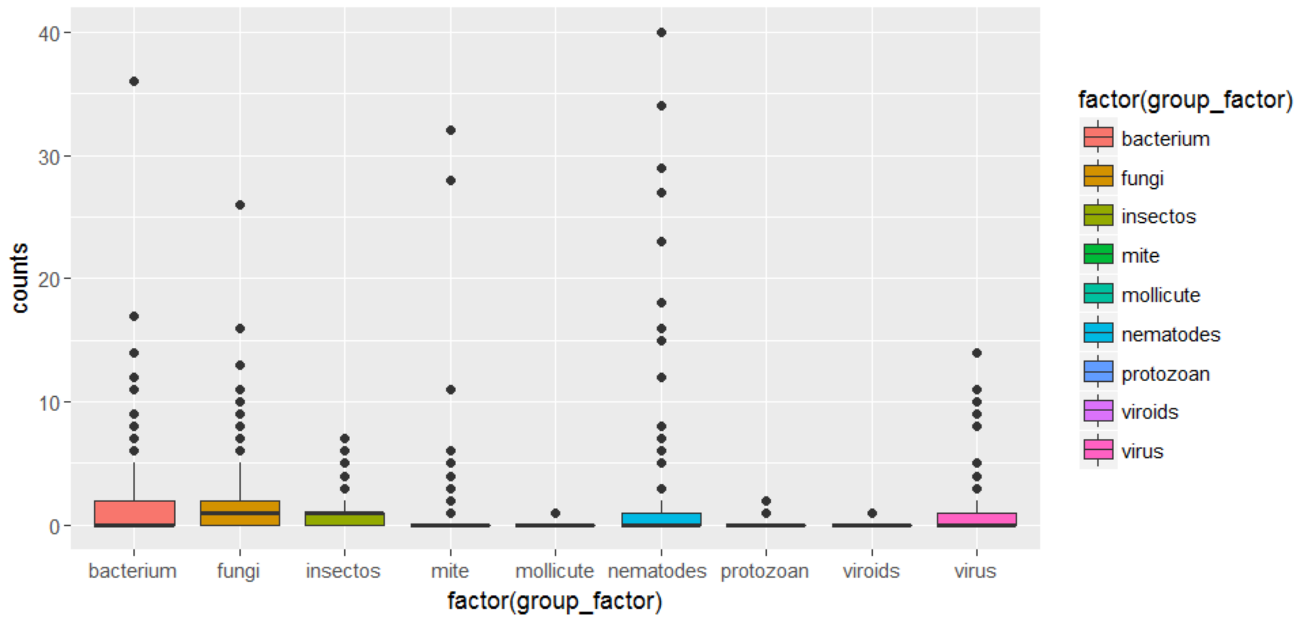
Predictive phytosanitary model for quarantine pests



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Contents

1. Motivation

Some questions related to risk base sampling:

1. What are the pests that excess zero detections in probability?
2. What are the high risk pests?
3. What are the low risk pests?
4. What are the high risk geographical areas, where the pests exceed the expected detections with respect the whole detected pests populaton?
5. What is 100% sampling inspecction?

1. Motivation

Some questions related to risk base sampling:

6. How to perform sampling inspection of reliable exporters involved in international trade?
7. Is it worthwhile to perform a skip lot sampling?
8. Is the same risk for ports, airports and frontiers?.
9. Which are the high risk products associated with pests detections?.
10. Which OISAS are the hotspots of pest detections?.

1. Proposal

Risk

To define risk statistically (to stablish a statistical methodology to estimate the probability of risky pests).

Samplig

- To establish 2 types of sampling:
- 1. 100% shipments inspection by sampling for high risk products.
- 2. Skip lot sampling for low risk products.

Improvement measurement

- 1. Human and economical savings if focus on risky pests.
- 2. To develop reliable exporters.
- 3. Save around 50% of spendings if skip lot sampling is performed.

Risk

Define risk

Use:

1. ***NB regresion*** to detect high quarantine pests.

2. ***Hurdle regression*** to estimate the probability to excess zero detections and to estimate the effectiveness of more strict inspection controls: P[X>0].

3. ***STAR models*** to represent relative high phytosanitary risk with respect to the whole population: RR=O/E. If RR exceeds 1 means the analysed pest is highly risky.

Risk

Non spatial models for counts

- Poisson:
  $$f(y_i/\underline{x_i}^T, \mu_i) = \frac{exp(-\mu_i)\mu_i^{y_i}}{y_i!} \; ; \; E(y_i/\underline{x_i}^T) = \mu_i$$
- BN:
  $$f(y_i/\mu_i, \theta) = \frac{\Gamma(y_i+\theta)}{\Gamma(\theta)y_i!}\frac{\mu_i^y\theta^\theta}{(\mu_i+\theta)^{y+\theta}} \; ; \; E(y_i/\underline{x_i}^T) = \mu_i$$
- RIC:
  $$f_{zero\_inflation}(y_i/\underline{x_i}^T, \underline{z_i}^T, \beta, \gamma) =$$
  $$f_{zero}(0/\underline{z_i}^T, \gamma)I_{\{0\}}(y_i) + (1 - f_{zero}(0/\underline{z_i}^T, \gamma)) \cdot f_{count}(y_i/\underline{x_i}^T, \beta)$$
  $$E\left(y_i/\,\underline{x_i}^T\right) = \pi_i \cdot 0 + (1-\pi_i)\cdot exp(\underline{x_i}^T\beta); \pi_i = f_{zero}(0/\underline{z_i}^T, \gamma)$$
- Hurdle:
  $$f_{hurdle}(y_i/\underline{x_i}^T, \underline{z_i}^T, \beta, \gamma) =$$
  $$\begin{cases} f_{zero}(0/\underline{z_i}^T, \gamma), & \text{if } y_i = 0 \\ \frac{(1-f_{zero}(0/\underline{z_i}^T, \gamma))\cdot f_{count}(y_i/\underline{x_i}^T, \beta)}{(1-f_{count(0/\underline{xi}^T, \beta)})}, & \text{si } y_i > 0 \end{cases}$$
  $$E\left(y_i/\,\underline{x_i}^T\right) =$$
  $$exp\left[\underline{x_i}^T\beta + log(1 - f_{zero}(0/\underline{z_i}^T, \gamma)) - log(1 - f_{count}(0/\underline{x_i}^T, \beta))\right]$$

(1^{st} data: 2001 – 2010, without coordinates)

Risk

Empirical Bayes models for mapping high relative risk areas (RR)

- $SMR_i = O_i/E_i$ where $O_i \backsim P(E_i\theta_i)$, E_i is the number of cases in region i and θ_i is relative risk. $Var(SMR_i) = O_i/E_i^2$ It is less efficient for little population areas.
- EBPG: With Poisson model for likelihood and Gamma for apriori distribution to estimate the parameters: ν and α which smooths rr: $(O_i + \nu)/(E_i + \alpha)$
- EBLN: with log-Normal Model for both likelihood and apriori (Cressie, 1992). Same failure as EBPG.
- EBMarshall: It considers the regional patron of the data, however it has the same failure that the EBPG model.
- EBMarsloc: It considers the local regional pattern of the data.

(2nd data shape: 32 Mexican States, wth coordinates)

Bayes Spatial models for mapping high risk areas (RR)

Risk

- PGBAYESX (a Structured Additive Regresion models: STAR). A nonlinear GAM model for spatially correlated data with two-dimensional surfaces and heterogeneity among individuals.
  $\eta_r = X\beta + f_{spat}(AREA)$
  r Is a generic variable. Function f can contain non linear,spatial,global and local effects. Local effects as:
  $f_{spat}(AREA) = \beta_x$ where $\beta_x \sim N(0, \tau^2)$
  It does not include W.
- CARBayes: Conditional autoregresive model (hierarchical): Uses W of neighbors.
  $\eta(\mu_k) = X\beta + \phi_k + O_k$
  ϕ_k random effect, O_k offset (observations). This model captures the spatial local correlation of the data yet after removing the covariables effect. Conditioning is over random effects of the adjacent areas by means of (W).

(2^{nd} data shape: 32 Mexican States, wth coordinates)

Samplig

1. 100% shipments inspection by sampling for high risk products

Manuals of statistical methodology for inspection

1. Seeds (2006)
2. Grains (2007)
3. Fruits and vegetables (2007)
4. Dehydrated products (2007)
5. Cut flower and fresh foliage (2007)
6. propagative plant material(2007)

Statistical distributions: binomial, beta-binomial and Poisson.


Curso - Taller
Metodología Estadística para la Inspección de Semillas

Dirigido a: Personal de la Dirección de Sanidad Vegetal y de la Dirección de Inspección Fitozoosanitaria

Manual del Participante

2006

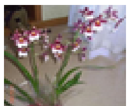
Instructores

Dra. Martha Elva Ramírez Guzmán y Dr. Quirio López Tirado

Samplig

1. 100% shipments inspection by sampling for high risk products

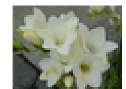
Manuals of statistical methodology for inspection



Material vegetal propagativo

Tabla 1b. Tamaño de muestra para material vegetal propagativo. BAJO RIESGO: Productos que *no* han presentado plaga cuarentenaria durante los últimos 5 años.

Tamaño de muestra para material vegetal propagativo: n_p: unidades primarias, n_c: muestra combinada. n_L: muestra para análisis de laboratorio y $n_{contramuestra}$: contramuestra.								
OFICIAL DE SEGURIDAD FITOZOOSANITARIA							LABORATORIO	
	Paquete o unidad	Unidad de inspección	Tamaño del lote	n_p: unidades de inspección	n_c: en piezas para enviar al laboratorio	n_c: en gramos	n_L: en gramos	$n_{contramuestra}$: en gramos
BAJO RIESGO				paquetes	paquetes			
	paqueres de: acodos, estacas o varetas, sarmientos, estolones y yemas	paquete o bolsa o caja	Para cualquier tamaño del lote	3	2	1,000	500	500
				bulbos	bulbos			
	bulbo	un bulbo	Para cualquier tamaño del lote	86	14	700	350	350
				cormos	cormos			
	cormo o rizoma	un cormo o rizoma	Para cualquier tamaño del lote	86	14	500	250	250
				plátulas	plántulas			
	plánula o esqueje o portainjerto o roseta	una plántula o esqueje o portainjerto o roseta	Para cualquier tamaño del lote	8	2	400	200	200
				tubérculos	tubérculos			
	tubérculo	un tubérculo	Para cualquier tamaño del lote	86	14	3,500	1,750	1,750



Flor cortada y follaje fresco

Tabla 1a. Tamaño de muestra para flor cortada y follaje fresco. ALTO RIESGO: Productos que han presentado plaga cuarentenaria durante los últimos 5 años.

