence of 1996. The corresponding linear equations are presented in Table 2 and Fig. 2 to 4.

In general, global correlation coefficients, *r*, are quite high and standard errors low. Confidence intervals are also small, mainly for the third flight. Both the equations and correlation coefficients of first and third generations are very similar to the ones obtained for the different years. Only the second flight presents correlation coefficients rather different from the ones obtained for the different years.

In any case, the relationship between the accumulated temperature and adult captures, conveniently transformed, reveals a strong linear performance in

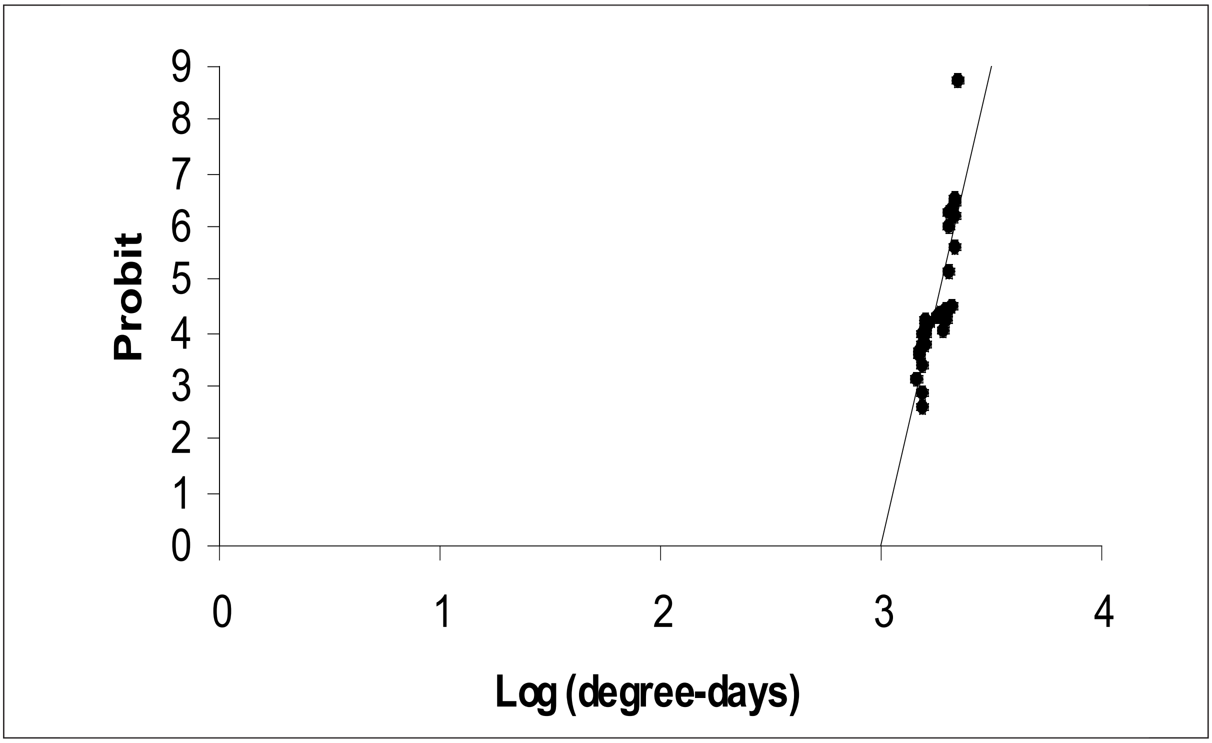

Figure 2. First flight linear regression of trap captures of *Oc. caspius* (probit) versus degree-days accumulation (log). Probit (y) = 17,8781x-53,5598.

Figura 2. Recta de regresión para el primer vuelo de *Oc. caspius* (probit) capturados frente a la acumulación de días-grado (log). Probit (y) = 17,8781x-53,5598.

