Parasites, climate and fuzzy inference systems

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ECOSISTEMAS
Y DESARROLLO SUSTENTABLE

Tools used in the model

- Difference equations with daily step

  (formulation)

- Fuzzy inference systems (parameterization)
  - Takagi-Sugeno: provides an intuitive representation of a non linear system through a non linear interpolation of linear systems.
  - Mamdani: allows representing empirical knowledge when the system's behavior is not known.

Why Fuzzy Logic?

- It makes possible to represent linguistic expressions and allows to include non quantitative information gathered during field work.
- Allows enriching the model without replacing crisp logic.
- Permits a flexible design.
- Improves the model's performance.
- It is easy to implement.

Basic Definitions

Definition: A fuzzy set *A* defined in an universe *X* is a set of pairs *(x,* $\mu_A(x)$*)* where *x* belongs to *X* and $\mu_A(x)$ is a number in the interval *[0, 1]* representing the degree of membership of *x* in *A*.

$$\mu_A : X \rightarrow [0,1]$$

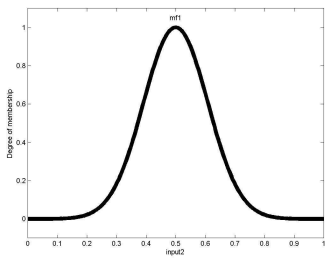
This suggests that membership in a fuzzy subset should not be on a 0 or 1 basis, but rather on a 0 to 1 scale. That is, the membership should be an element of the interval *[0, 1].*

Membership functions

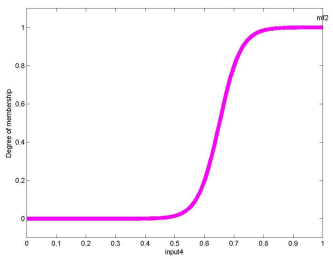
Membership functions are used to quantify the degree of membership of an element of the universe X to the associated fuzzy set A.

The choice of such function depends on the context of the variable. Most common functions are:

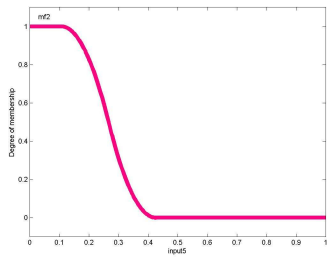
Gaussian



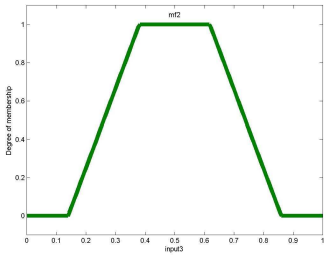
S-sigmoids



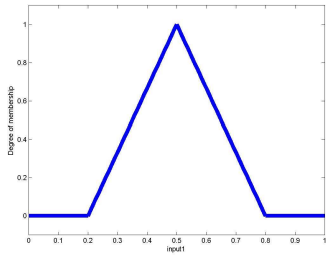
Z-sigmoids



Trapezoidal



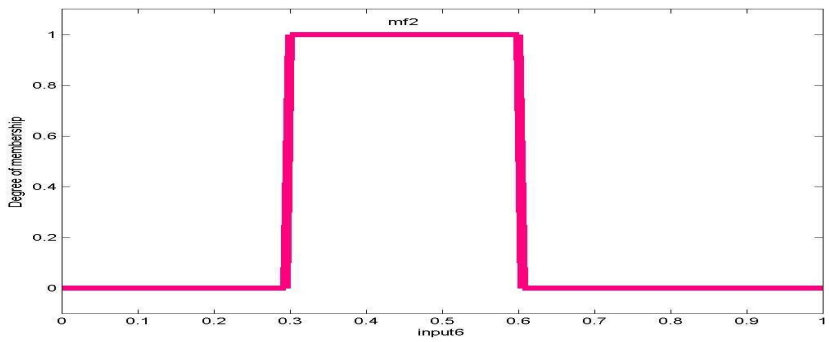
Triangular



Membership functions

Example: “fuzzified” classic sets

It is possible to look at a classic or crisp set as a fuzzy set by taking the characteristic function as the membership function.



Fuzzy rules

Usually, the degree of membership is assigned through the application of a certain number of rules.

A fuzzy rule is a set of *IF-THEN* propositions that model the problem to be solved.

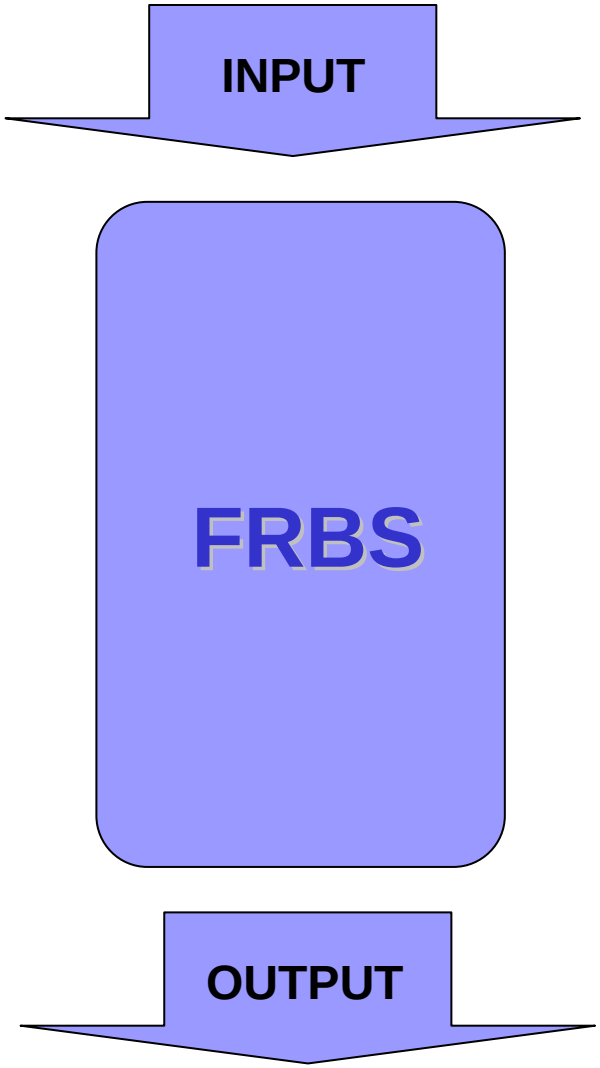
The simpler rules have the format:

"If x is A then y is B"

A rule expresses a relationship between two fuzzy sets A *and* B*, whose membership function is represented by a logical implication*

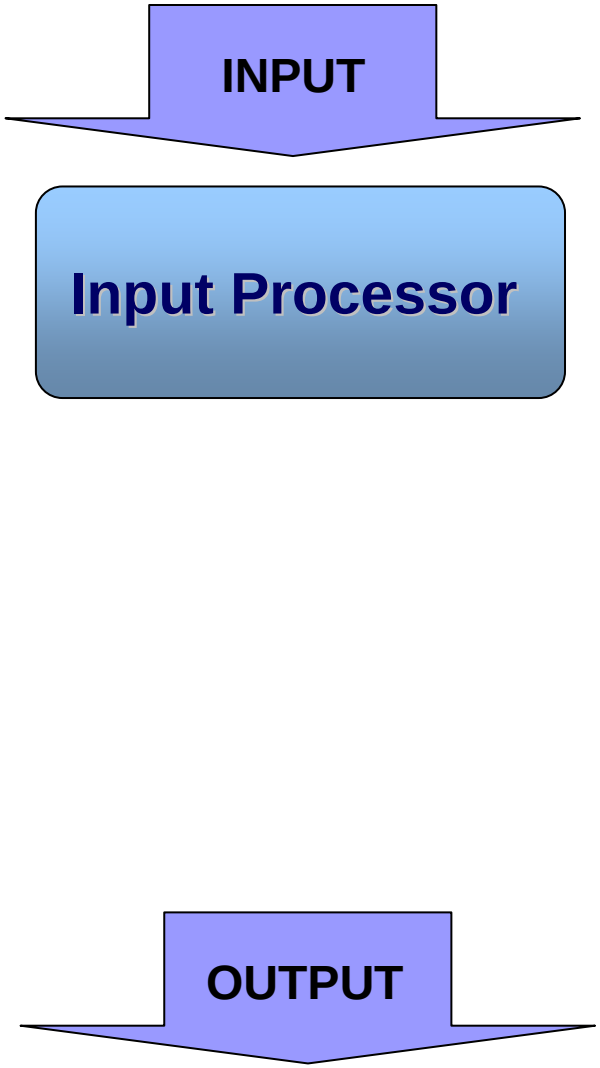
$$\mu_{A \to B}(x, y)$$

Fuzzy rule-based systems (FRBS)