Tamaño de muestra para material vegetal propagativo: n_p: unidades primarias, n_c: muestra combinada. n_L: muestra para análisis de laboratorio y $n_{contramuestra}$: contramuestra.								
OFICIAL DE SEGURIDAD FITOZOOSANITARIA							LABORATORIO	
	presentación (unidad de inspección)	Tamaño del lote: paquetes o piezas			n_p: unidades de inspección	n_c: en piezas para enviar al laboratorio	n_L: en gramos	$n_{contramuestra}$: en gramos
ALTO RIESGO	Flor cortada							
					paquete	paquete	hojas, flores y tallos	hojas, flores y tallos
	flor cortada ramo, combo, bouquet		N≤	100	14	5	250 (Peciolo y al menos 50 hojas jóvenes maduras completamente expandidas) y tallos (al menos 10)	250 (al menos 10 tallos)
		101	<N		31			
					pieza	pieza	hojas, flores y tallos	hojas, flores y tallos
	flor cortada a granel		N≤	100	14	5	250 (Peciolo y al menos 50 hojas jóvenes maduras completamente expandidas) y tallos (al menos 10)	250 (igual que n_L)
		101	<N		31			
	Follaje fresco							
					paquete	paquete	hojas y tallos	hojas y tallos
	follaje fresco ramo, combo, bouquet		N≤	100	14	5	250 (al menos 100 hojas y 10 tallos)	250 (igual que n_L)
		101	<N		31			
					pieza	pieza	hojas y tallos	hojas y tallos
	follaje fresco a granel		N≤	100	14	5	250 (al menos 100 hojas y 10 tallos)	250 (igual que n_L)
		101	<N		31			

Tables

Samplig

2. Skip lot sampling for low risk products

1. CSP – 3 continuous sampling for seeds lots with a fraction f for reliable importers (2013)

Skip lot sampling (Schilling, 1982, Duncan, 1989 y MIL.STD-1235C, 1988).

Sampling: CSP-3

AMSAC

Senasica

Dirección General de Sanidad Vegetal

Improvement measurement

1. Savings

Estimated savings from 100% sampling to skip lot samplig:

Inspection type	Pesos	%
100% shipments inspection by sampling (DGSV)	$93,249,085.44	
Skip lot sampling (DGIF)	$46,820.826.78	
Economical saving	$46,428,258.66	49.78%

Expected improvements after the proposal:

1. Human and economical savings if focus on risky pests.

2. To develop reliable exporters.

3. Save around 50% of spendings if skip sampling is performed.

3.Results

3.1 Descriptive statistics

Pest	mean	sd	min	max	sum
Weeds	6.58	14.69	0	141	2519
Nematodes	2.4	6.76	0	40	286
Fungi	1.73	3.25	0	26	260
Bacteria	1.66	3.97	0	36	232
Insects	1.02	1.43	0	7	164
Virus	1.19	2.63	0	14	146
Mite	1.1	4.24	0	32	121
Protozoan	0.03	0.24	0	2	3
Viroids	0.02	0.15	0	1	2
Mollicute	0.01	0.11	0	1	1
TOTAL	2.58	8.47	0	141	3734

From 2001 to 2010

(1st data: 2001 – 2010)

3.Results

3.1 Excess zeros

Counts	Freq.	Rel (%)	Acum. (%)
0	746	53.78514780	53.78515
1	239	17.23143475	71.01658
2	109	7.85868782	78.87527
3	77	5.55155011	84.42682
4	46	3.31651045	87.74333
5	24	1.73035328	89.47368
6	22	1.58615717	91.05984
7	13	0.93727469	91.99712
8	15	1.08147080	93.07859
9	10	0.72098053	93.79957
10	6	0.43258832	94.23216
11	8	0.57678443	94.80894
12	7	0.50468637	95.31363
13	9	0.64888248	95.96251
14	4	0.28839221	96.25090
15	2	0.14419611	96.39510
16	1	0.07209805	96.46720
17	2	0.14419611	96.61139
18	6	0.43258832	97.04398
19	3	0.21629416	97.26027
20	2	0.14419611	97.40447

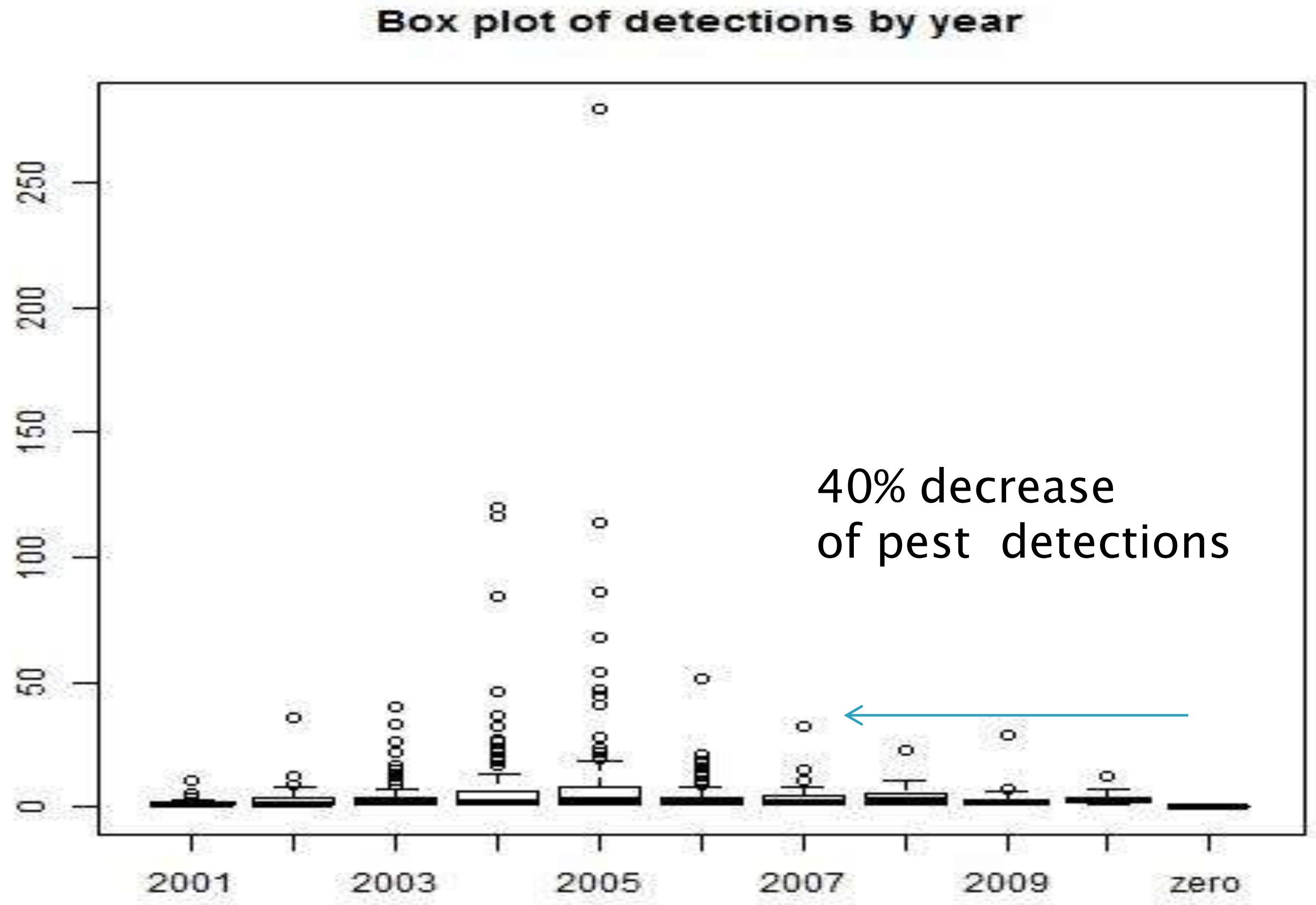
Counts	Freq.	Rel (%)	Acum. (%)
23	1	0.07209805	97.83706
24	3	0.21629416	98.05335
26	2	0.14419611	98.19755
27	2	0.14419611	98.34174
28	1	0.07209805	98.41384
29	1	0.07209805	98.48594
32	2	0.14419611	98.63014
33	1	0.07209805	98.70224
36	1	0.07209805	98.77433
37	1	0.07209805	98.84643
40	1	0.07209805	98.91853
41	1	0.07209805	98.99063
44	1	0.07209805	99.06273
46	1	0.07209805	99.13482
47	3	0.21629416	99.35112
51	1	0.07209805	99.42322
54	1	0.07209805	99.49531
68	1	0.07209805	99.56741
84	1	0.07209805	99.63951
86	1	0.07209805	99.71161
114	1	0.07209805	99.78371
116	1	0.07209805	99.85580
120	1	0.07209805	99.92790
279	1	0.07209805	100.00000

- **Zero excess: 54%**
- **expected zeros=3734*exp(-2.58)=282.94<746**

(1st data: 2001 – 2010)

