Spatial Dispersion Pattern and Development of a Sequential Sampling Plan for The Asian Citrus Psyllid (Hemiptera: Liviidae) in Mexico

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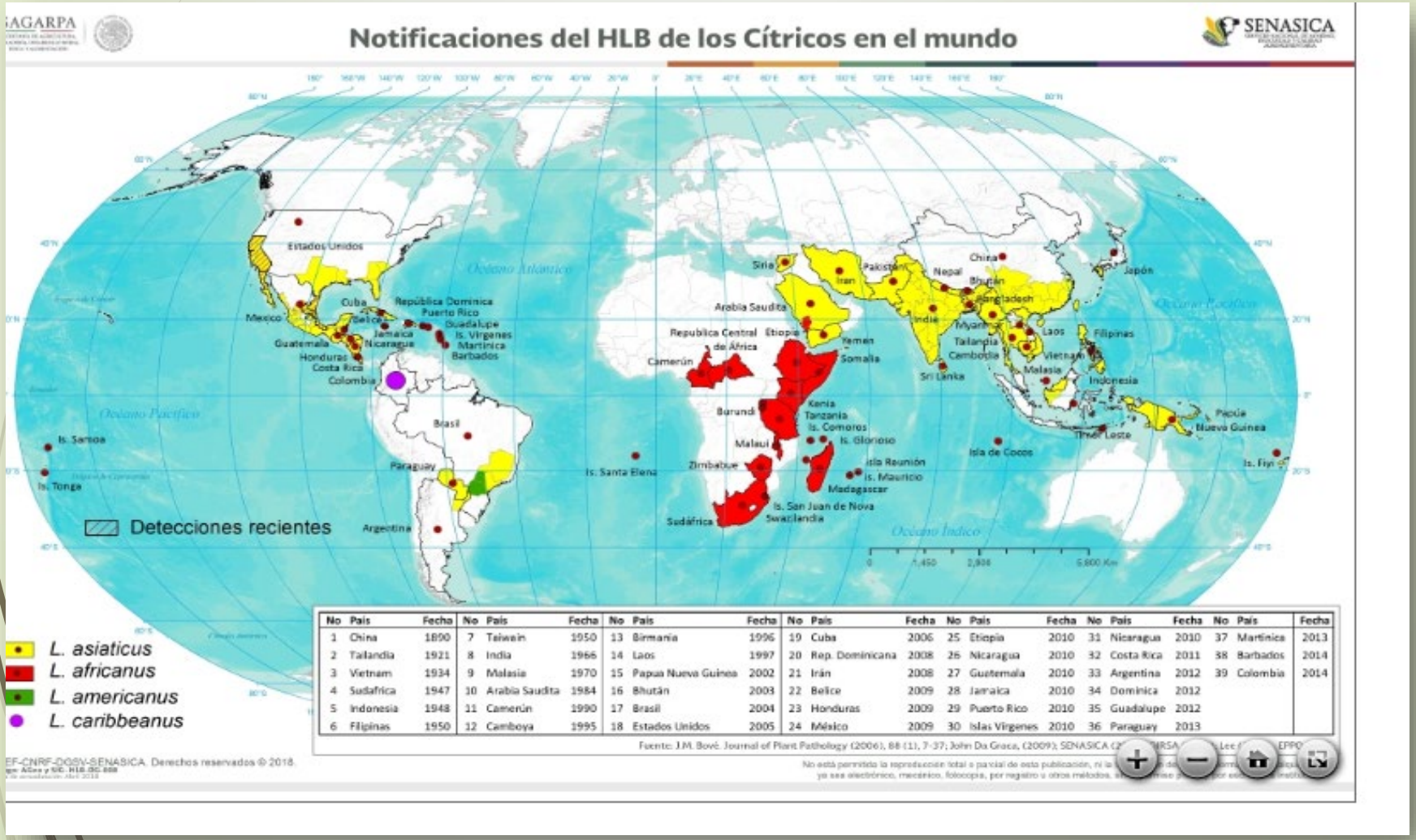
The Asian citrus psyllid (ACP), *Diaphorina citri,* Kuwayama (Hemiptera: Liviidae),

- Is the vector of Candidatus Liberibacter spp., an alphaproteobacterium associated with Huanglongbing
- the most devastating citrus disease in the world