A **FRBS** has 4 components:

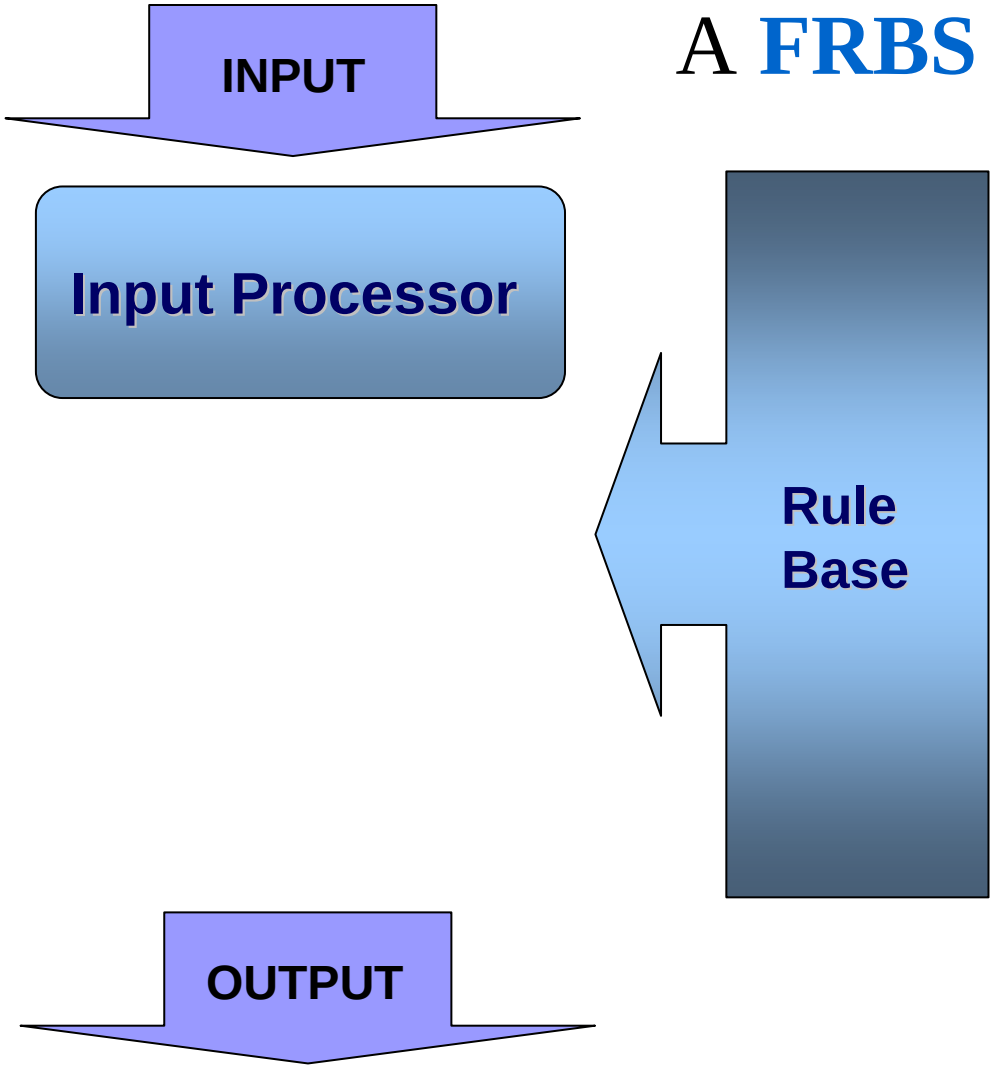
Fuzzy rule-based systems (FRBS)



A **FRBS** has 4 components:

Here, non quantifiable input is translated into fuzzy sets of their respective universes. It assigns to each input variable a membership value into each fuzzy set.

Fuzzy rule-based systems (FRBS)



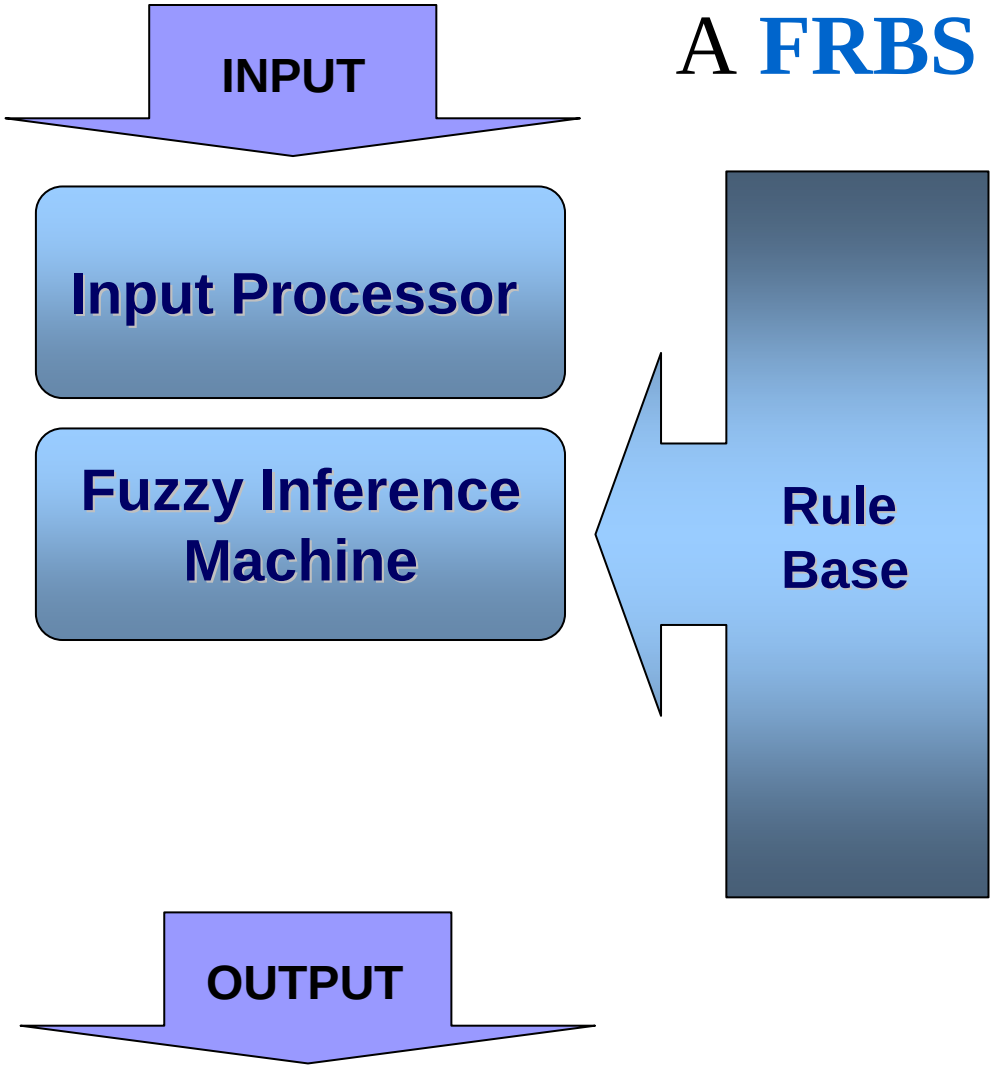
A **FRBS** has 4 components:

This is a key knowledge-encoding component of fuzzy rule-based systems.