3.Results

3.1 Box plots by time



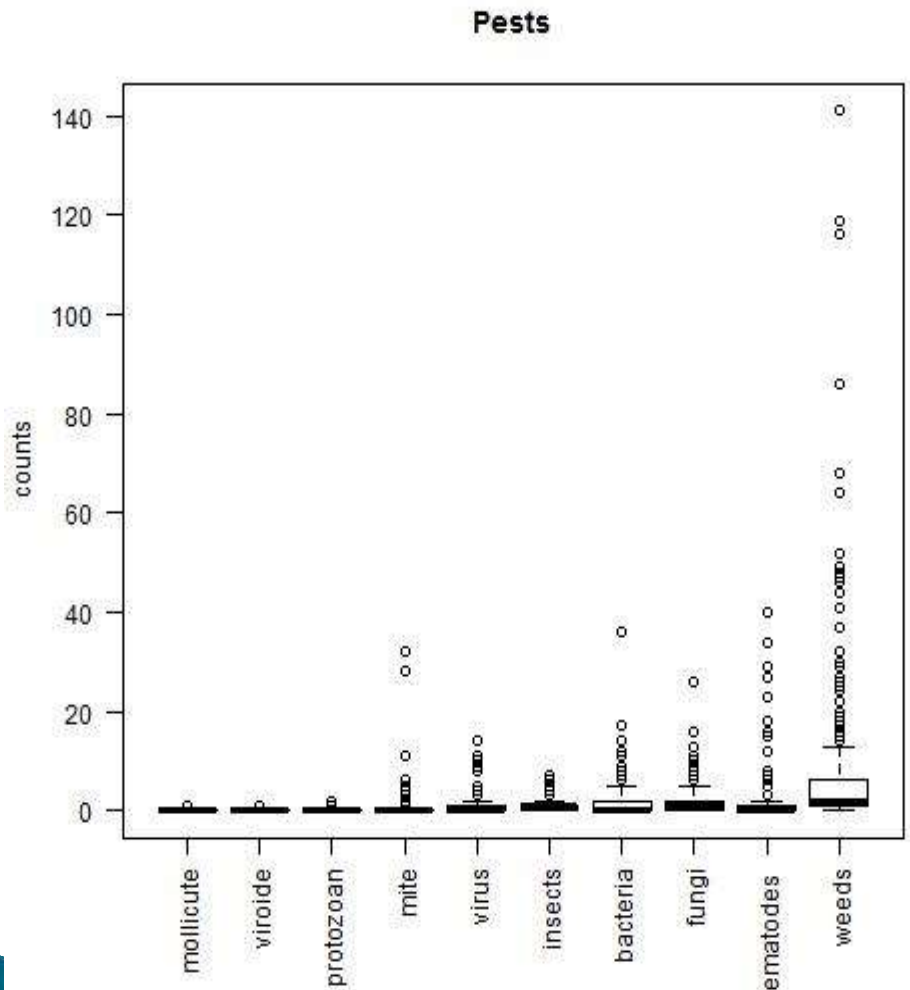
Before the sampling manuals

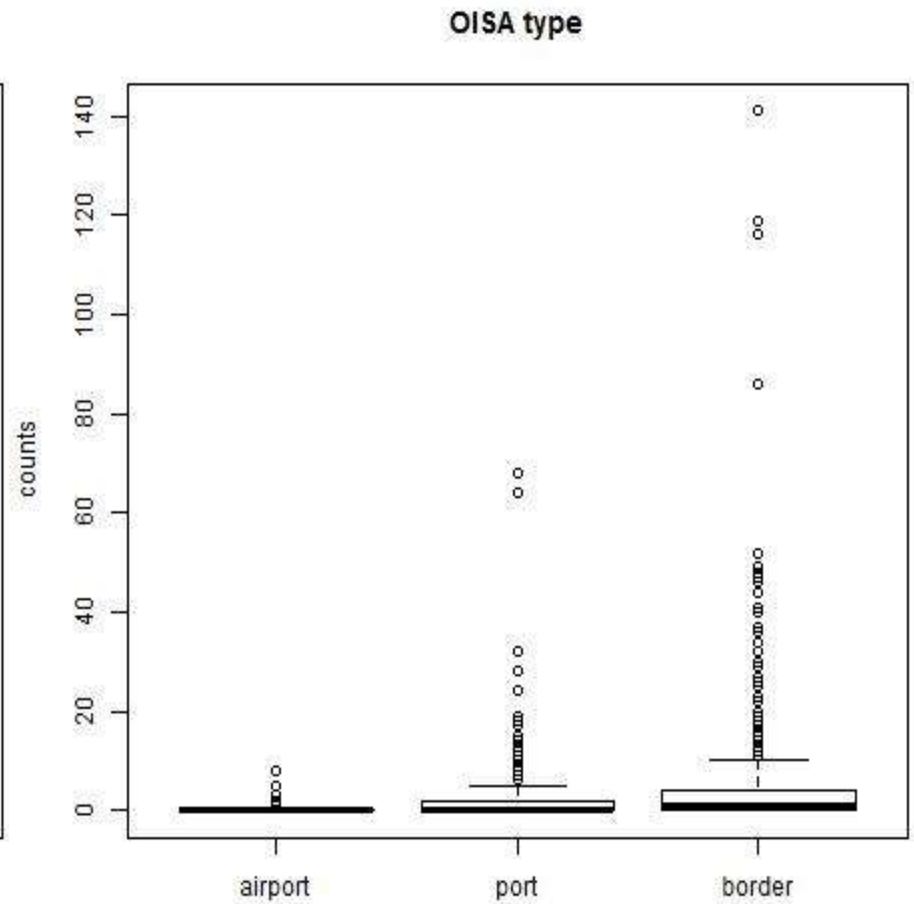
After the intervention of new sampling inspection schemes.

(1st data: 2001 – 2010)

3.Results

3.1 Box plot by pests and receiver

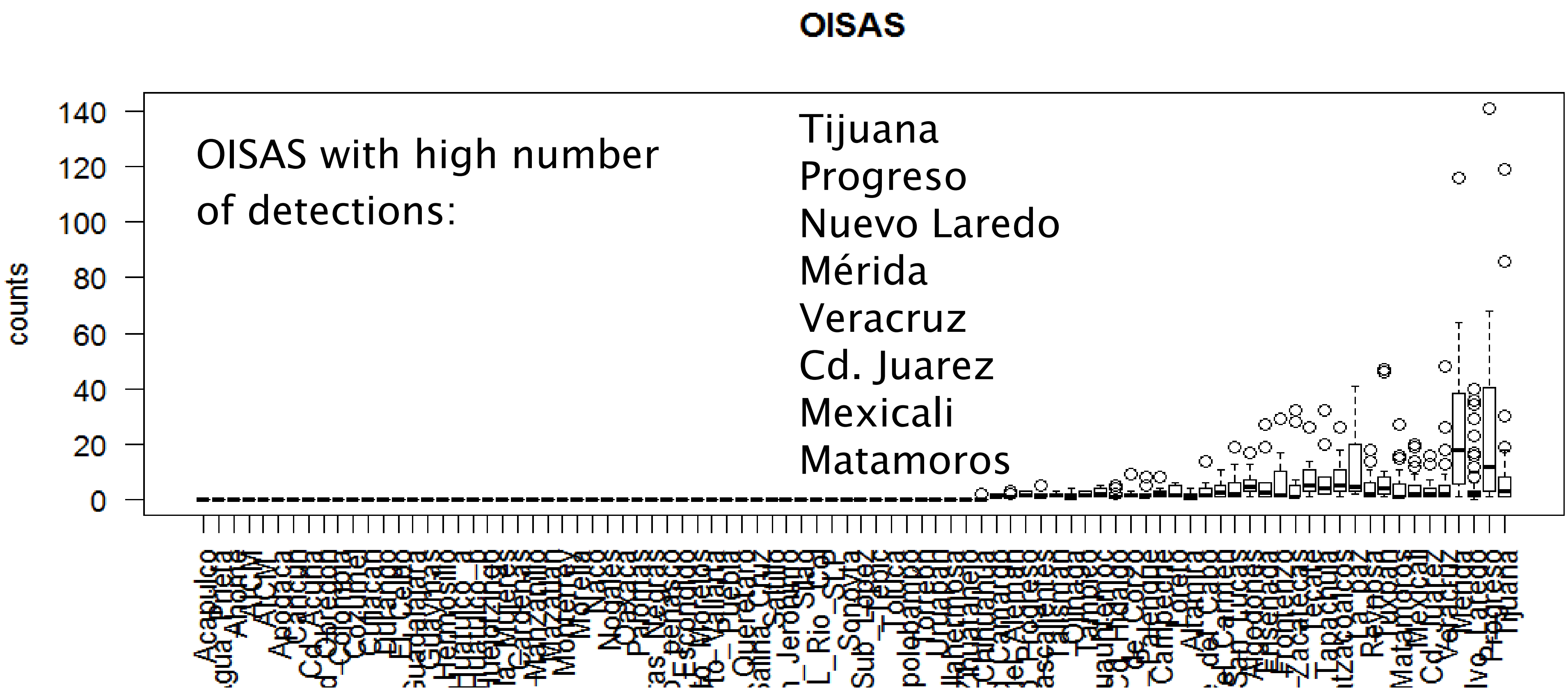




(1st data: 2001 – 2010)

3.Results

3.1 Box plots by OISA



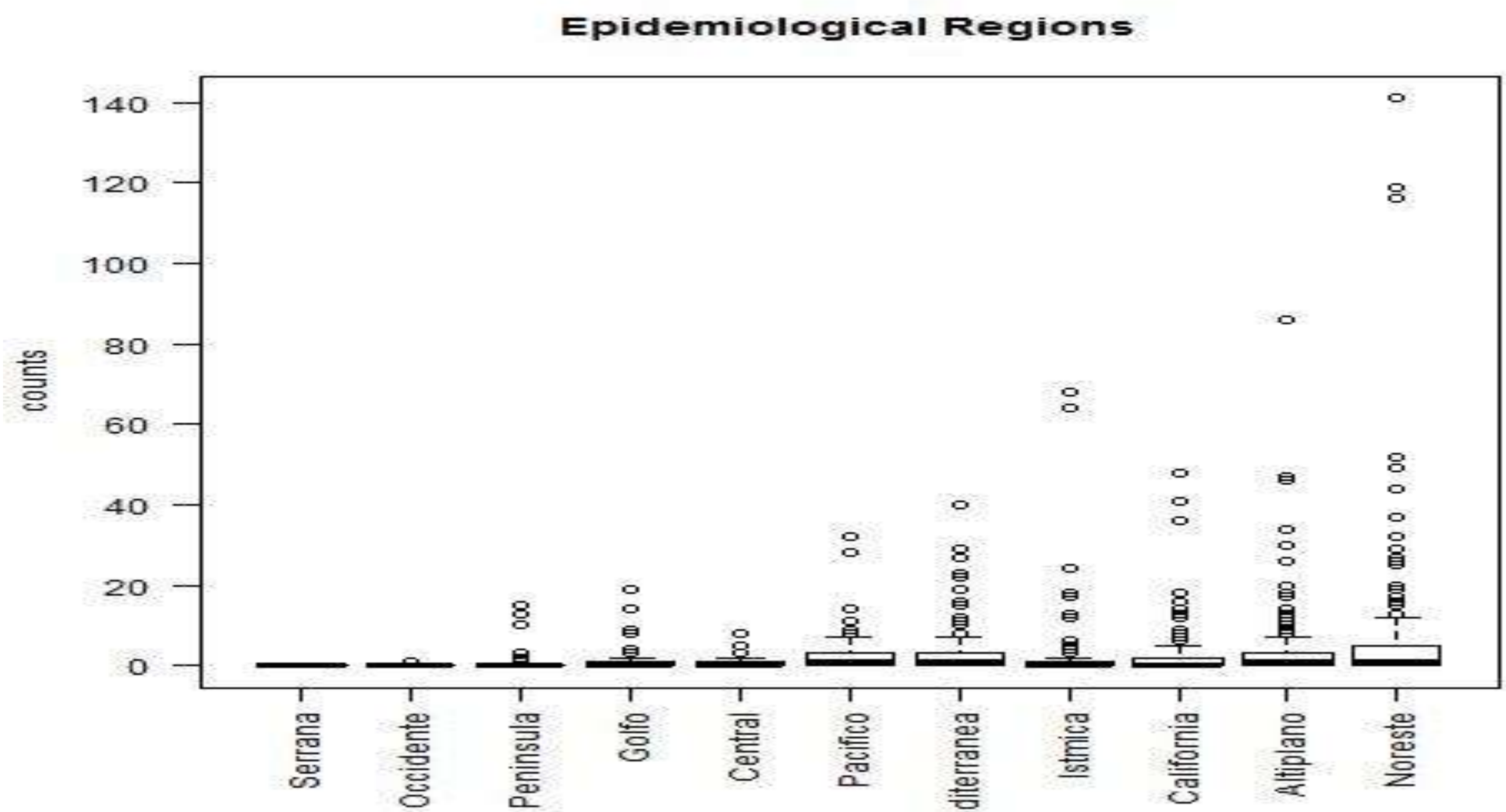
OISAS with high number of detections:

Tijuana
Progreso
Nuevo Laredo
Mérida
Veracruz
Cd. Juarez
Mexicali
Matamoros

(1st data: 2001 – 2010)