Year of incidence and presence of HLB in the world

The first outbreaks were recorded in 1890 in China

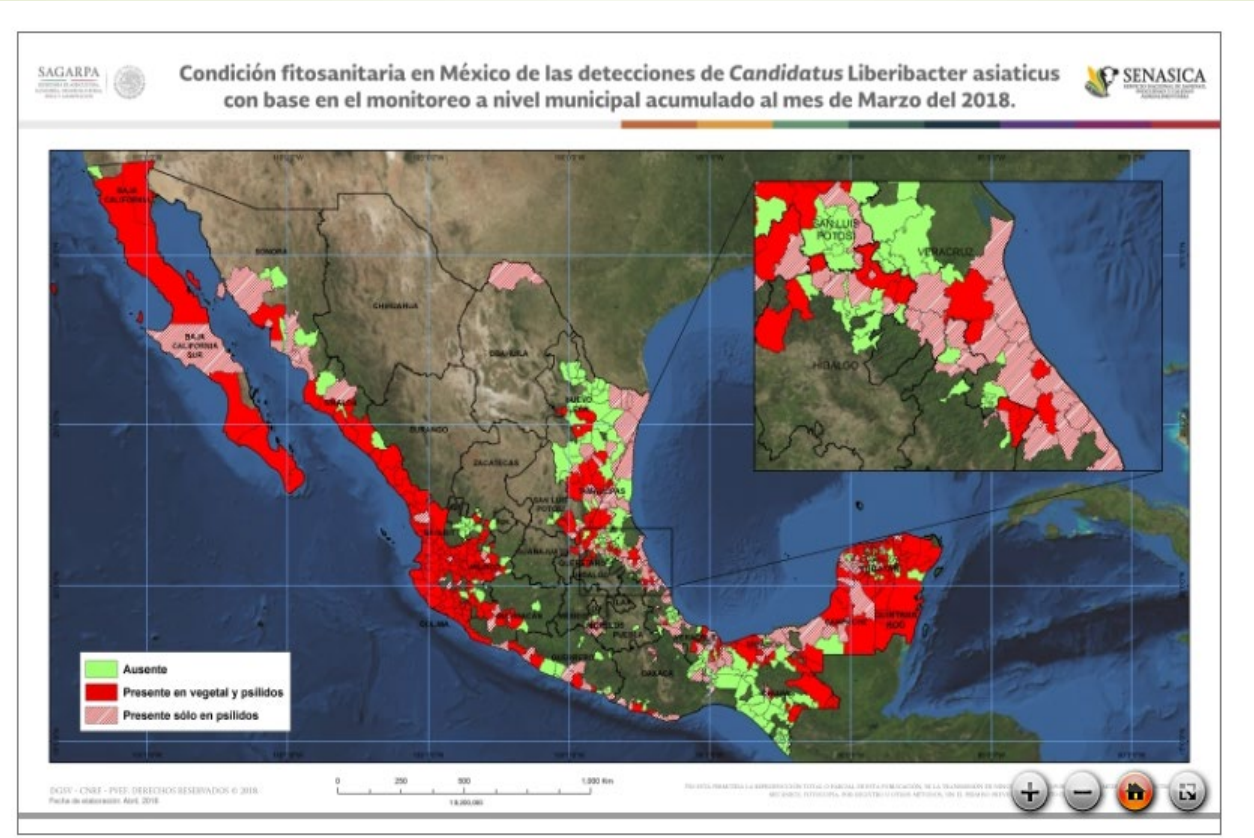
HLB disease is present in 39 countries around the world



No	País	Fecha	No	País	Fecha	No	País	Fecha	No	País	Fecha	No	País	Fecha	No	País	Fecha	No	País	Fecha
1	China	1890	7	Taiwain	1950	13	Birmania	1996	19	Cuba	2006	25	Etiopia	2010	31	Nicaragua	2010	37	Martinica	2013
2	Tailandia	1921	8	India	1966	14	Laos	1997	20	Rep. Dominicana	2008	26	Nicaragua	2010	32	Costa Rica	2011	38	Barbados	2014
3	Vietnam	1934	9	Malasia	1970	15	Papua Nueva Guinea	2002	21	Irán	2008	27	Guatemala	2010	33	Argentina	2012	39	Colombia	2014
4	Sudafrica	1947	10	Arabia Saudita	1984	16	Bhután	2003	22	Belice	2009	28	Jamaica	2010	34	Dominica	2012			
5	Indonesia	1948	11	Camerún	1990	17	Brasil	2004	23	Honduras	2009	29	Puerto Rico	2010	35	Guadalupe	2012			
6	Filipinas	1950	12	Camboya	1995	18	Estados Unidos	2005	24	México	2009	30	Islas Vírgenes	2010	36	Paraguay	2013			

Status of the HLB in Mexico

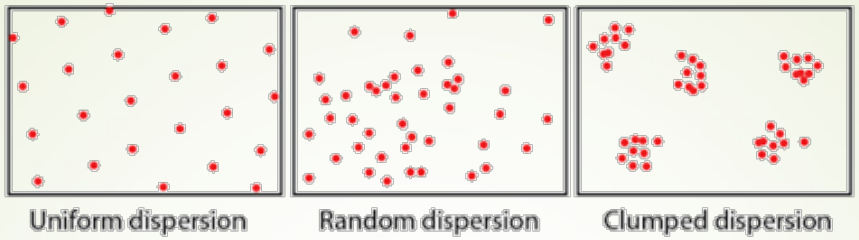
Dissemination of HLB in Mexico – March 2018



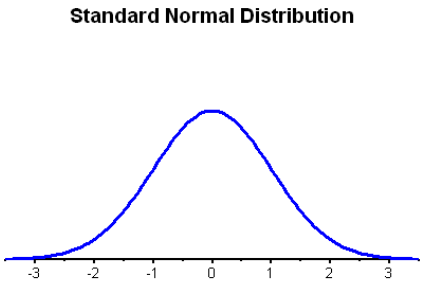
The pathogen was found in the Mexican citriculture during 2009, where it has affected to date 15% of the citrus area and the vector is present in all the citrus areas

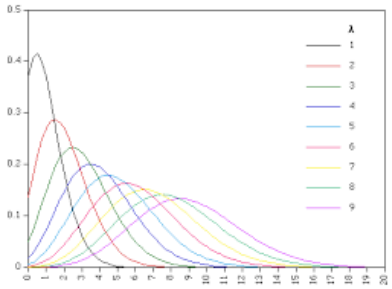
In Integrated Pest Management, it is essential to know:

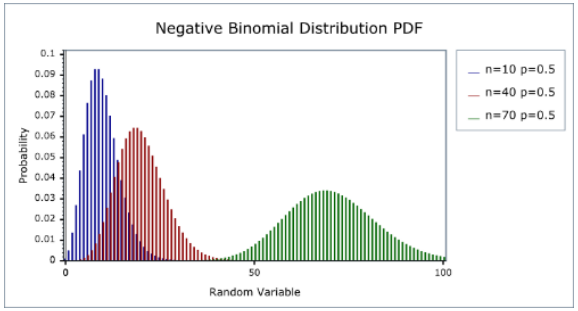
What is the dispersion pattern of the insect ?