The base is composed by a collection of fuzzy conditional propositions in the form of *IF-THEN* rules.

Essentially, fuzzy rules are fuzzy relations of the Cartesian product of the universes of the variables of interest.

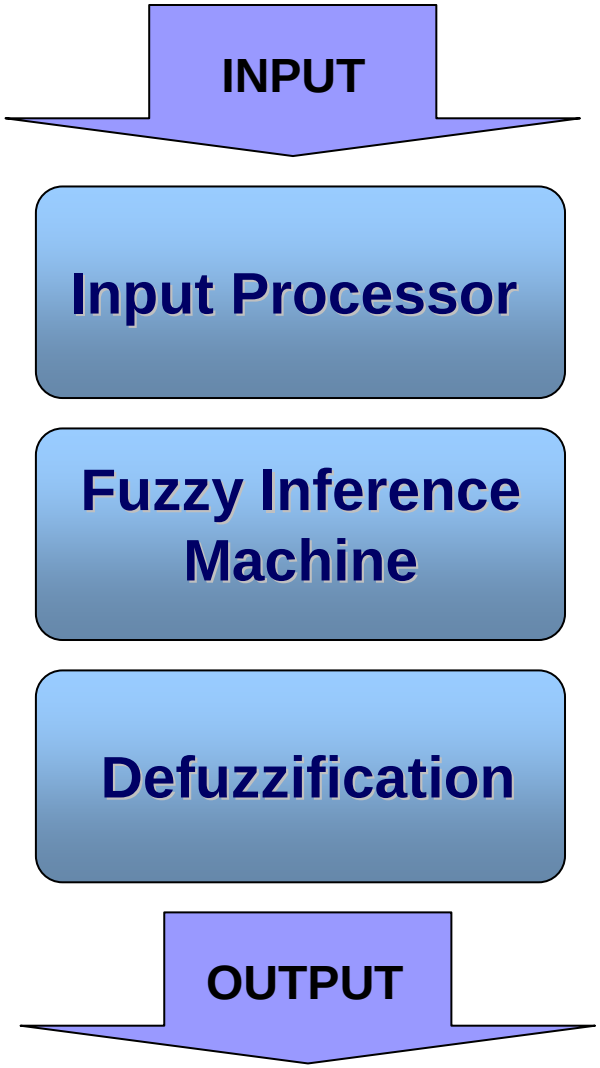
Fuzzy rule-based systems (FRBS)



A **FRBS** has 4 components:

The fuzzy inference machine performs approximate reasoning using the compositional rule of inference.

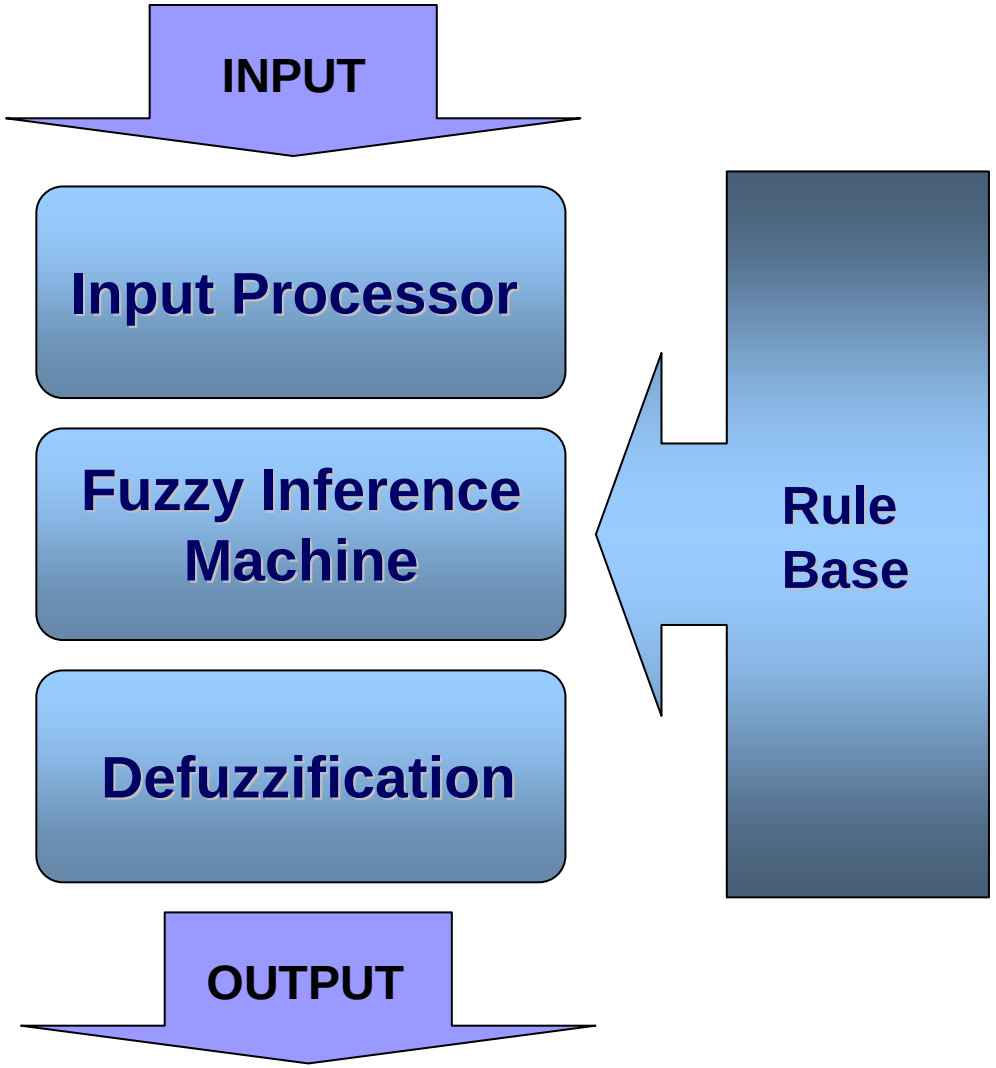
Fuzzy rule-based systems (FRBS)



A **FRBS** has 4 components:

In fuzzy rule-based systems, the output is usually a fuzzy set. Often, especially in system modelling, a real number is required as output. The output processor provides real-valued output through defuzzification, a process used to choose a real number that is representative of the corresponding fuzzy set.

Fuzzy rule-based systems (FRBS)

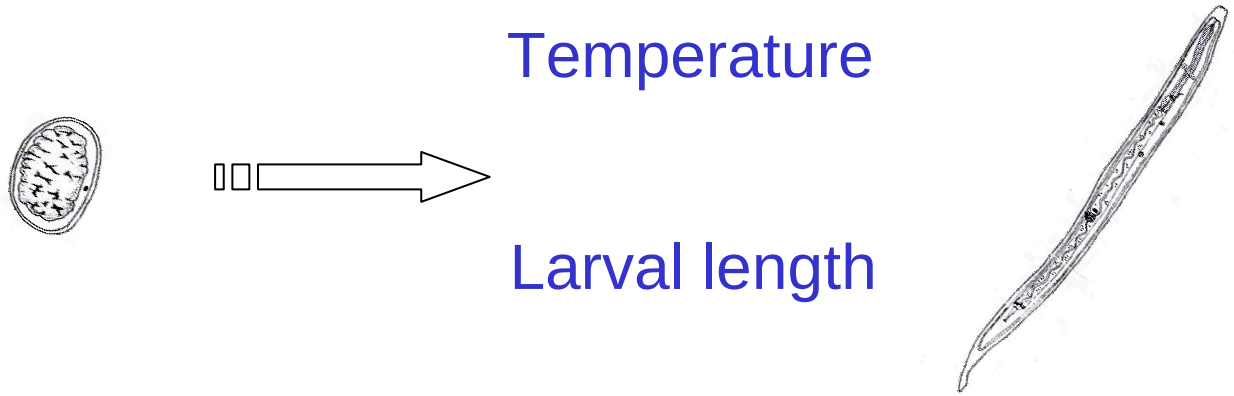


Also called **Fuzzy Inference System (FIS)**

Development time from egg to infecting larvae

- Development time is regulated by temperature. Higher temperatures yield shorter development time, as in Pandey (1972), Gibson (1981), Catto (1982), Levine (1978), Rossanigo (1995), Fiel et al. (2008).