3.Results

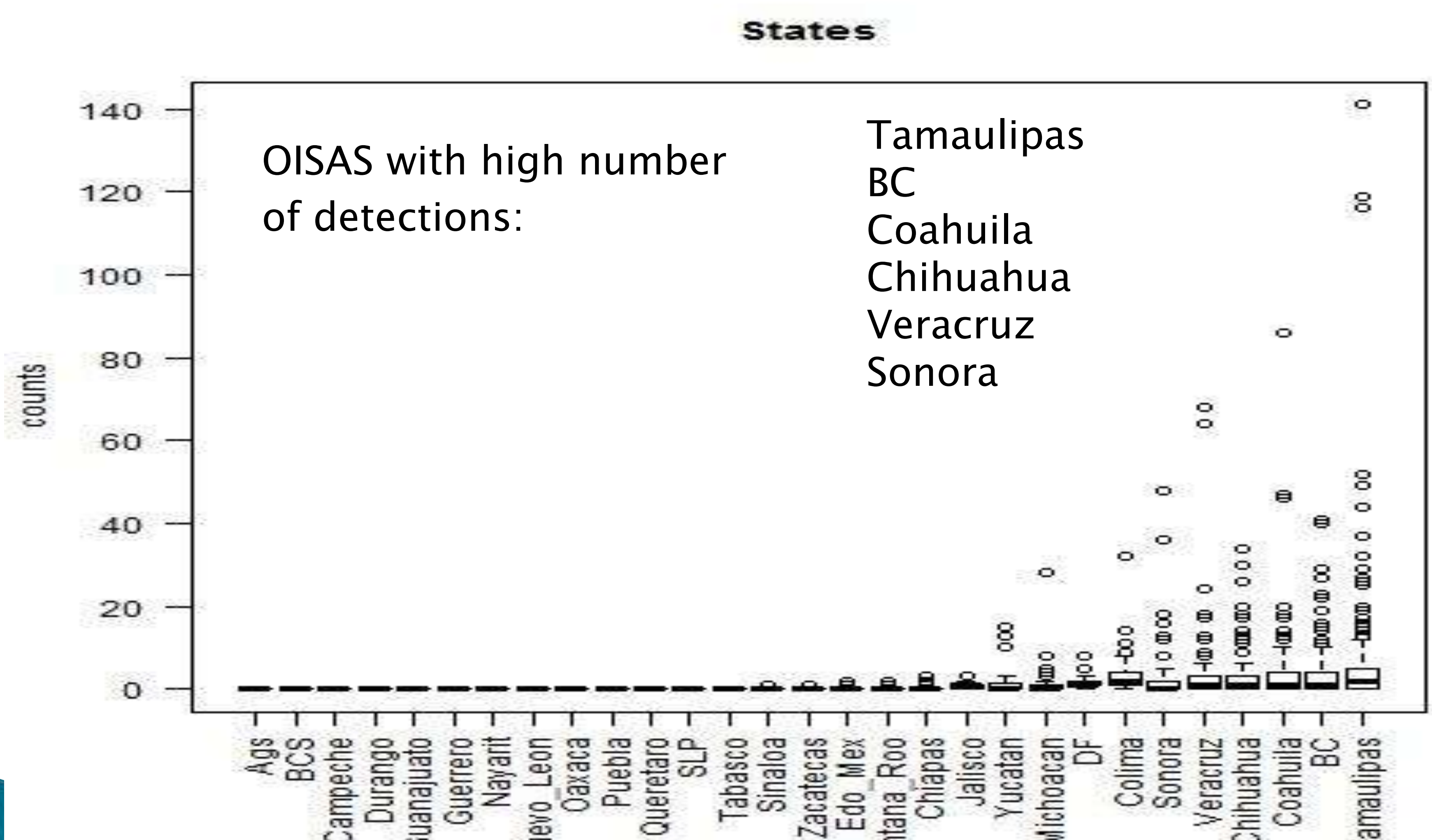
3.1 Box plot by epidemiological regions



(1st data: 2001 – 2010)

3.Results

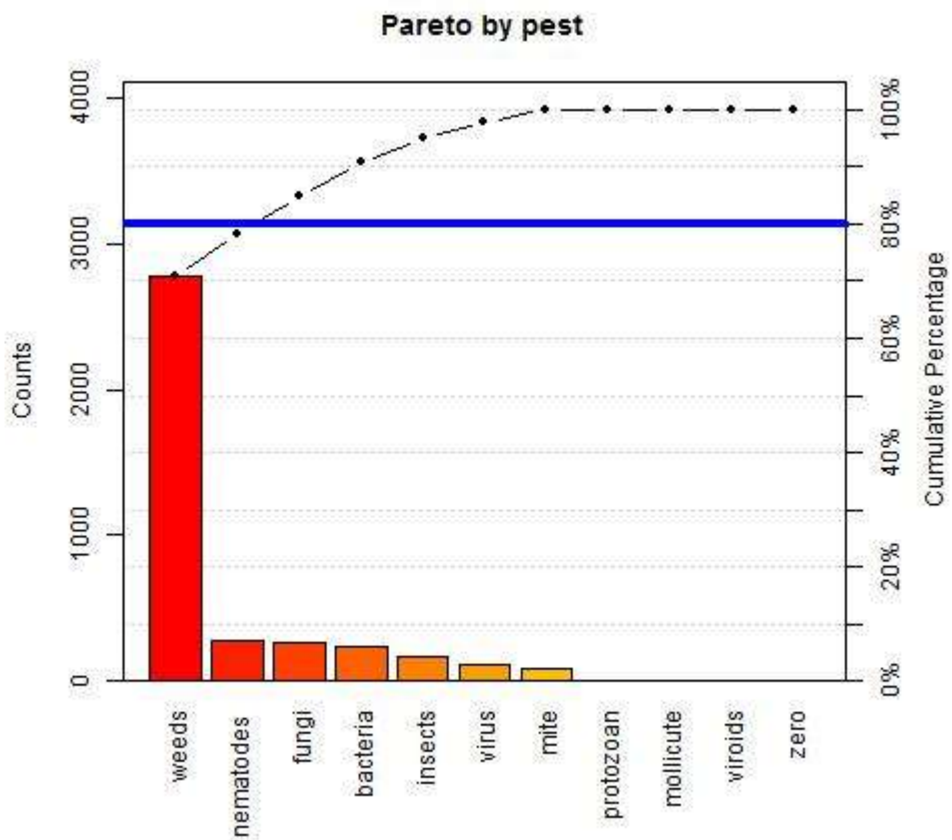
3.1 Box plot by State

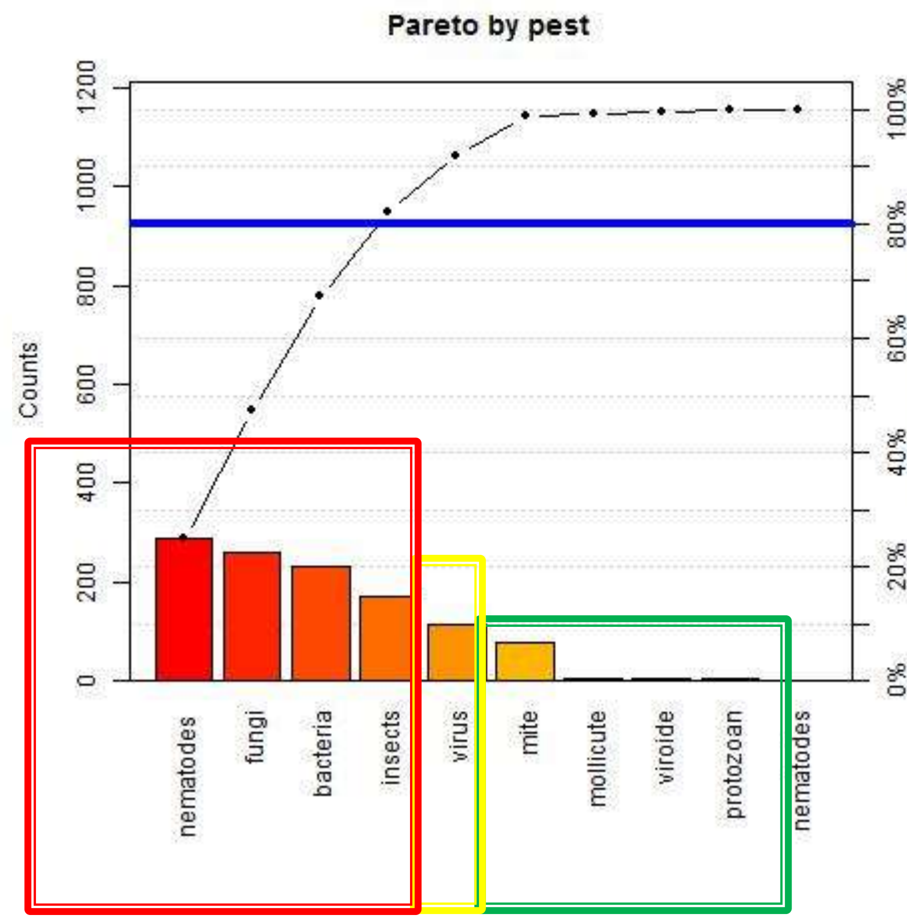


(1st data: 2001 – 2010)

3.Results

3.1 Pareto by pest





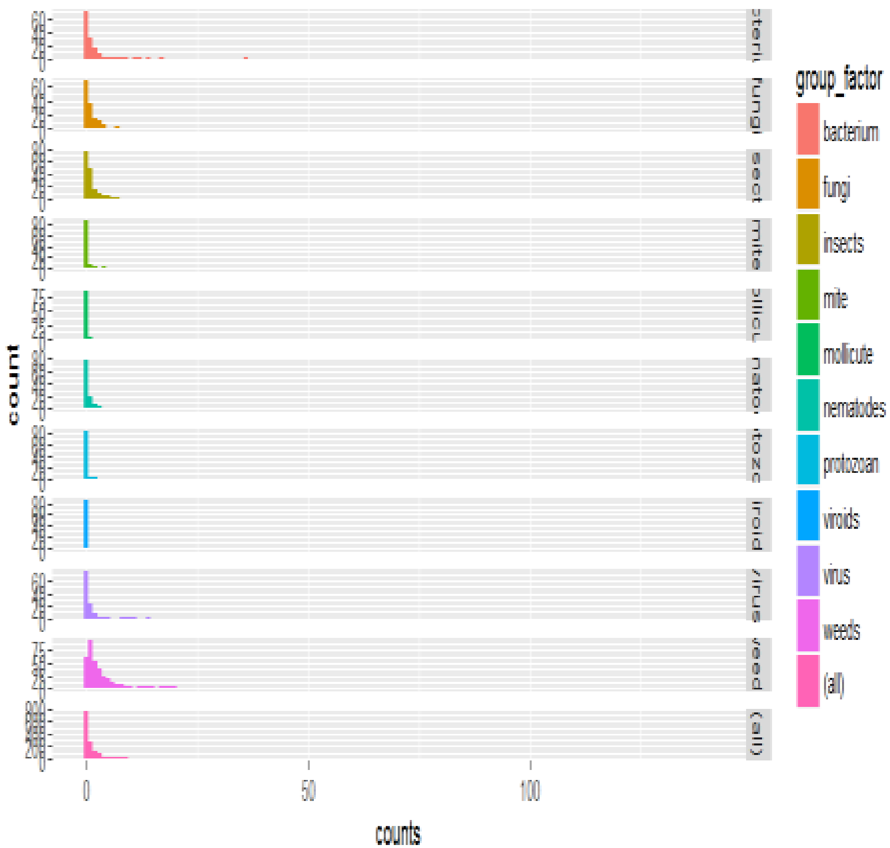
80%: Weeds and nematodes

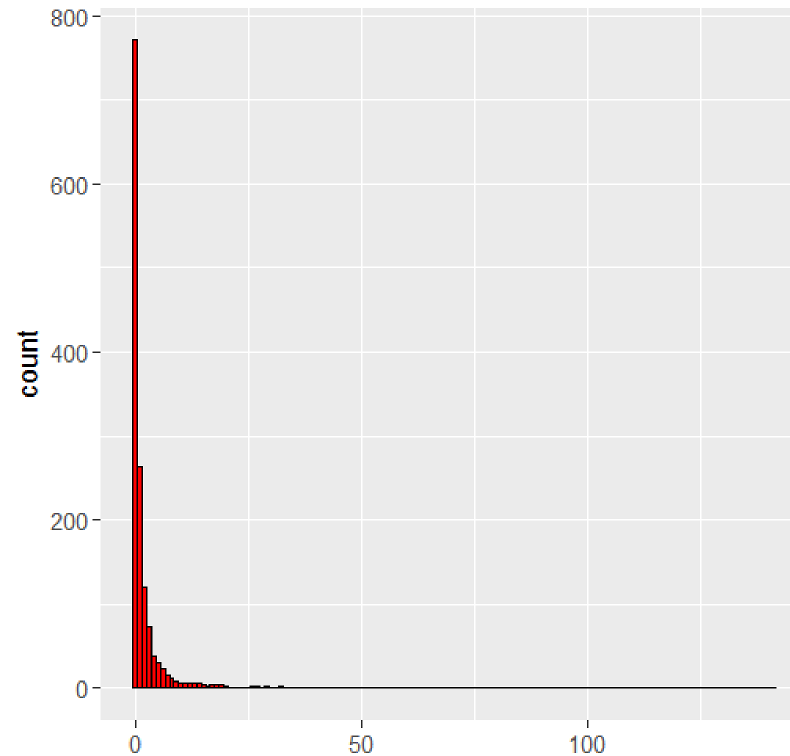
80%: Nematodes,fungi,bacteria and insects (after removimg weeds)