Empirical distribution to which the presence of the pest is adjusted



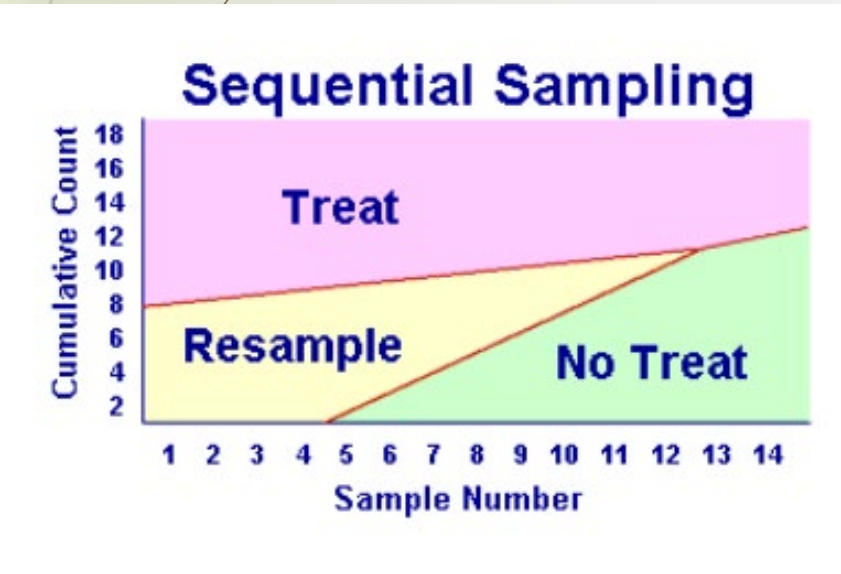


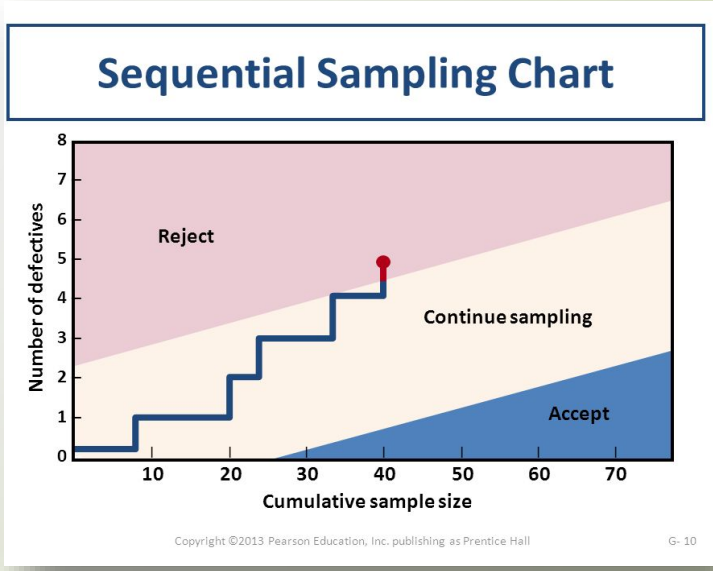


***What is the right time to apply some control techniques*?**

Sequential Sampling (SS)

- Mminimizes the sample size, (Wald1940, Krebs, 1999) and reduce the inspection and monitoring costs
- In citrus, there are few examples of sequential sampling (eg. Trumble et al., 1995).
- Tsai et al. (2000) established the bases for the development of the sequential sampling design for the control of the Asian Citrus Psyllid (ACP)





Database and Species of Study

2015-2016

Crop	State	Area Sown (ha)	Percent of the national total	Number of Traps	Total records
Orange (Citrus sinensis)	**Veracruz**	168,635	52.3%	5,227	261,350
Persian lime(Citrus latifolia Tanaka **)**	**Veracruz**	44,934	54.1%	2,274	113,700
Mexican lime (Citrus aurantifolia)	**Colima**	18,996	23.4%	2,784	139,200
National total		**555,833**		**86,337**	**3,264,715**

Yi = The study variable was psyllids captured by trap by week

Basic Statistics and Dispersion of the Number of Captured Psyllids per Trap In a Week, for different States and Citrus Species In Mexico (2015-2016).

					CONFIDENCE INTERVAL (95%)	
STATE / SPECIES	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	LOWER	UPPER
COLIMA STATE						
Mexican Lime	103,516	1.20319	4.47275	0.0139	1.175	1.232
VERACRUZ STATE						
Orange	265232	0.22288	1.32166	0.00257	0.218	0.22791
Persian Lime	116220	0.37145	2.36001	0.00692	0.35954	0.38519
TOTAL	**3,264,660**	**0.26657**	**1.89891**	**0.00105**	**0.2645**	**0.26878**

Evaluation of Dispersion Indices based in Variance and Mean

Parametro	Formula	Nacional	Naranja	Limon Persa	Limón Mexicano
n (tamaño de muestra)	n	3264660	265232	116220	103516
m (media)	$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}$	0.2666	0.2228	0.3714	1.2031
S2 (varianza)	$s^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}$	3.6058	1.7467	5.5690	20.0055
Indice de Dispersión (*ID*)	$ID = \frac{s^2}{\bar{x}}$	13.5251	7.8398	14.9946	16.6283
Indice de aglomeracion(IA)	$ICS = \frac{s^2}{\bar{x}} - 1 = ID - 1$	12.5251	6.8398	13.9946	15.6283
Indice de Green (IG)	$GI = \frac{\frac{s^2}{\bar{x}} - 1}{n-1} = \frac{ICS}{n-1}$	3.8366E-06	2.5788E-05	1.2042E-04	1.5098E-04
Indice de Frecuencia de Clusters (IFC)	$ICF = \frac{\bar{x}}{\frac{s^2}{\bar{x}} - 1} = \frac{\bar{x}}{ICS}$	0.0213	0.0326	0.0265	0.0770
Indice de Aglomeraciόm Medio (IAM)	$IMC = \bar{x} + \frac{s^2}{\bar{x}} - 1 = \bar{x} + ICS$	12.7917	7.0626	14.3660	16.8314
Index of Patchiness (*IP*)	$IP = \frac{\bar{x} + \frac{s^2}{\bar{x}} - 1}{\bar{x}} = \frac{IMC}{\bar{x}} = 1 + \frac{1}{ICF}$	47.9810	31.6991	38.6807	13.9900
Indice de Morisita (I_M)	$I_M = \frac{n\sum x(x-1)}{n\bar{x}(n\bar{x}-1)} = \frac{n\bar{x}IP}{(n\bar{x}-1)}$	47.9810	31.6997	38.6816	13.9901
Factor k calculado por momentos		0.0213	0.0325	0.0265	0.0769
Factor k calculado por maxima verosimilitid		0.0730	0.0738	0.1223	0.1558