- Average larval length indicates development.



Model for development time from eggs to infecting larvae

$$L_t(a)=\begin{cases}[1+r(T_{t+a})]\,L_t(a-1) & si\ L_t(a)< l_{L3}(T_{t+a})\\ l_{L3}(T_{t+a}) & si\ L_t(a)> l_{L3}(T_{t+a})\end{cases}$$

$$IC:\ L_t(0)=l_0(T_t)$$

where $L_t(a)$ average length of the "t" cohort aged "a",

$r(T_t)$ growth rate,

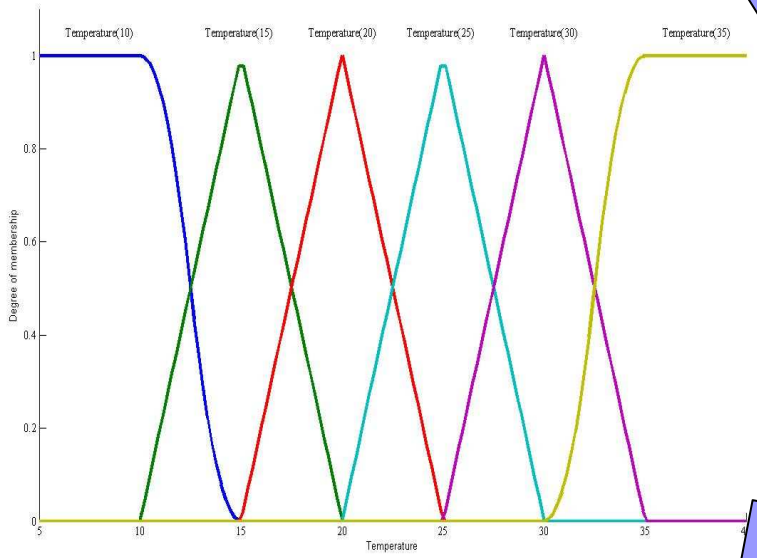
$l_0(T_t)$ length at eclosion and $l_{L3}(T_t)$ initial length of L3 larva.

Maturation time is reached when "a" is such that:

$$L_t(a)< l_{L3}(T_{t+a})< L_t(a+1).$$

Here $r(T_t)$, $l_0(T_t)$ and $l_{L3}(T_t)$ are FIS of the Takagi-Sugeno type

Model for development time from eggs to infecting larvae



$$l_{L3}(T)=[1+r](a)\ l_0(T)$$

Data from Pandey (1972)

$l_0(T_t)$

$f_{[10]}(T)$=6T+323
$f_{[15]}(T)$=-13.8T+620
$f_{[20]}(T)$=1.2T+320
$f_{[25]}(T)$=-4.6T+465
$f_{[30]}(T)$=-2.4T+399
$f_{[35]}(T)$=9

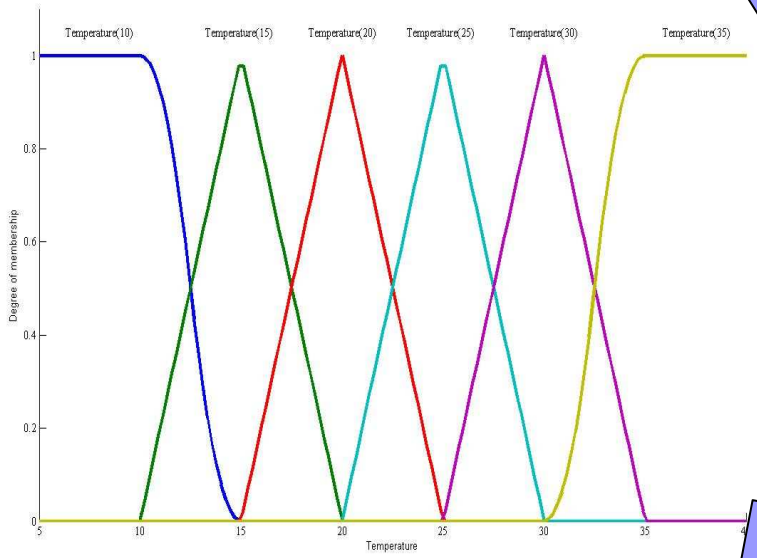
$l_{L3}(T_t)$

$g[_{10]}(T)$=4T+799
$g_{[15]}(T)$=2.8T+817
$g_{[20]}(T)$=-5.8T+989
$g_{[25]}(T)$=-3.6T+934
$g_{[30]}(T)$=-13.8T+1240
$g_{[35]}(T)$=21.62

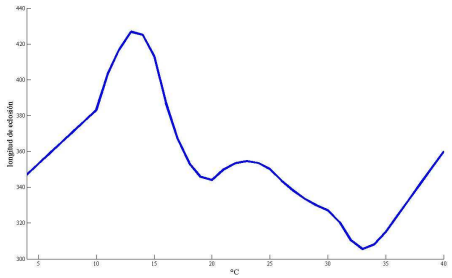
$r(T_t)$

$h_{[10]}(T)$=0.0036
$h_{[15]}(T)$=0.0184T-0.2
$h_{[20]}(T)$=0.0049T+0.0696
$h_{[25]}(T)$=0.0136T-0.1485
$h_{[30]}(T)$=-0.0031T+0.3545
$h_{[35]}(T)$=0.007

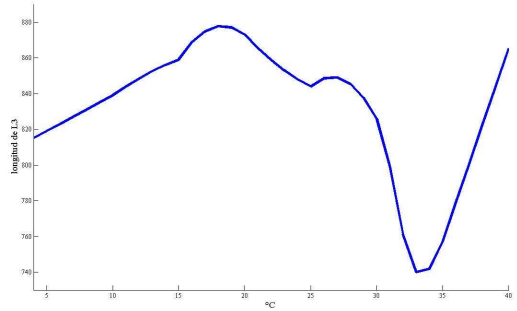
Model for development time from eggs to infecting larvae



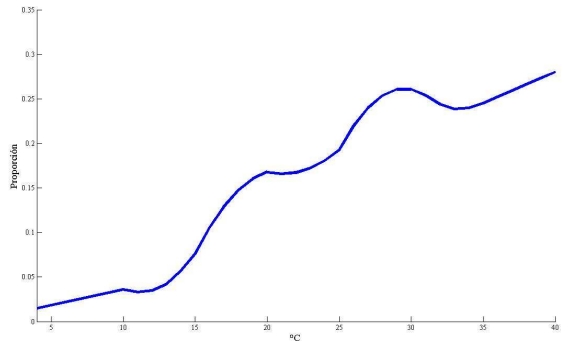
$l_0(T_t)$



$l_{L3}(T_t)$



$r(T_t)$



$$l_{L3}(T)=[1+r](a)\ l_0(T)$$

Data from Pandey (1972)

Field work

A 0.96 hectare paddock located on the University Campus (UNCPBA) in Tandil was used for the field work. The paddock was divided into 16 sub-paddocks.

Two naturally infected calves contaminated the sub-paddocks with eggs of gastrointestinal parasites.

Faecal samples for egg counts and coprocultures were taken weekly from the "contaminating" calves during the grazing period. Faecal egg counts were used to plot the contamination of the paddock. Coprocultures allowed the identification of which nematode species were present in the contamination.