(1st data: 2001 – 2010)

3.Results

3.1 Statistical distribution





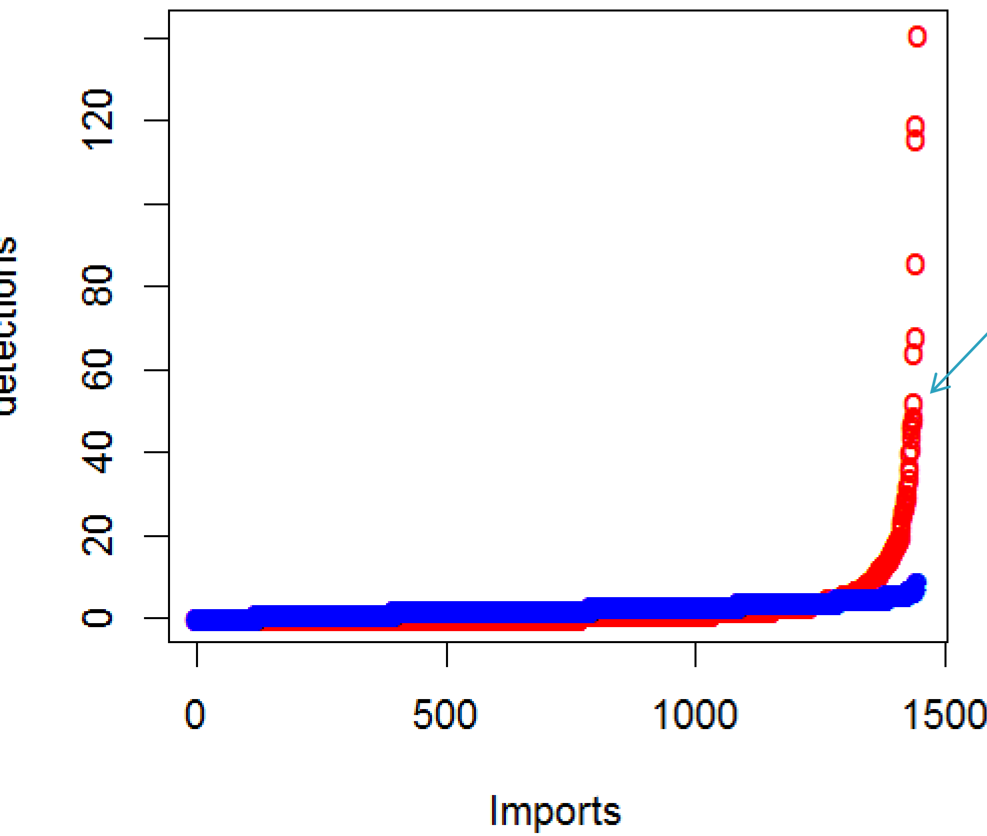
Asimetrical distribution

(1st data: 2001 – 2010)

3.Results

3.1 Overdispersion

Detections (red)- Expected by Poisson (blue)



It is confirmed the **overdispersion** in contrast with Poisson distribution

Ho: Overdispersion does not exist

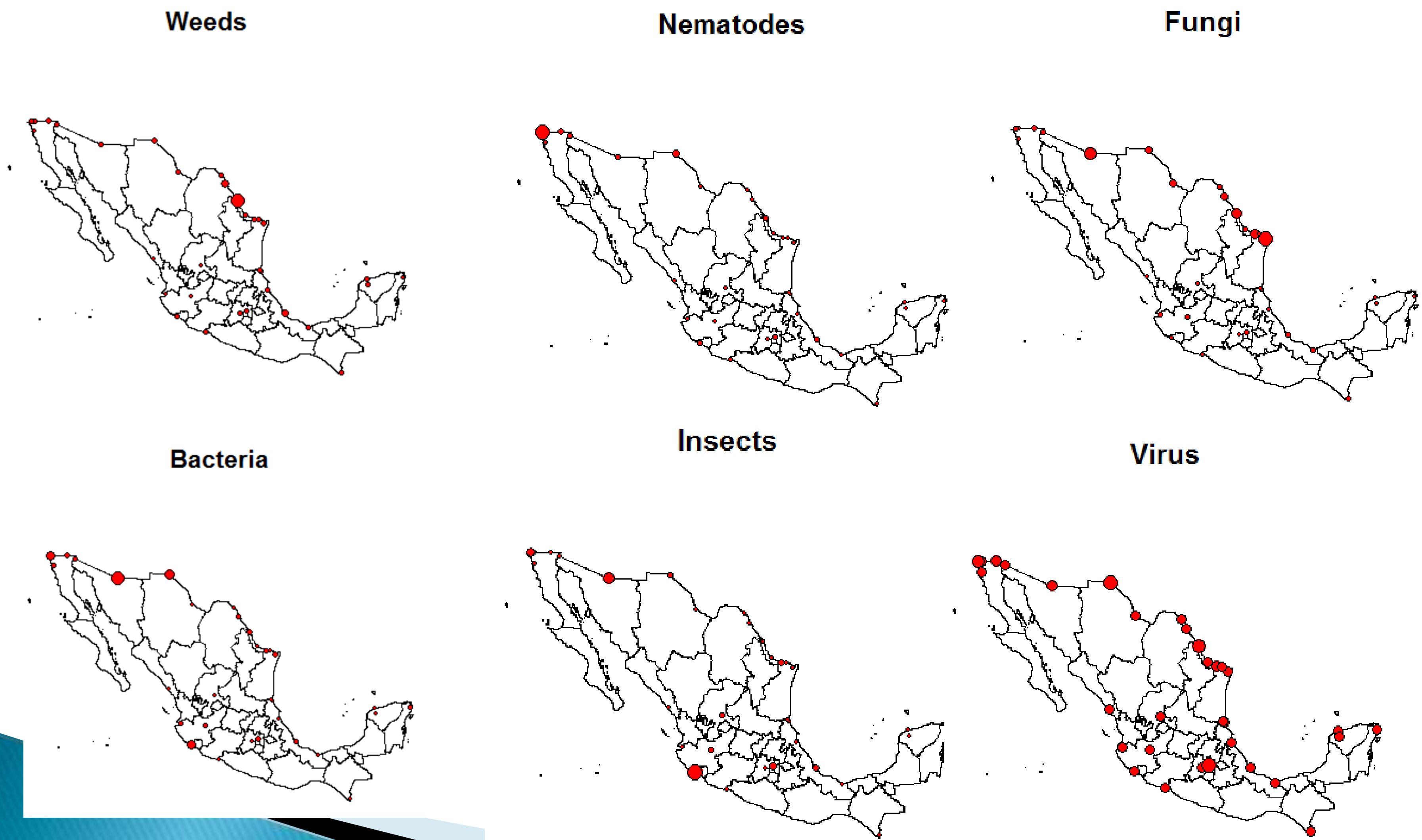
Ha: Overdispersion exists

Overdispersion test	Obs.Var/Theor.Var	Statistic	p-value
poisson data	44.96191	62317.21	0

We rejects Ho, so there exists evidence of overdispersion.

(1st data: 2001 – 2010)

3.1 Data characteristics



(2nd data shape)

3.1 Data characteristics

Mite

Protozoan

Viroids

Mollicute

(2^{nd} data shape)

3.Results

3.1 Data characteristics

Overdispersion, excess of zeros and asimetrical distribution implies to work with alternative regression models:

- NB
- Zero inflation
- Hurdle
- Empirical bayes models
- Structured additive regression (Bayes)

(1st data: 2001 – 2010)

3.2 Identification of highest risk pests with NB (includes weeds)

SENASICA

The incident rate for **weeds**, **nematods, fungi** and **bacteria** are 5.98, 2.18, 1.58 and 1.51 times the incident rate for mites (1.1). Likewise, the incident rate for **protozoan**, **viroids** and **mollicute** are 0.03, 0.02 and 0.01 times the incident for mites.

Insects and virus have similar incidence rate as mites (1.1).

Group	x'β		E(Y)=exp(x´β)
mite	0.0953 (0.1750)		1.10
bacteria	0.4098 (0.2291)	.	**1.51**
fungi	0.4547 (0.2255)	*	**1.58**
insects	-0.0768 (0.2280)		0.93
weeds	1.7882 (0.1935)	***	**5.98**
mollicute	-4.5612 (1.0290)	***	0.01
nematods	0.7816 (0.2341)	***	**2.18**
protozoan	-3.4626 (0.6263)	***	0.03
viroids	-3.8565 (0.7478)	***	0.02
virus	0.0761 (0.2397)		1.08
dispersion parameter	0.39		
2xlog_likehood	-4,714.40		
AIC	4,776.80		

§ In parenthesis SE.

* p<0.005; ** p<0.001; *** p<0.0001

base_grupos_MODIFICADA_SINTETICA.csv

3.2 Identification of higher risk pests with NB (includes weeds)

Incidente rate ratio

Cluster	Pest	Incident rate with respect the reference pest=mites (1.1)
1	weeds	5.98
2	nematodes	2.18
3	bacterias	1.58
4	virus, mites and insects	1.1
5	protozoan, viroids and mollicute	0.02

base_grupos_MODIFICADA_SINTETICA.csv

OISA and Products comparison (includes weeds)