According of the rules of decisión of each Index the result is that the spatial patern of dispersion is agregated

Taylor's Power Law

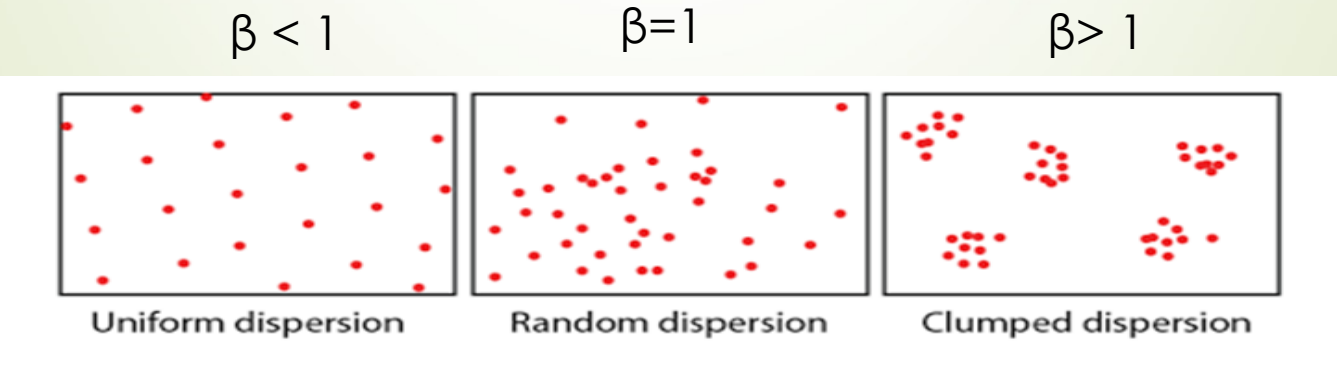
Taylor and collaborators proposed the so-called Taylor's model, that assume that spatial variance (V) is proportional to a fractional power of the mean population density (M), that is [1]

$$V = \alpha M^{\beta}$$

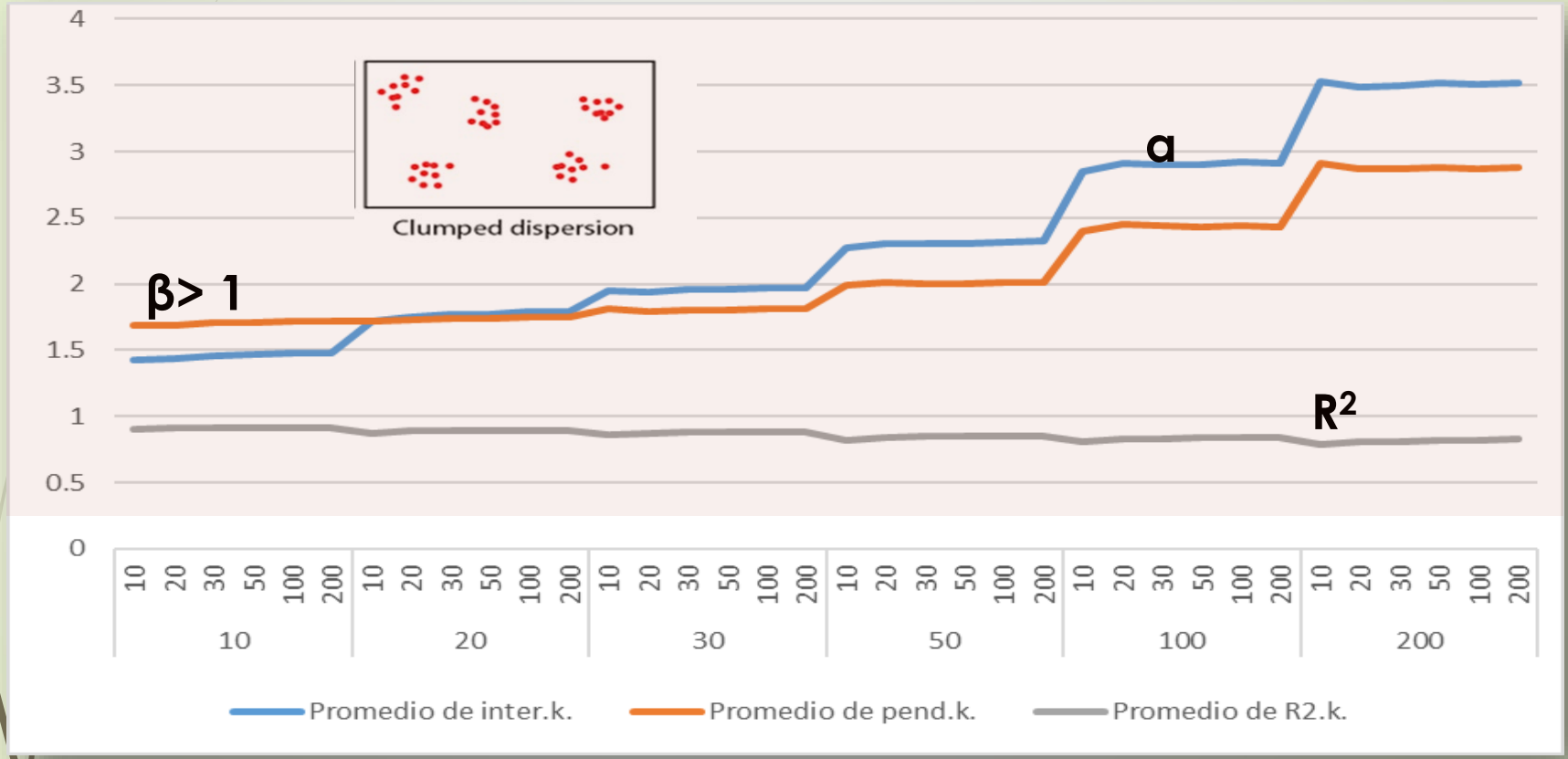
which can be represented by log-log plots as

$$\log V = \log \alpha + \beta \log M$$

where α is a proportionality parameter and β was regarded as an index of aggregation, which takes a characteristic value for each species



Resampling 1,000 times and testing diferents groups and simple sizes, the conclusión is that: the spatial dispersión of diaphorina citri is agreegated.