On the 15th day of each month, faecal matter was collected from the paddock. Then weekly samples were taken in the lab from collected faecal matter in order to analyse the development from egg to *L3*. Simultaneously, grass samples were regularly taken from the paddock over the 16-month period to assess the infection of pastures as well as the survival of *L3* larvae in pasture. (Fiel, C.A., et al., 2008)

Data

- HPG (eggs per gram): from field data. Value constant from the day of the sampling till next day of sampling (max. 15 days)

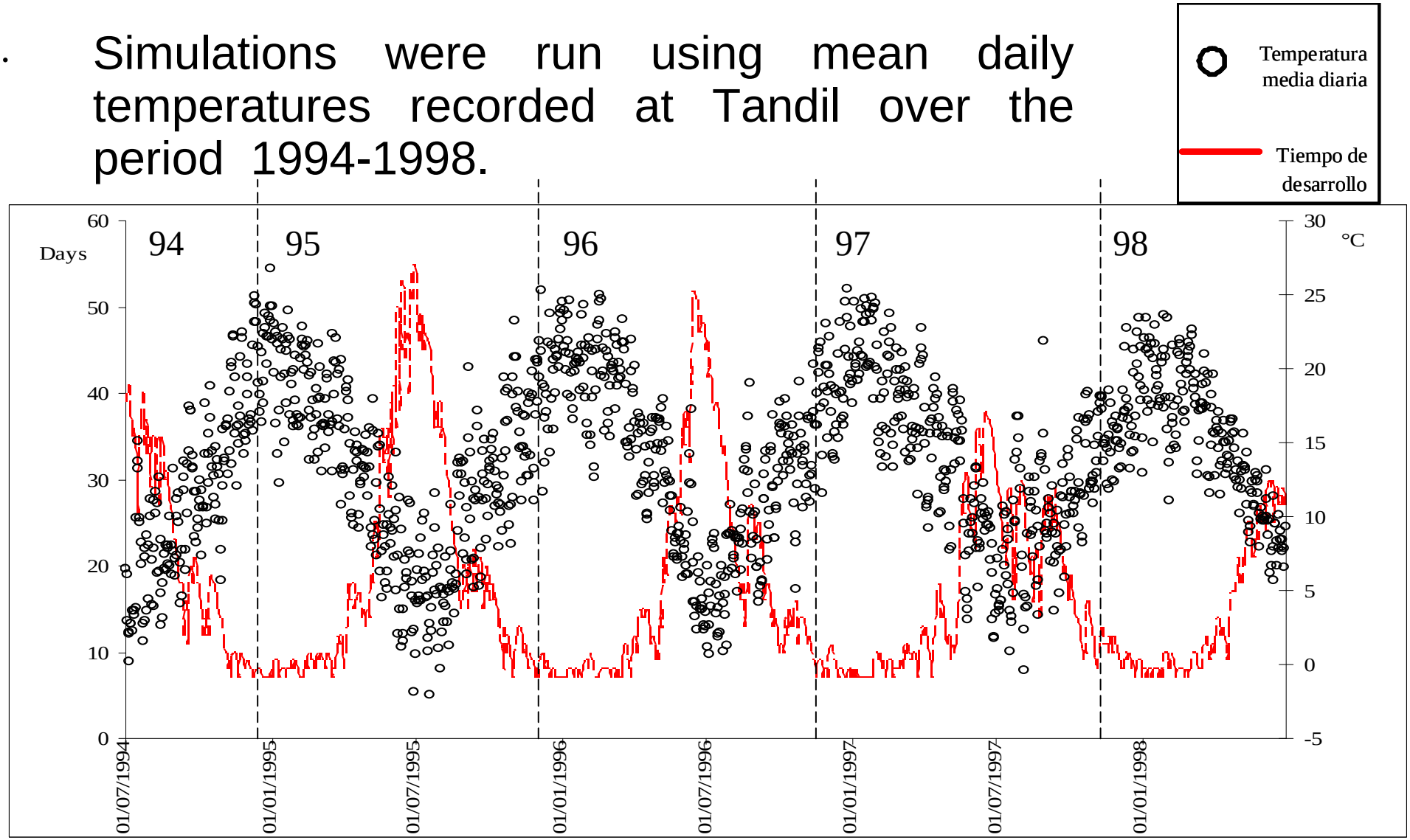
Sampling day

Example Year 1994, 2º semester

S2 year 94																															
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
July	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785
August	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930	930
September	930	930	930	930	195	195	195	195	195	195	195	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	365	
October	365	365	365	365	30	30	30	30	30	30	30	30	30	30	30	30	30	30	55	55	55	55	55	55	55	40	40	40	40	40	40
November	40	70	70	70	70	70	70	70	50	50	50	50	50	50	50	110	110	110	110	110	110	110	95	95	95	95	95	95	95	200	
December	200	200	200	200	200	200	200	200	200	200	200	200	130	130	130	130	130	130	130	130	25	25	25	25	25	25	25	20	20	20	20

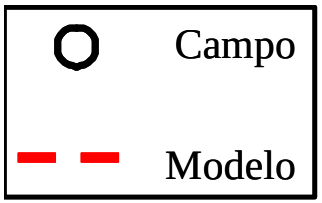
Simulations of development time from eggs to infecting larvae

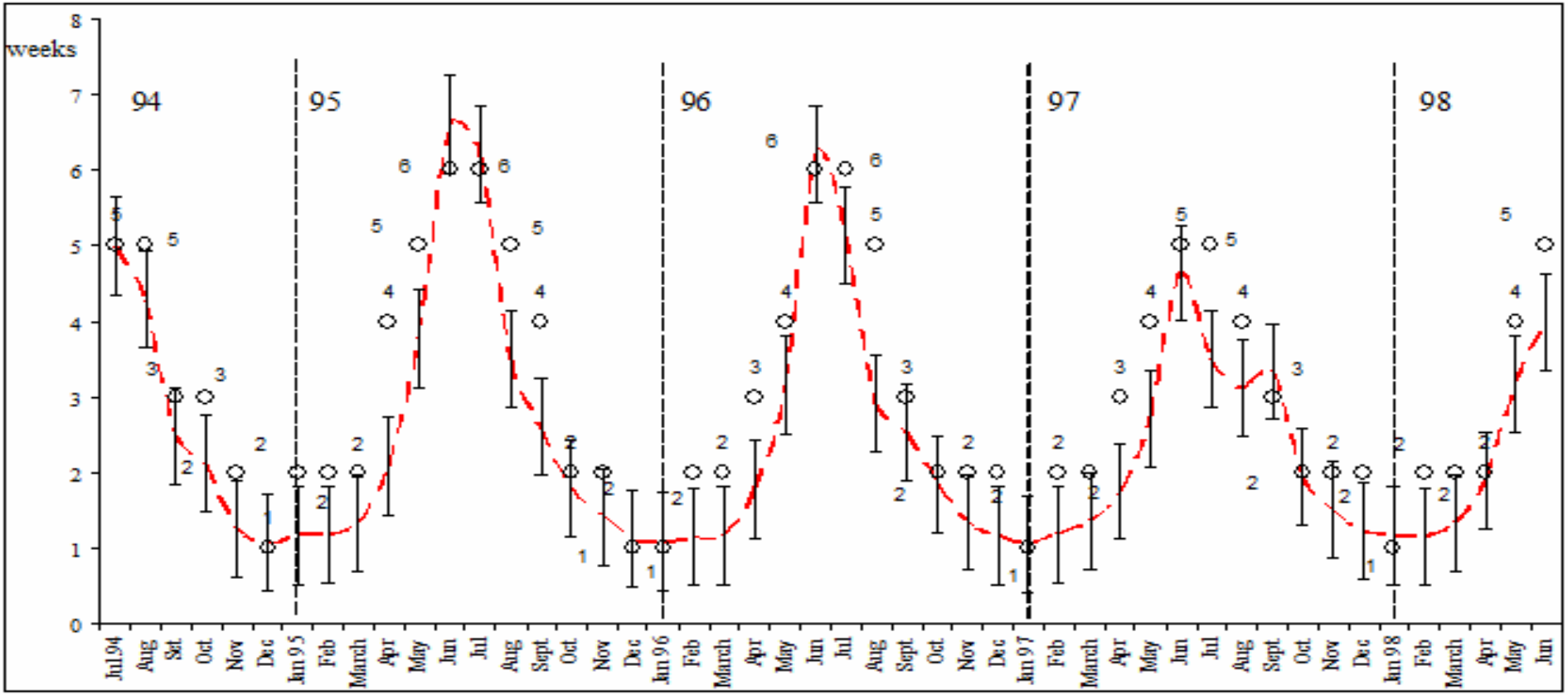
- Simulations were run using mean daily temperatures recorded at Tandil over the period 1994-1998.