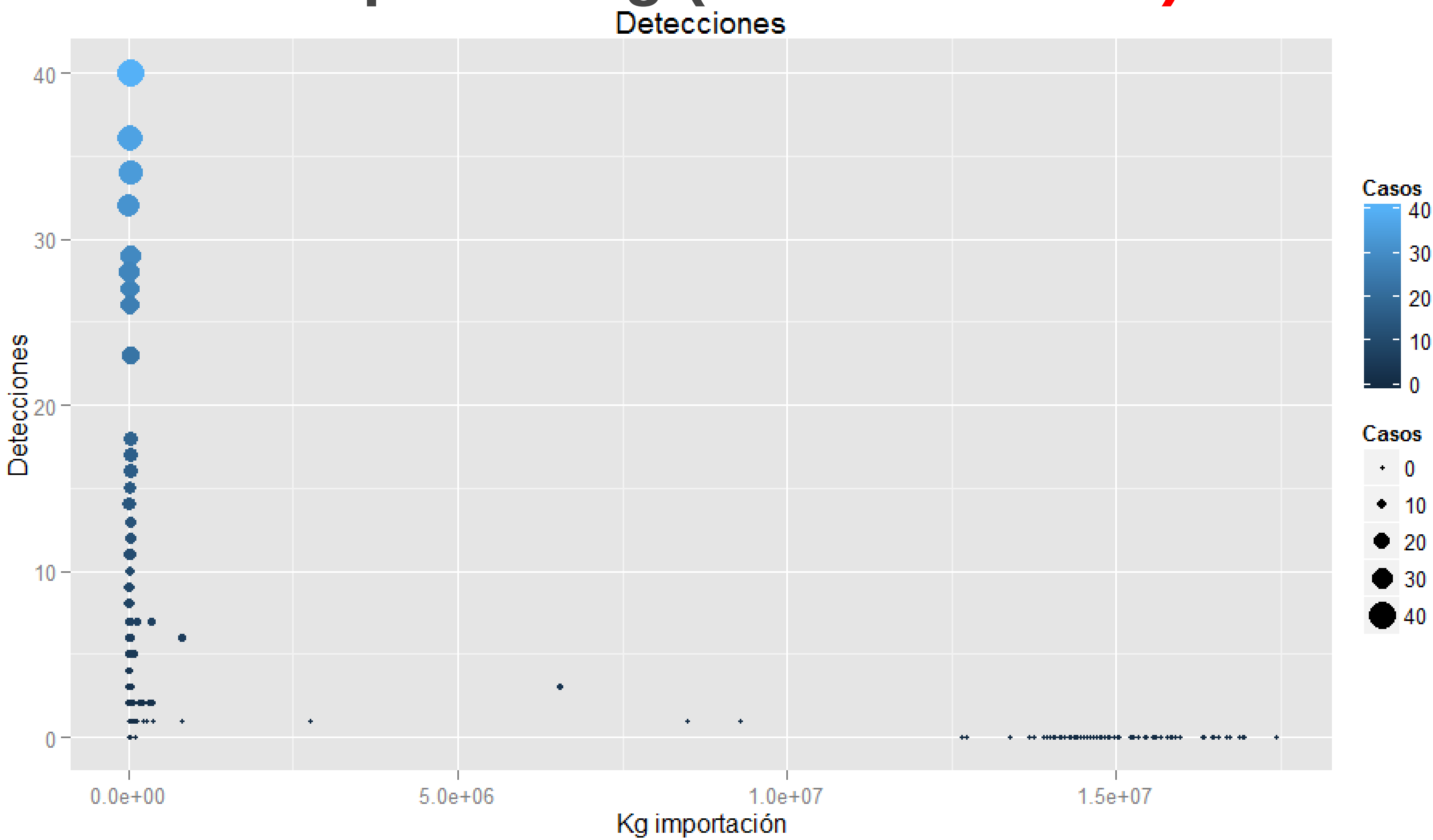
Comparation between OISA types

Detections increase by 17.43 and 8.19 times with respect to airport (0.27) if goods come through *frontier* and **port**, respectively.

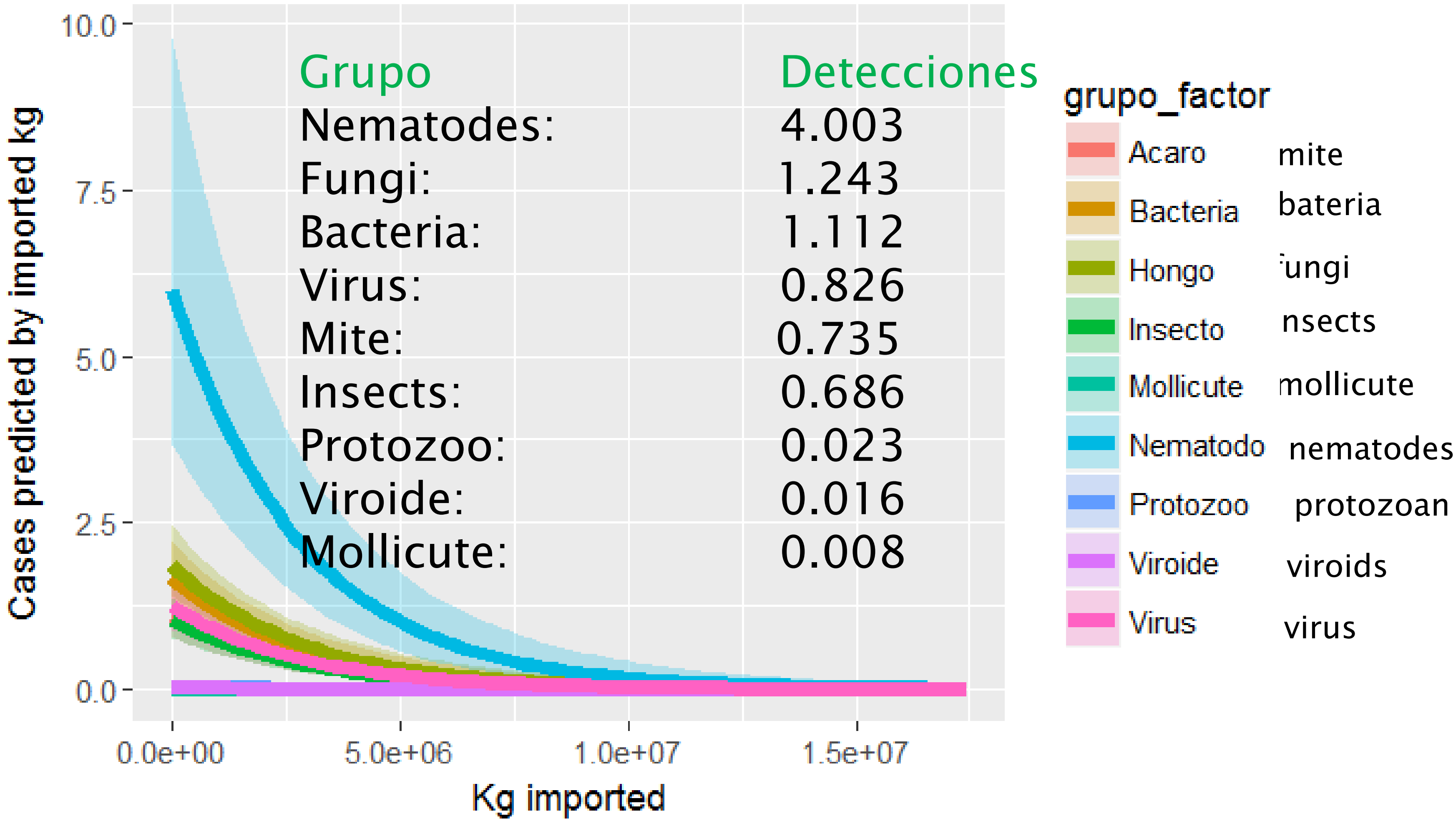
Comparation between products

Detections increase by 8.93, 7.81, 7.72, 7.11, 6.48 times for barley, potato, linseed, lentil, oats with respect to garlic (1).

3.4 Observed detections by imported kg (without weeds)



3.4 Predicted detections for imported products (without weeds)



Grupo	Detecciones
Nematodes:	4.003
Fungi:	1.243
Bacteria:	1.112
Virus:	0.826
Mite:	0.735
Insects:	0.686
Protozoo:	0.023
Viroide:	0.016
Mollicute:	0.008

The increment percentage of detections is of 1% by kg of imported kg. Expected detections for weeds=6 with other data.

base_grupos_MODIFICADA_SINTETICA_SIN_MALEZA

3.3 Hurdle model
(includes weeds)

1. Weeds, fungi, insects, bacteria, virus and nematods have a **Prob[Y>0]** , which indicates that a pest will be presented.

2. E(Y)=exp(X´β) determines how many cases will be detected of this pests.

Pest	Prob[Y>0]		X´β		E(Y)=exp(X´β)
Mite	-1.224	***	-7.145		0.0008
	(0.2275)		18.085		
Bacteria	**1.195**	***	-0.593		**0.5527**
	(0.283)		0.484		
Fungi	**1.411**	***	-0.695		**0.4992**
	(0.281)		0.474		
Insects	**1.311**	***	-1.672	***	0.1879
	(0.277)		0.473		
Weeds	**2.868**	***	**0.714**	.	**2.0430**
	(0.267)		0.435		
Mollicute	-3.230	**	-10.923		0.0000
	(1.031)		93.843		
Nematods	**0.618**	*	**0.512**		**1.6686**
	(0.298)		0.535		
Protozoo	-2.526	***	-2.400		0.0907
	(0.751)		1.600		
Viroids	-2.514	***	-18.215		0.0000
	(0.751)		2585.607		
Virus	**0.743**	*	-0.731		**0.4813**
	(0.294)		0.511		
Dispersion parameters	1e-04»		0.40		
2 x log-likelihood:	-2251				

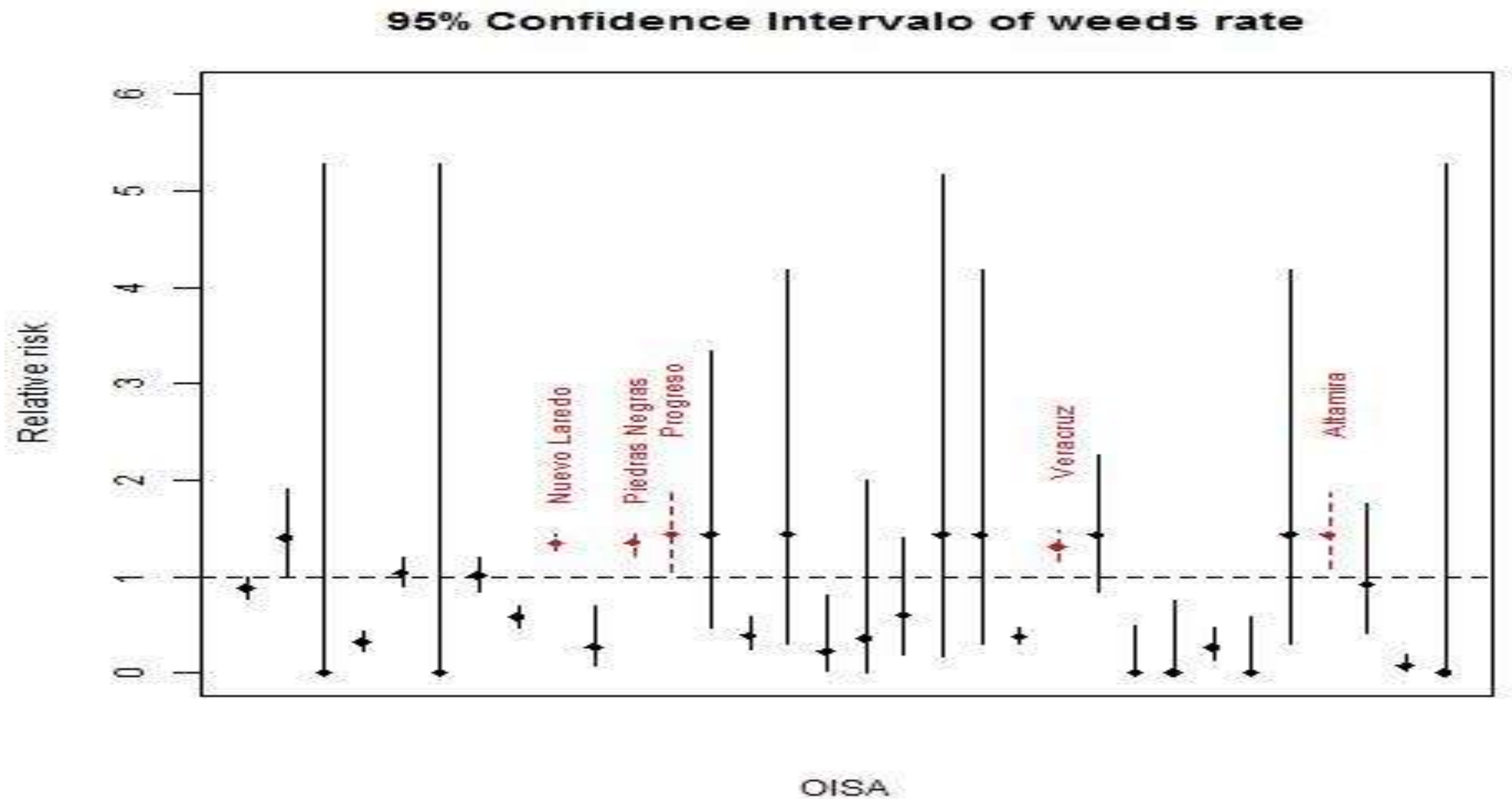
§ Standar error in parenthesis

* p<0.005; ** p<0.001; *** p<0.0001

base_grupos_MODIFICADA.csv

3.4 Searching the best estimator of relative risk =O/E

Weeds excess



	mean	sd	min	max	sum
Weeds	89.06	211.09	0	1,119	2,850
Total	**127.66**	**232.93**	**1**	**1,185**	**4,085**