In all the cases the β> 1

Goodness of fit of the psyllids' population using Chi Square algorithm developed in R

An example is developed below: for which a sample size and a crop of interest are determined.

Example: Mexican lemon, Colima state and sample size = 200

First resampling:

```
> sampling
  [1]   0 1 8 0 0 6 2 0 0 0 0 1 0 0 0 2 1 0 0 0 0 1 0 0 0
 [26]  4 0 1 0 0 3 0 0 6 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1
 [51]  1 1 1 0 0 0 3 0 0 0 0 4 0 0 0 0 0 0 2 3 0 0 0 0 0
 [76]  0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 0 2 0 0 1 0 0 1 0
[101] 6 0 2 3 0 0 1 0 0 0 0 1 4 0 1 0 0 0 0 2 0 0 1 0 0
[126] 0 0 0 0 0 1 0 3 0 0 6 0 0 0 2 0 0 0 4 0 0 0 0 0 0
[151] 0 0 0 0 0 3 13 4 0 0 0 0 0 2 1 0 0 1 0 5 0 2 1 0 0
[176] 8 3 1 0 0 0 0 0 0 0 0 0 0 5 3 0 1 0 0 0 34 0 0 12 4
>
```

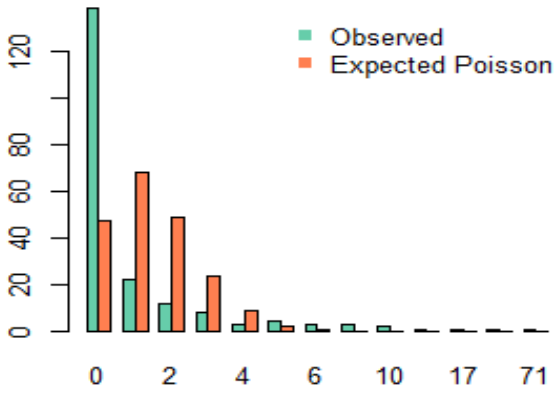
Testing the Estimated Frecuencies for differents Empirical Distributions

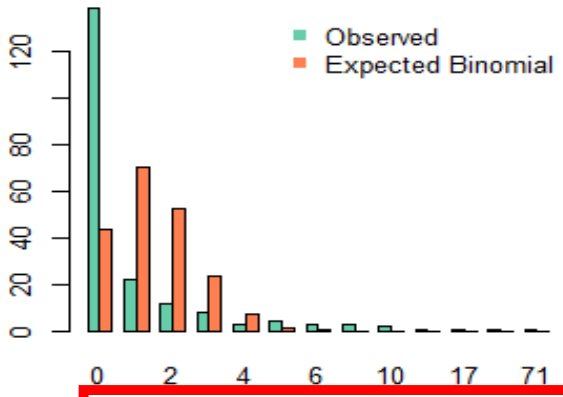
Psyllids	Frequency	round.RF..5.	Poisson	Binomial	Geometric	Neg_ Bin*	Neg_ Bin**
0	139	0.695	47.38555	43.47286	81.96721	162.18515	140.22914
1	22	0.110	68.23519	70.39896	48.37409	10.45169	19.12210
2	12	0.060	49.12934	52.61653	28.54865	5.32875	9.95942
3	8	0.040	23.58208	24.03246	16.84838	3.50798	6.46357
4	3	0.015	8.48955	7.48416	9.94331	2.56976	4.60896
5	4	0.020	2.44499	1.67811	5.86818	1.99693	3.46371
6	3	0.015	0.58680	0.27872	3.46319	1.61108	2.69181
8	3	0.015	0.02173	0.00324	1.20621	1.12573	1.73264
10	2	0.010	0.00050	0.00001	0.42011	0.83492	1.17678
13	1	0.005	0.00000	0.00000	0.08635	0.57024	0.69976
17	1	0.005	0.00000	0.00000	0.01048	0.36994	0.37470
23	1	0.005	0.00000	0.00000	0.00044	0.21214	0.15973
71	1	0.005	0.00000	0.00000	0.00000	0.00824	0.00052

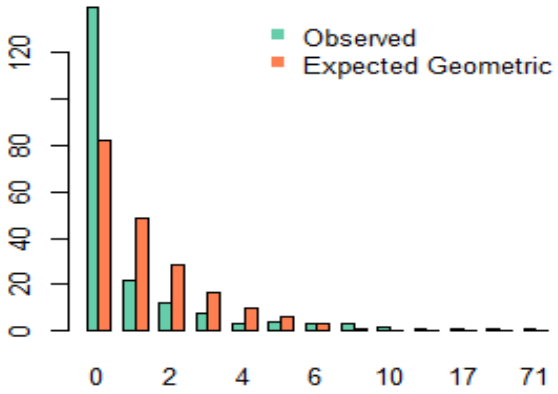
Neg_ Bin*= Negative binomial estimating for the moments method.