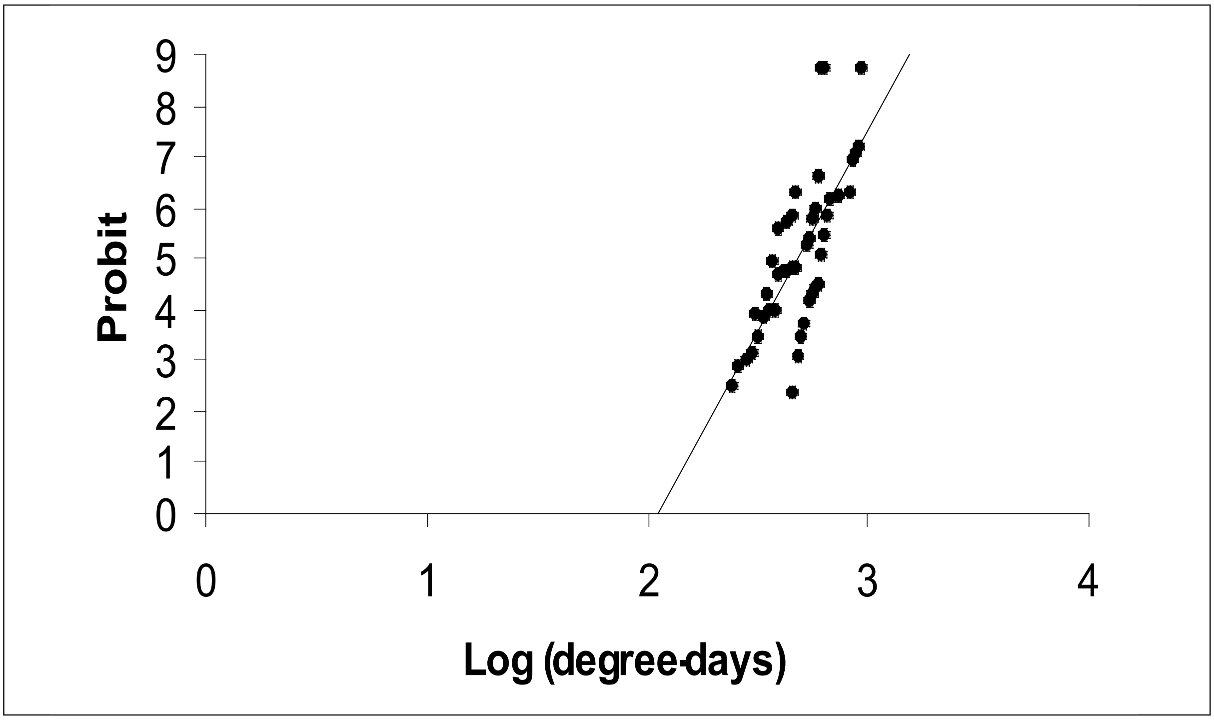

Figure 3. Second flight linear regression of trap captures of *Oc. caspius* (probit) versus degree-days accumulation (log). Probit (y) = 7,9388x - 16,2871

Figura 3. Recta de regresión para el segundo vuelo de *Oc. caspius* (probit) capturados frente a la acumulación de días-grado (log). Probit (y) = 7,9388x - 16,2871

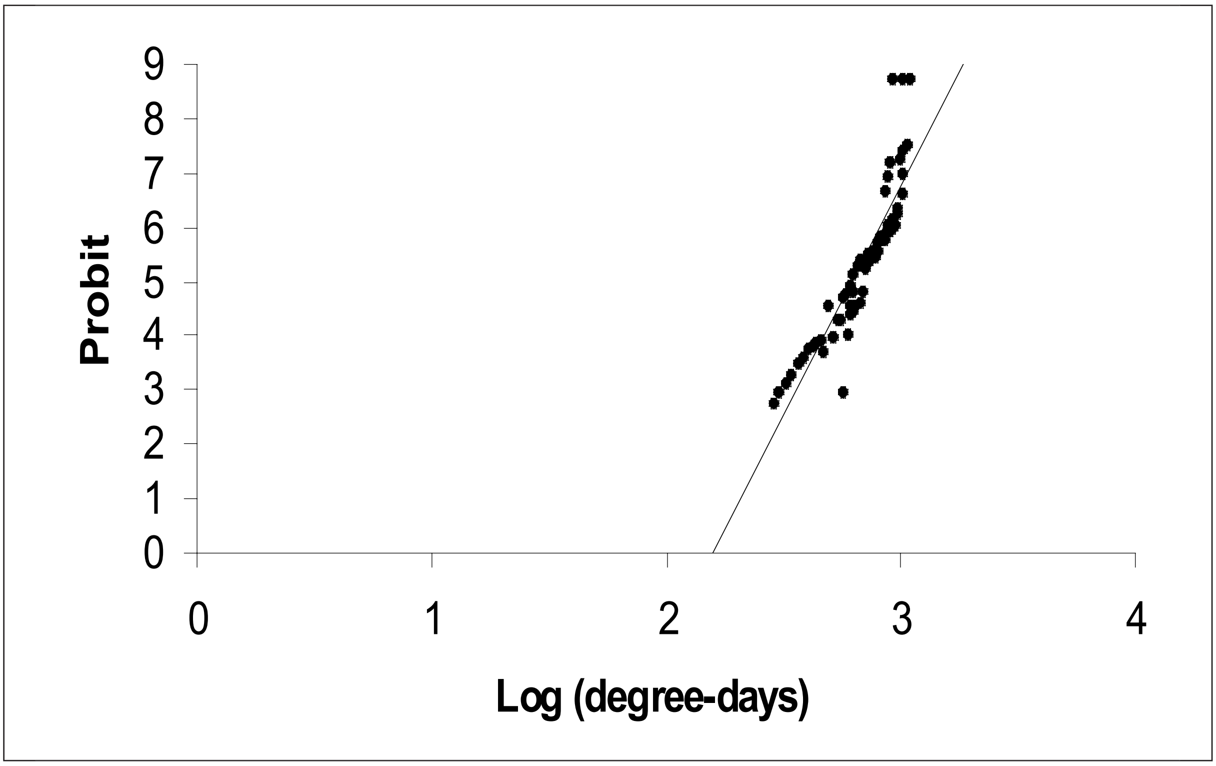

Figure 4. Third flight linear regression of trap captures of *Oc. caspius* (probit) versus degree-days accumulation (log). Probit (y) = 8,4572x - 18,6249.