(2nd data shape)

3.4 Spatial analysis

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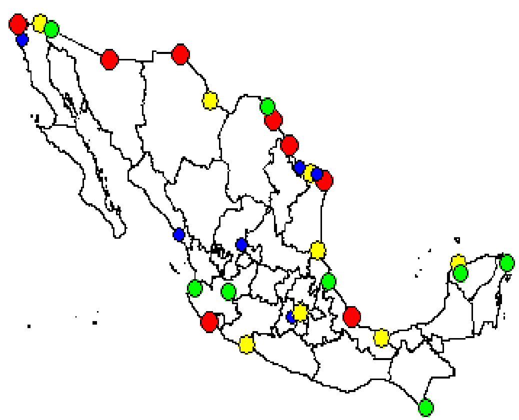
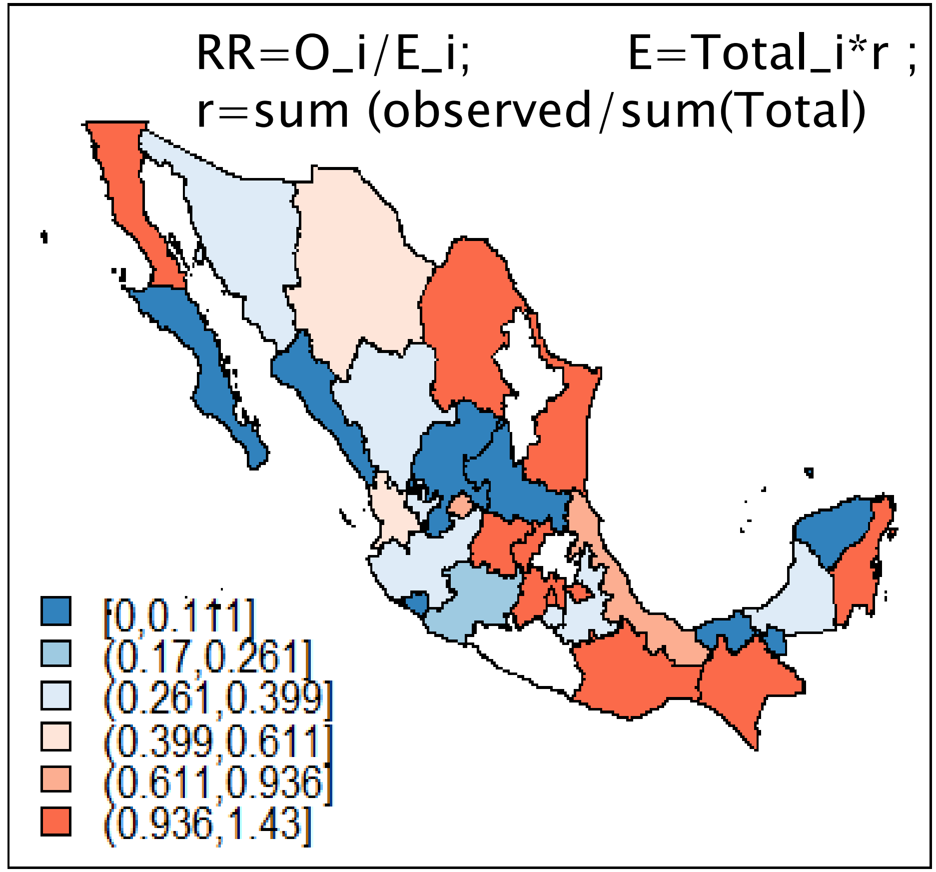
Relative weeds risk (RR)

Risk strata:

- Low
- Low medium
- High medium
- High

Four stata detections





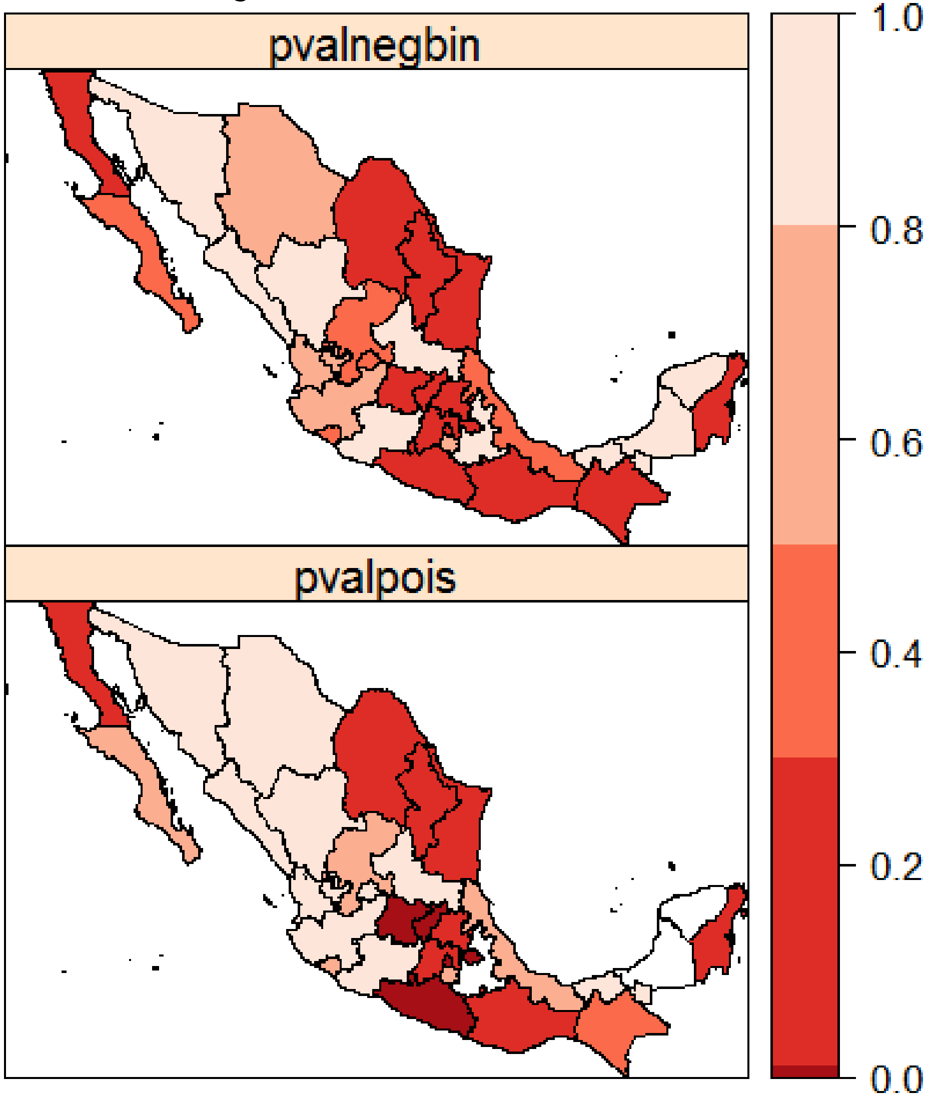
RR=(weeds/total pest)=2850/4085=0.70
If RR>1, implies «excess of weeds»
According to Poisson distribution.

(2nd data shape)

3.4 Spatial analysis

Ho:P(θ<= 1), Where θ =RR: relative risk

p−values <0.05 means rejection of low RR

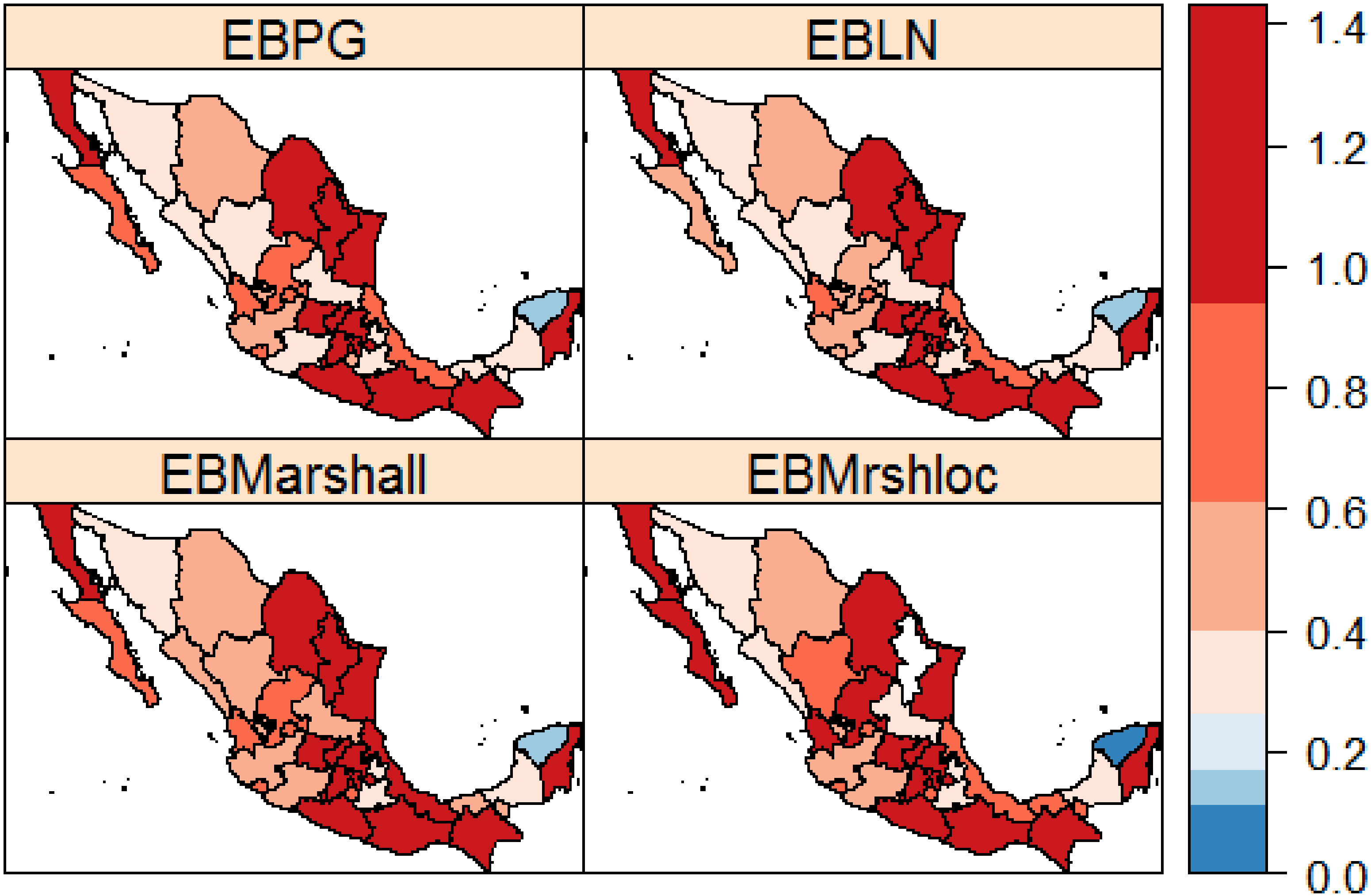


P-values from ***NB*** distribution (NB alert more than Poisson distribution)