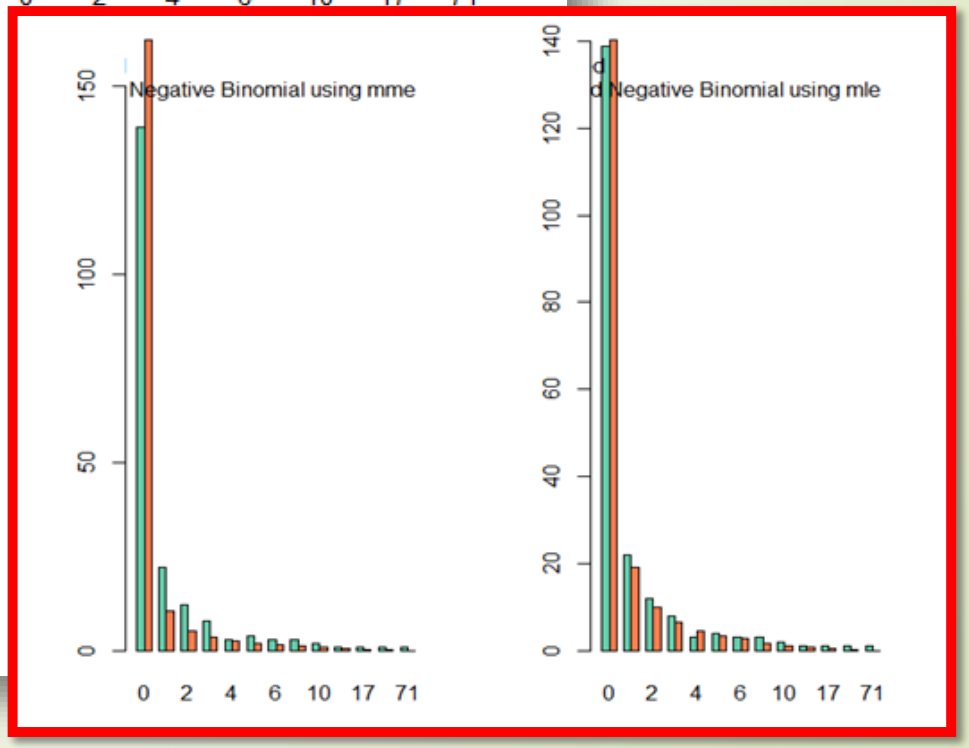
Neg_ Bin** = Negative binomial estimating for Maximun Likelihood.

Observed Vs Expected frecuency observation for differents distributions









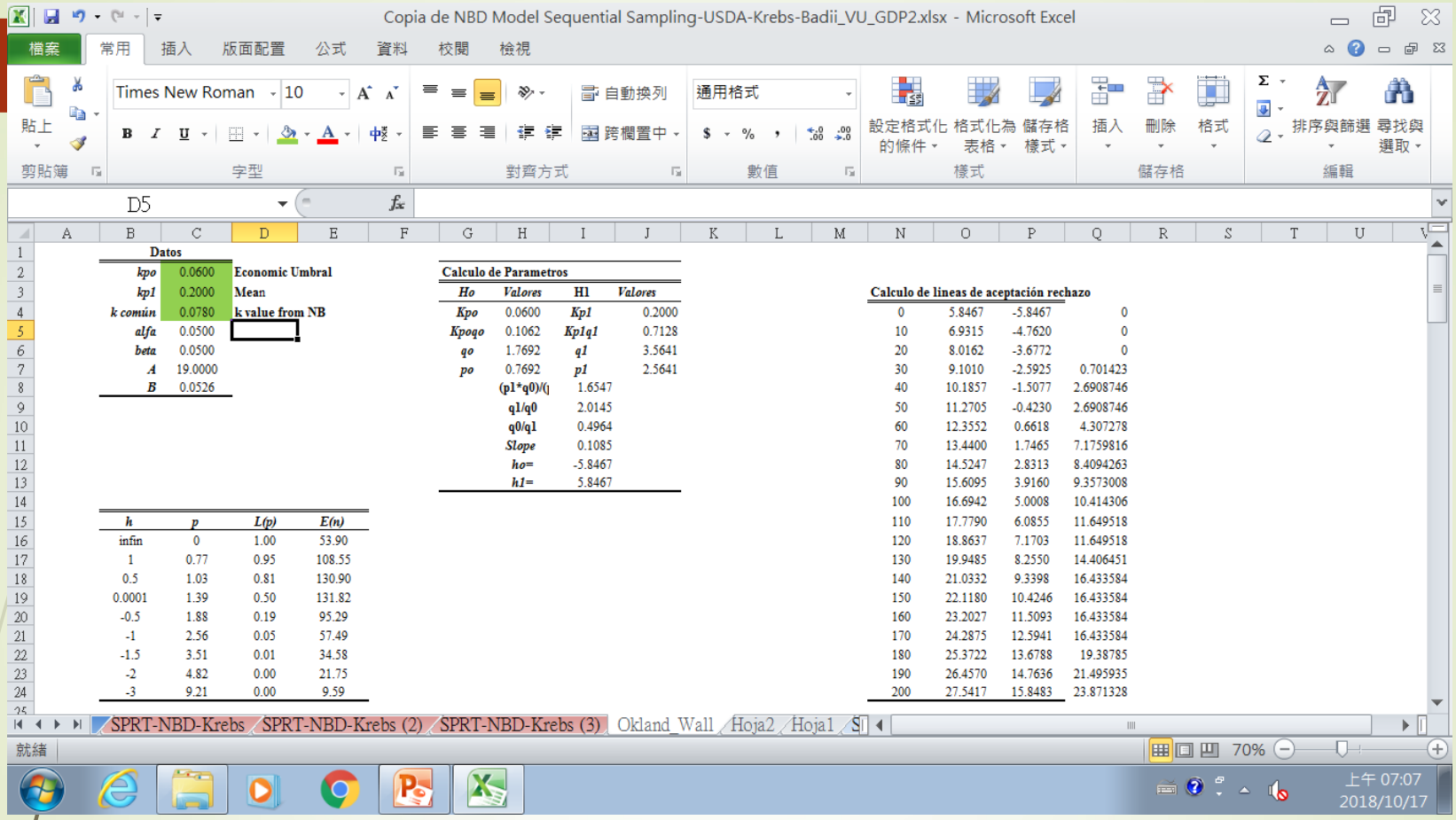
Chi-square and other statistc for testing differents distributions

	Poisson	Binomial	Geometric	Negative Binomial(mme)	Negative Binomial(mle)
sum of residuals	0.1243	0.0350	3.2634	9.2275	9.3172
Chi-square Statistic	112.5171	123.0327	44.1295	14.3522	3.2322
p-value	0.0000	0.0000	0.0000	0.2788	0.9937
MSE	939.0411	1032.6554	335.5326	57.5986	1.8276

We resampling 1000 times for differents samples sizes (10,20,200,500,1000) and the results were identical, so we concluded that the psyllids population follows a negative binomial distribution with an alpha close to 95 %.