Simulations of development time from eggs to infecting larvae

Data were provided by Fiel and collaborators from their field work carried on in 1994-1998.





Simulations of development time from eggs to infecting larvae

How important is the order in which daily average temperatures occur? In other words, if we take any given temperature vector and rearrange its components, is the development time the same?

If we take two vectors with mean temperature μ, is there a significant difference between the outputs of the model if the ranges of temperature are different? In other words, if the components of the temperature vector are within the interval $[\mu-\sigma,\mu+\sigma]$ or the interval $[\mu-2\sigma,\mu+2\sigma]$, is there any significant difference?

The answer is **YES**

Model for development time from eggs to infecting larvae

- The output error is less than the sampling error in the field experiments.

- Simulation results yield a mean estimation error (MEE) of 0.64 weeks, with variance 0.34, and a determination coefficient $R^2 = 0.74$.

- The model exhibits high sensitivity to daily temperature variation and thermal amplitude.

Free-Living Stage Model

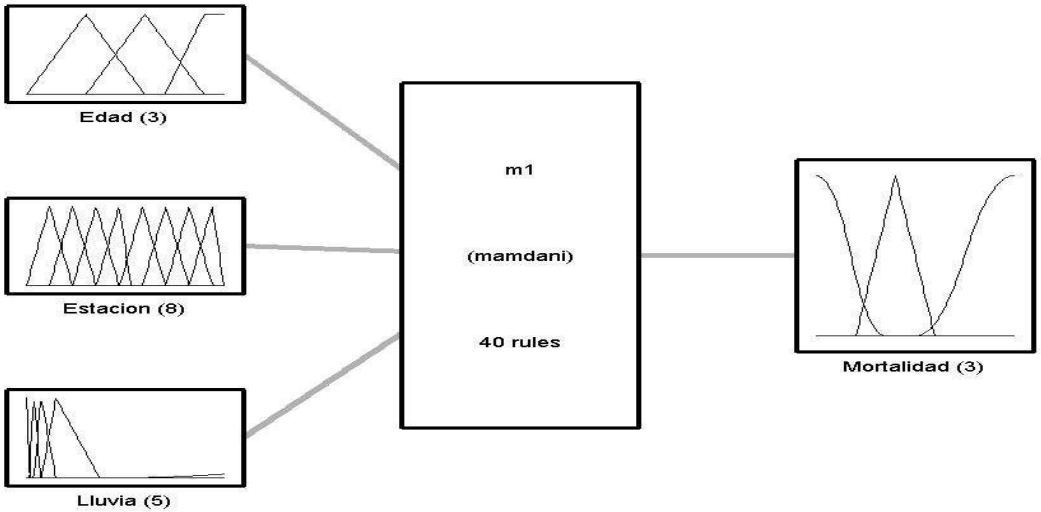
How does rainfall affect the life-cycle?

Two effects:

- Regulates migration of L3 larvae to pasture.
- Affects pre-infective mortality of L3 larvae.

Free-Living Stage Model

Pre-infective mortality



	Age ([%])	Season ([d])	Rainfall ([mm])	Mortality ([%])
1	L1(0-0.6)	Summer (-45-136)	Drizzle1 (0-2)	Low (0-0.35)
2	L2 (0.3-0.9)	Winter (136-319)	Drizzle2 (2-10)	Moderate (0.2-0.6)
3	L3 (0.7-1)	Spring (228-365)	Rain (5-20)	High (0.5-1)
4		Autumn (45-228)	Downpour1 (10-50)	
5			Downpour2 (50-600)	

Free-Living Stage Model

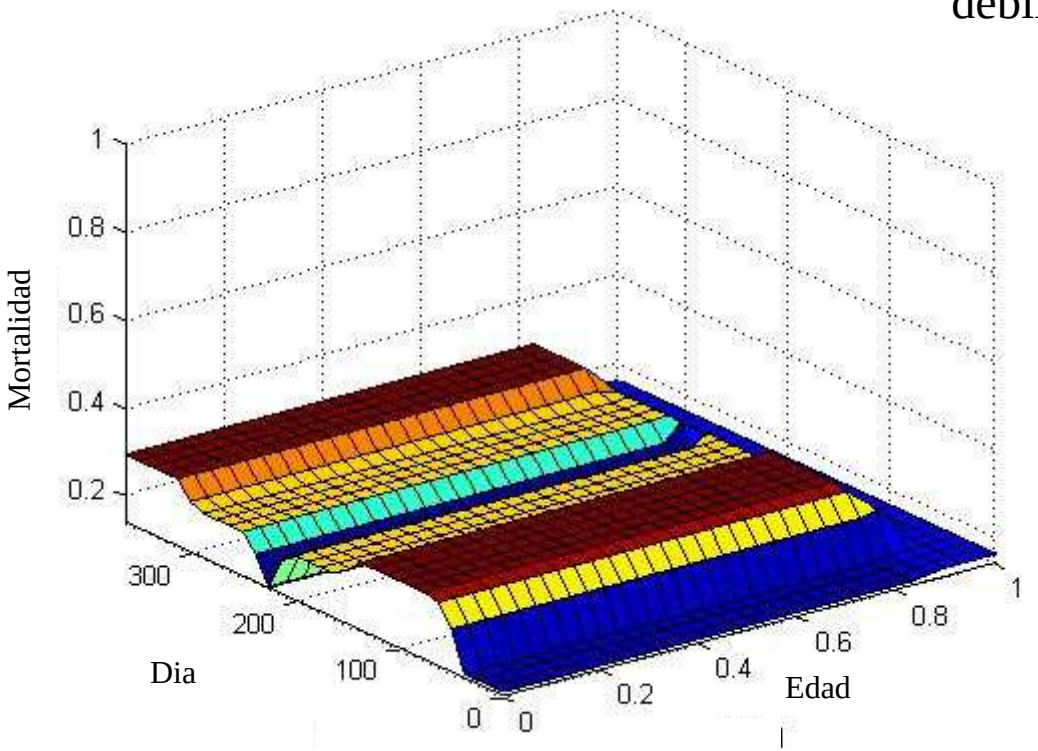
***Preinfective Mortality*.**

Variable Linguistic(type)	***Name***	***Type***	***Parameters***			
			α	β	γ	η
Age (input)	*L*1 *L*2 *L*3	*Z* *Trapezoidal* *S*	*0* *0.2* *0.7*	*0.52* *0.4* *1*	 *0.7*	*0.9*
Precipitation (input)	Drizzle1 Drizzle2 Rain Downpour1 Downpour2	*Z* *Triangular* *Trapezoidal* *Trapezoidal* *S*	*2* *2* *5* *10* *40*	*5* *5* *8* *20* *70*	 *10* *17* *40*	 *20* *50*
Season (input)	*Summer* *Autumn* *Winter* *Spring*	*Z* *Trapezoidal* *Trapezoidal* *S*	*0* *45* *136* *228*	*136* *121* *213* *365*	 *151* *243*	 *228* *319*
preMortality (output)	*Low* *Moderate* *High*	*Z* *Triangular* *S*	*0* *0.2* *0.5*	*0.35* *0.4* *1*	*0.6*	