P-values from ***Poisson*** distribution

(2nd data shape)

3.4 Spatial analysis EB Risk estimates



Empirical bayesian modelling

(2nd data shape)

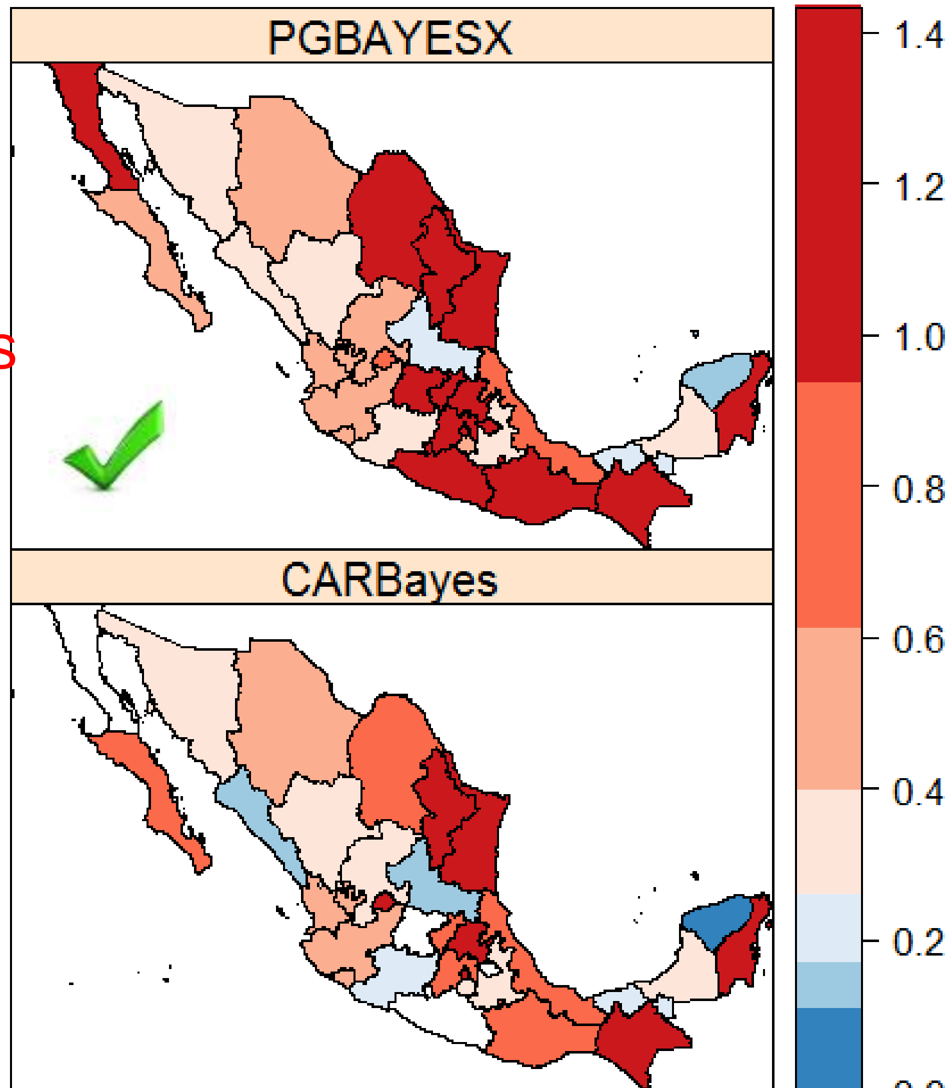
3.4 Spatial analysis (STAR and neigborhood bayesian model)

DIC= 61.45

Bayesian modelling with smooth functions (STAR: Generalized Additive model).

DIC= 487.05

Bayesian modelling with W neighborhood matrix

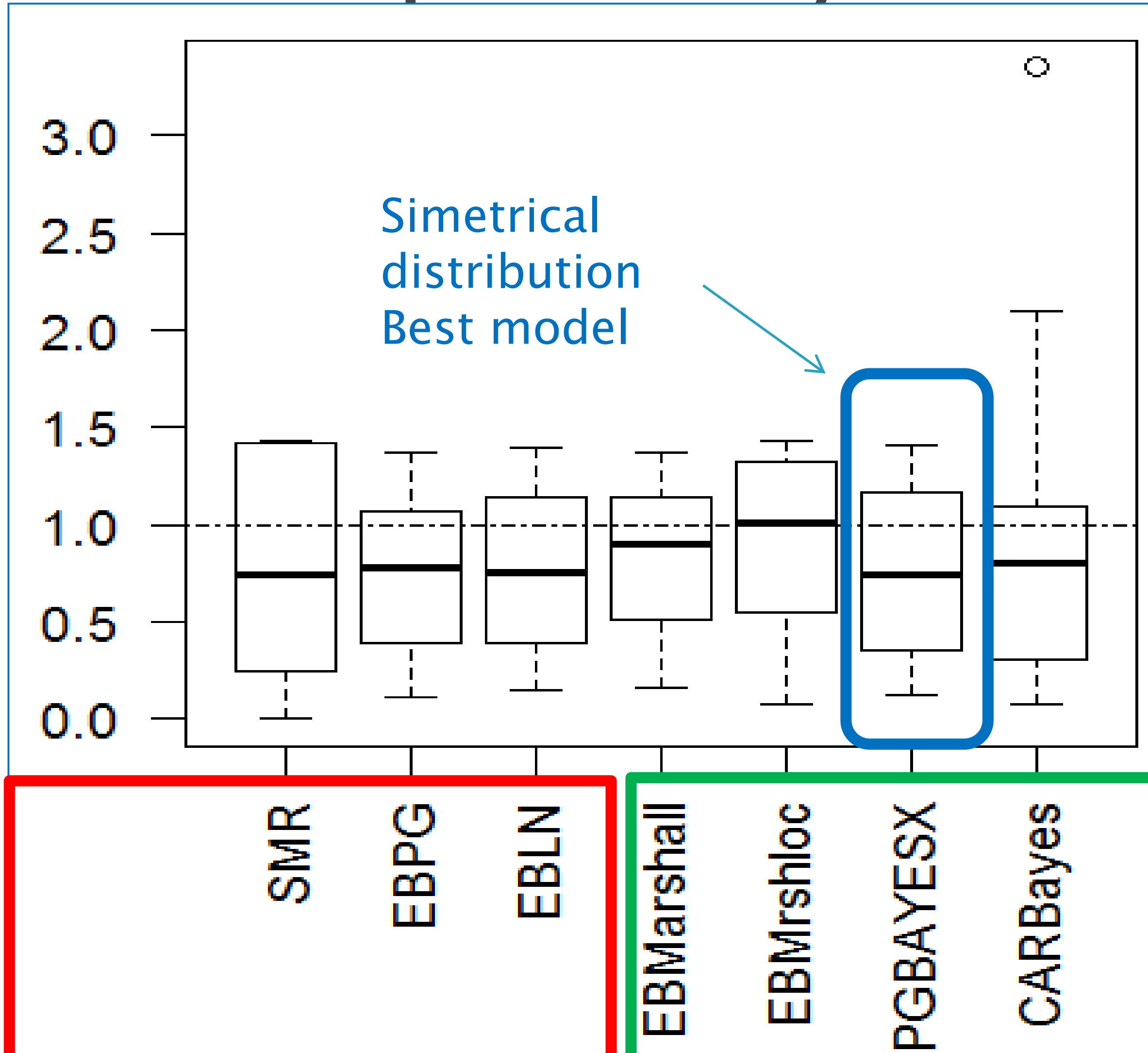


RR	Estado
1.40	Chihuahua
1.40	Sinaloa
1.35	BCS
1.35	Tamaulipas
1.35	Sonora
1.33	Jalisco
1.30	México
1.21	SLP
1.12	Distrito Federa
1.11	Querétaro
1.08	Morelos
1.05	Nayarit
1.03	Zacatecas
1.01	Veracruz
0.88	Campeche
0.87	Chiapas
0.61	Nuevo León
0.60	Coahuila
0.60	BC
0.58	Tlaxcala
0.58	Yucatán
0.52	Oaxaca
0.40	QR
0.38	Michoacán
0.34	Tabasco
0.34	Puebla
0.33	Aguascaliente
0.29	Guanajuato
0.28	Guerrero
0.25	Durango
0.23	Hidalgo
0.12	Colima

(2nd data shape)

3.4 Spatial analysis

Structural Regression model: Statistical Analysis of Discrete Structures



W W S W

Non spatially correlated

Spatially correlated
S: Spline
W: neighborhood matrix

(2nd data shape)

3.5 Answers

1. What are the pests that excess zero detections in probability?: Weeds, Nematodes, fungi, bacteria, virus, mite and insects.
2. What are the high risk pests?: weeds (6), nematodes (4), fungi (1.24), bacteria (1.11). In parenthesis: predicted detections.
3. What are the low risk pests?: protozoo, viroids and mollicute
4. What are the high risk geographical areas where the pests exceed the expected detections with respecto the whole detected pests popilation?: Chihuahua, Sinaloa, BCS, Tamaulipas,…,Veracruz
5. What is 100% sampling inspecction?. Guías

3.5 Answers

6. How to perform sampling inspection of reliable exporters involved in international trade? Skip sampling inspection CSP-3
7. Is it worthwhile to perform a skip lot sampling?: 50% of saving
8. Is the same risk for ports, airports and frontier?. : No. Detections increase by 17.43 and 8.19 times factor with respect to airport (0.27) if goods come through frontier and port, respectively.
9. Which are the high risk products associated with pests detections?: barley, potato, linseed, lentil, oats increase by 8.93, 7.81, 7.72, 7.11, 6.48 times with respect to garlic (1).
10. Which OISAS area the hotspots of pest detections?.: Nuevo Laredo, Piedras Negras, Progreso, Veracruz y Altamira.

4. Conclusions

- NB regresion is recommended to estimate de risk probability for quarantine pests.

- Hurdle regression would be useful to estimate the probability risk to excess threshold of zero detections and to estimate the intensity of expected detections once the zero detections has been crossed. It could be useful to measure effectiveness of more strict inspection controls.

- STAR models are a good option to represent graphical variation of the phytosanitary risk.

- Propose a NOM in the Diario Oficial that includes the NB,, Hurdle and STAR regression models to monitor and represents the relative risk geographicaly of quarantine pests.

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