The maximun likelihood method present a better fit than the moment method.

Sequential Sampling – Wald - Okland



p: indicates the average density, ***po*** the minimum value observed to avoid the insect control,

q: standard deviation and, k-value from the negative binomial obtained by maximum likelihood

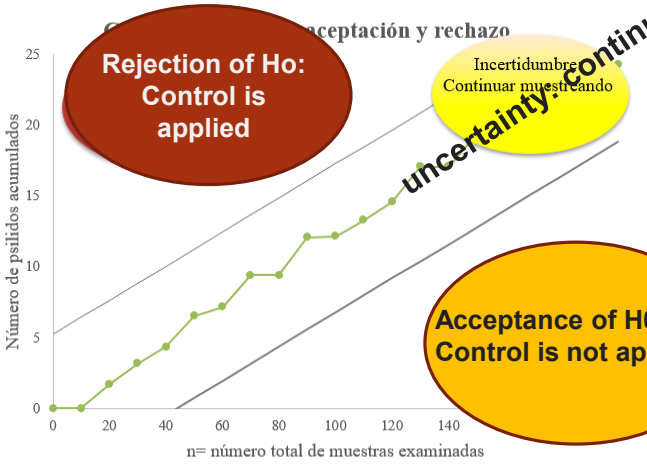
For alpha and beta it is suggested to assign values of 0.05.

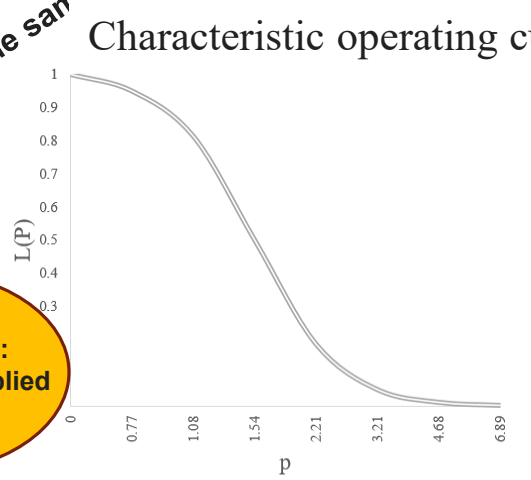
Copia de NBD Model Sequential Sampling-USDA-Krebs-Badii_VU_GDP2 - Excel

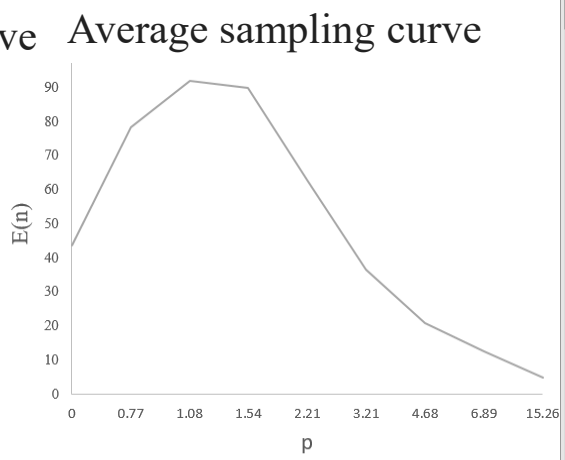
19	0.0001	1.54	0.50	89.96
20	-0.5	2.21	0.19	62.80
21	-1	3.21	0.05	36.40
22	-1.5	4.68	0.01	20.91
23	-2	6.89	0.00	12.50
24	-3	15.26	0.00	4.90

150	23.2897	12.7993	19.4092505
160	24.4927	14.0022	21.161463
170	25.6956	15.2052	21.2530385
180	26.8986	16.4082	22.0048236
190	28.1016	17.6111	22.0048236
200	29.3045	18.8141	24.2629773