Free-Living Stage Model

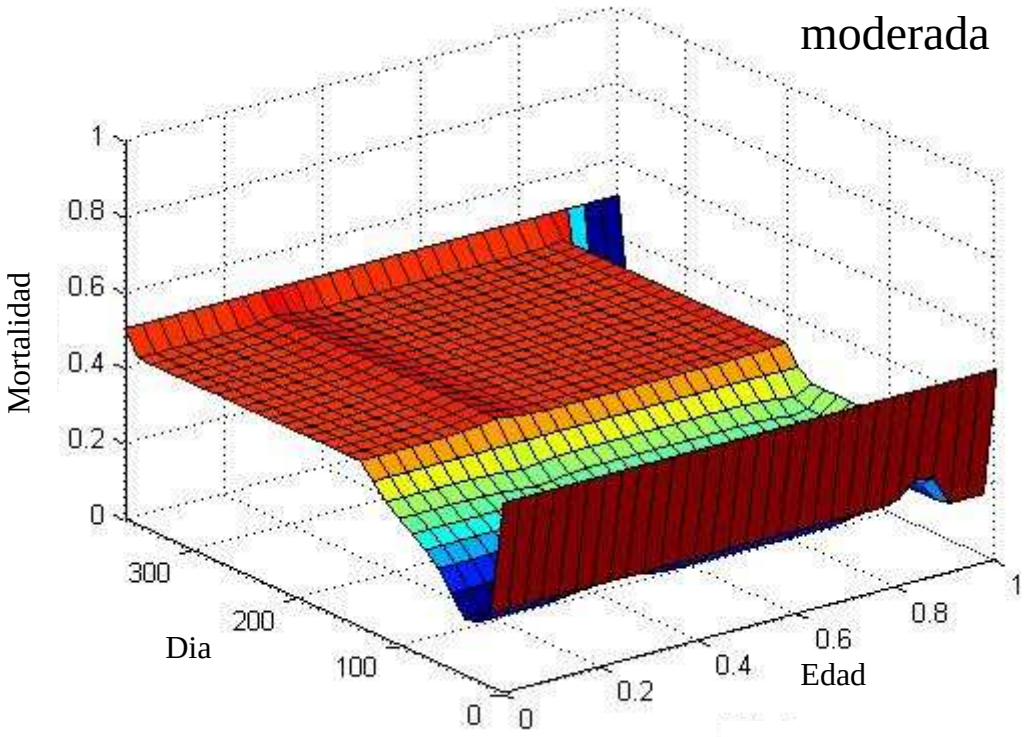
Preinfective mortality for each precipitation intensity