Figure 4. Recta de regresión para el tercer vuelo de *Oc. caspius* (probit) capturados frente a la acumulación de días-grado (log). Probit (y) = 8,4572x - 18,6249.

Flight		Degree-day accumulation		
		10% captures	50% captures	95% captures
First	predicted values	1598.89	1885.84	2330.83
	observed values (mean)	1544.60	2065.25	2202.90
	error	54.29	179.41	127.93
Second	predicted values	331.10	480.18	773.74
	observed values (mean)	389.23	512.47	693.67
	error	58.13	32.29	80,07
Third	predicted values	438,46	621.54	972.66
	observed values (mean)	495.30	661.13	962.67
	error	56.84	39,59	9.99

Table 3. Comparison between predicted and observed values of degree-day accumulations corresponding to 10%, 50% and 95% of captures.

Tabla 3. Comparación de los valores observados y estimados de la acumulación de días-grado para el 10%, 50% y 95% de las capturas.

all cases, and, considering that for every flight the F value was much higher than the 5% confidence threshold (Table 2), the proposed equations have predictive value on *Oc. caspius* adult emergences in the area.

Finally, in order to present a preliminary quantification in days of the expected errors, Table 3 compares the mean degree-day accumulation values corresponding to 10, 50 and 95% of captures, to the predicted ones. As expected, the highest errors correspond to the considered first flight, and the lowest to the third. Notice that the first flight requires a higher accumulation of degree-days owing to a much longer period of time, starting on the 1st of January, and that temperatures during the third emergence were much higher than during the first. Consequently, the errors in degree-days correspond to 0-2 days for the considered third flight and 2-4 days for the second, being a bit larger for the first flight. Consequently, despite the need of further validation, the differences between the degree-day forecast and the observed values would be acceptable to schedule measures to control this species.

Discussion

The linear relationship between temperature accumulations and trap catches of *Oc. caspius*, conveniently transformed, has shown to be statistically significant. As a result, the equations obtained by correlation (Table 2) could be used as another helpful tool in the control programmes that are being implemented in the area, specially to predict adult emergences, taking into account that the rate of development is predominantly directed by temperature, and that accurate information about the life cycle of this insect is needed in order to improve the efficiency of control methods.

The choice of the moment from which to start computing the degree-days was the main cause of uncertainty. This is especially important in the case of the first generation, for which there is no reliable data for 1996, and whose corresponding degree-days are computed starting from an arbitrary date (1st of January) which does not reflect any definite biological event. This source of uncertainty is reduced in the cases of the second and third generations by adding up the degree-days from the moment when 50% of the previous adult emergence had been reached.

The second flight, however, presents more dispersed results when data of all years are jointly considered, which affected the correlation coefficient, as has been previously commented. The low number of data for 1996 might have lightly distorted the results (see Fig. 1). In general, it must be noticed that there are different behaviours of the populations, different requirements of degree-days to complete the second flight. However, in order to justify this result, some additional facts about this species should also be considered such as the eggs being laid on the soil, and that hatching only takes place after flooding. These facts have not been indeed considered in the proposed model to compute the flight curves, and yearly variations on the flooding in the area may influence the number of degree-days required to complete the life cycle of this species. Obviously, these influences, which might explain the errors on the second flight with respect to the first and the third flights, can be internalised by incorporating data of more years. Furthermore, if samplings were implemented taking into account the well-known influence of several factors such as the saltness, the organic content of the soil, plant species associations and vegetation community composition (Metge & Hassaine 1998, Franquet et al. 2002), even the possible capability of regulating the density of natural populations of the crowding (Gleiser et al. 2000), the degree of uncertainty would surely decrease and results would probably improve.

On the other hand, and in contrast with previous, similar studies on different insects, this study presents the added difficulty of larval and pupal stages taking place under water. However, as these phases always imply a close contact with the air, computations have been performed without including corrections for any phase of the cycle. Besides, degree-day accumulations have shown to be useful to predict the emergences of other species of the *Aedes* genus, only using the temperature of the air (Teng & Apperson 2000).

The obtained results may be improved by reducing the inherent degree of uncertainty (e.g., starting degree-day computations in dates determined by biological events and adding more sampling data). However, the high degree of linear correlation between the considered variables, and the statistical significance of the results presented show that the proposed technique is reliable and can be used for prediction.

Finally, the simplicity of the proposed technique and the fact that several reported studies have also shown the usefulness of similar methodologies applied to improve pest control (Cravedi & Mazzoni 1994, Ahmad et al. 1995) aim at the need of including this technique in the studies being carried out in the Huelva Marshes, and to its possible application in mosquitoes pest control.

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