ACCEPTANCE AND REJECTION LINES



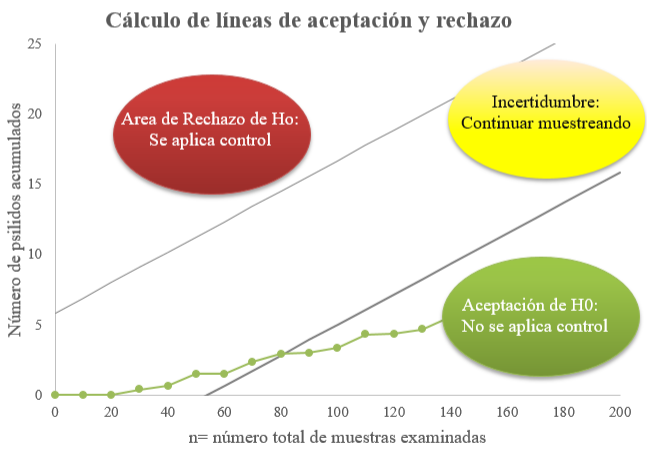


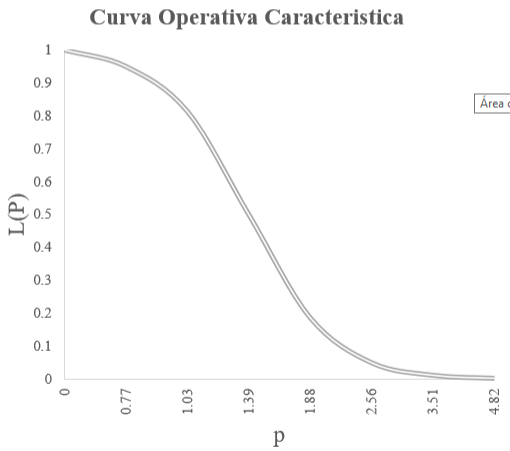


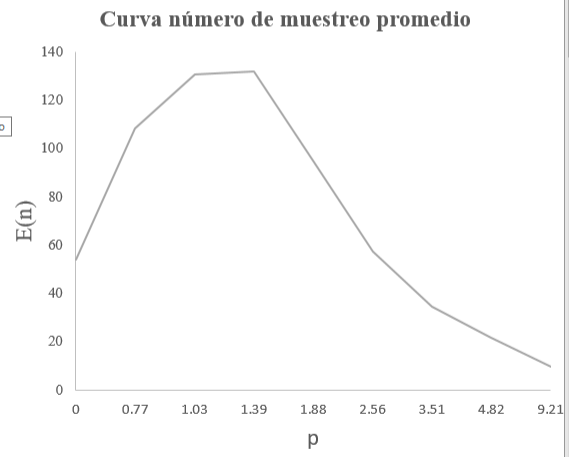
Copia de NBD Model Sequential Sampling-USDA-Krebs-Badii_VU_GDP2 - Excel

-0.5	1.88	0.19	95.29	
-1	2.56	0.05	57.49	
-1.5	3.51	0.01	34.58	
-2	4.82	0.00	21.75	
-3	9.21	0.00	9.59	

160	23.2027	11.5093	6.71577247
170	24.2875	12.5941	6.90292687
180	25.3722	13.6788	7.15590739
190	26.4570	14.7636	7.49050563
200	27.5417	15.8483	7.49050563







Psilidos por trampa

SPRT-NBD-Krebs | SPRT-NBD-Krebs (2) | SPRT-NBD-Krebs (3) | Okland_Wall | Hoja2 | Hoja1 | SPRT-NBD-Binns-Nyrop | Stop line-Green-Nyrop

Listo

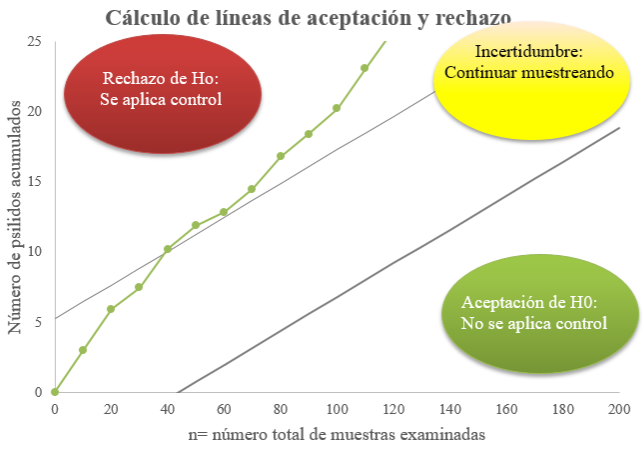
Buscar en la web y en Windows

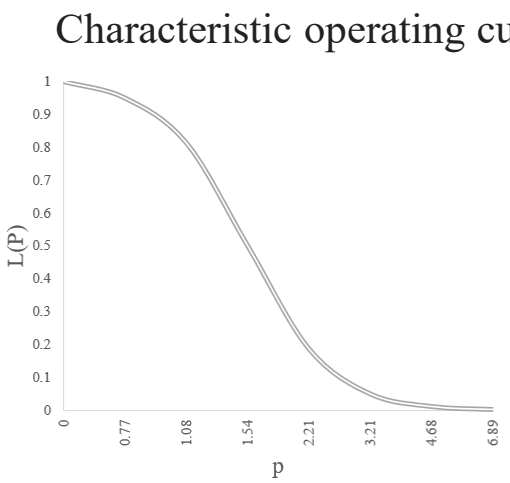
09:41 a. m.
05/10/2018

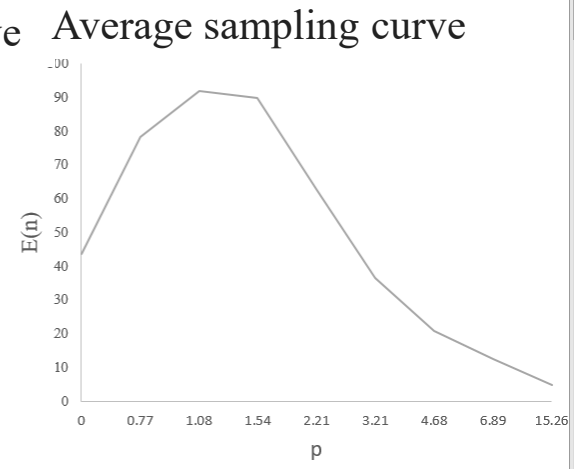
Copia de NBD Model Sequential Sampling-USDA-Krebs-Badii_VU_GDP2 - Excel

19	0.0001	1.54	0.50	89.96
20	-0.5	2.21	0.19	62.80
21	-1	3.21	0.05	36.40
22	-1.5	4.68	0.01	20.91
23	-2	6.89	0.00	12.50
24	-3	15.26	0.00	4.90

150	23.2897	12.7993	32.5349281
160	24.4927	14.0022	32.5349281
170	25.6956	15.2052	35.4081801
180	26.8986	16.4082	37.2273159
190	28.1016	17.6111	41.1259123
200	29.3045	18.8141	41.1259123







CONCLUSIONS

- It was found that the Asian citrus psyllid in Mexico presents an aggregate dispersion.
- The empirical distribution of the Asian Citrus Psyllid (ACP) is the negative binomial.
- For its management and control, a strategy based on sequential sampling is proposed, which will help to define in an accurate way the opportune moment to apply some pest control measures, this ***could bring a decrease in crop losses, control costs and reduce the environmental impact.***

非常感謝你

Muchas Gracias