debil



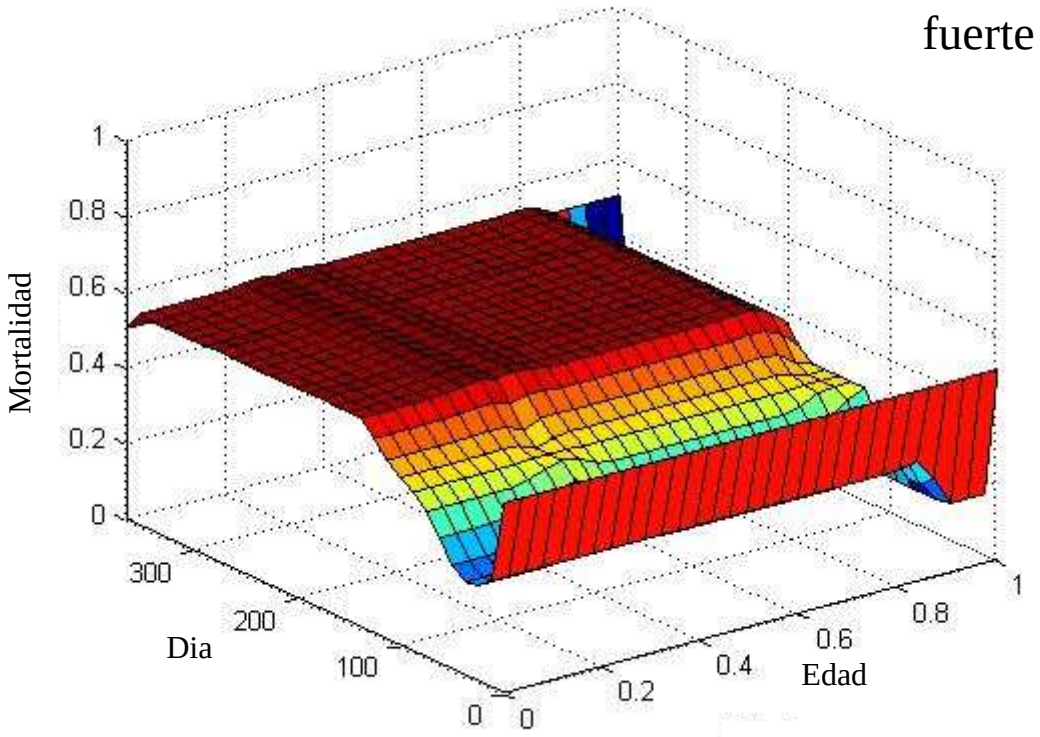
Free-Living Stage Model

Preinfective mortality for each precipitation intensity



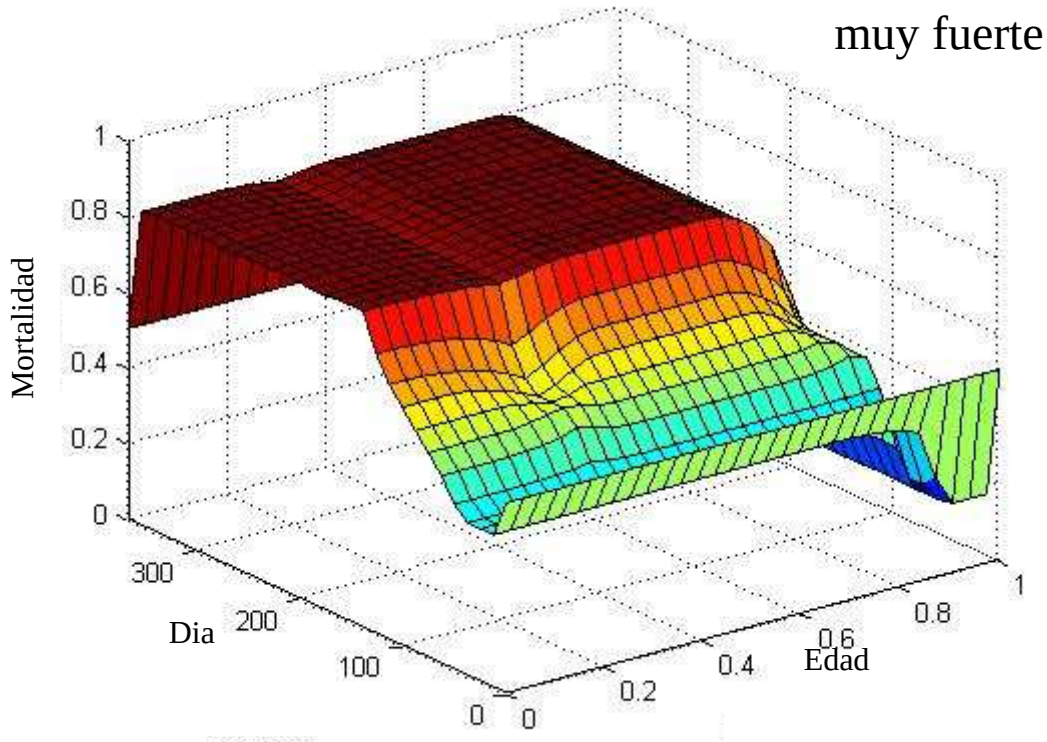
Free-Living Stage Model

Preinfective mortality for each precipitation intensity



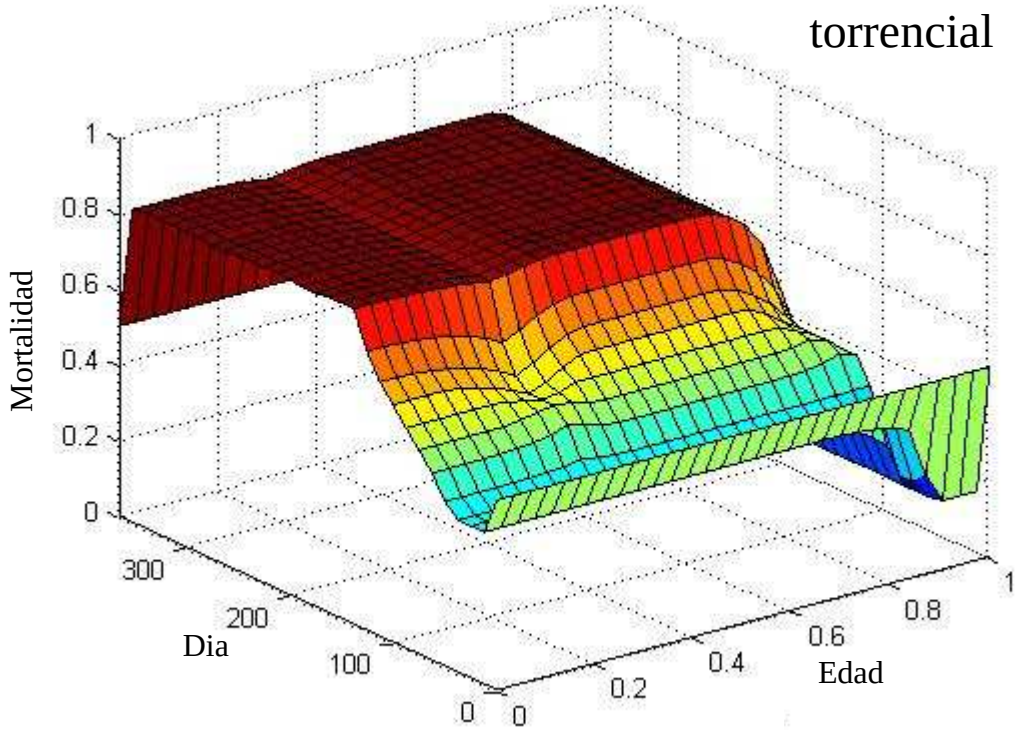
Free-Living Stage Model

Preinfective mortality for each precipitation intensity



Free-Living Stage Model

Preinfective mortality for each precipitation intensity



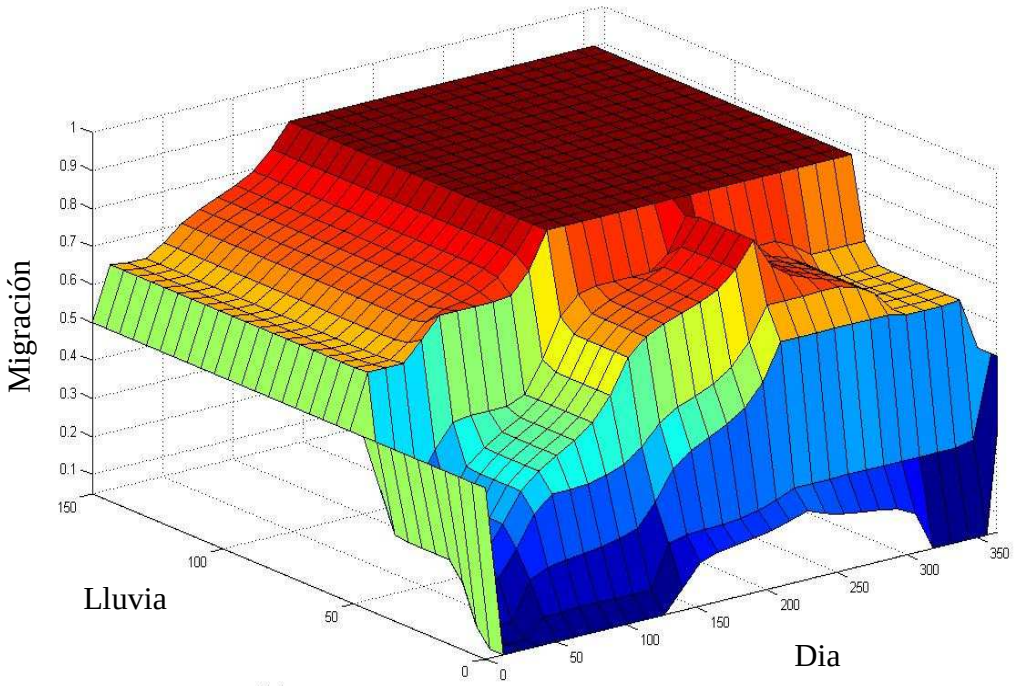
Free-Living Stage Model

Migration

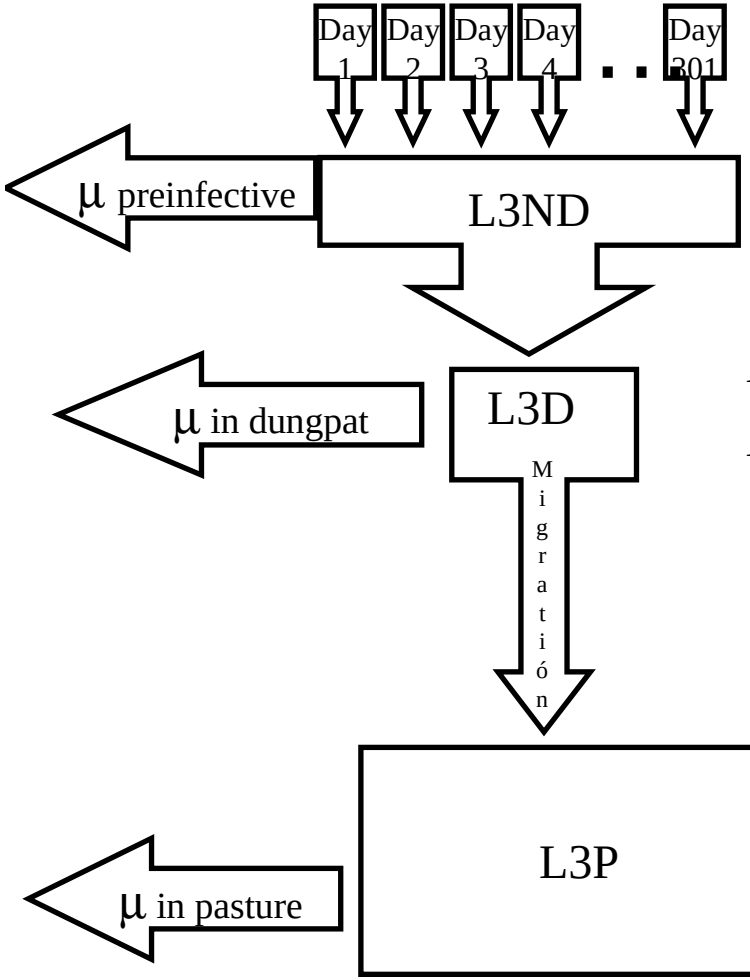
Variable Lingüística(tipo)	***Nombre***	***Tipo***	***Parámetros***			
			α	β	γ	η
Estación (entrada)	*Verano*	*Z*	*0*	*136*		
	Otoño	*Trapezoidal*	*45*	*121*	*151*	*228*
	Invierno	*Trapezoidal*	*136*	*213*	*243*	*319*
	Primavera	*S*	*228*	*365*		
Lluvias (entrada)	Debil	*Z*	*2*	*5*		
	Moderada	*Triangular*	*2*	*5*	*10*	
	Fuerte	*Trapezoidal*	*5*	*8*	*17*	*20*
	Muy Fuerte	*Trapezoidal*	*10*	*20*	*40*	*50*
	Torrenciales	*S*	*50*	*70*		
Migración (salida)	*Muy Baja*	*Z*	*0*	*0.1*		
	Baja	*Triangular*	*0.1*	*0.2*	*0.4*	
	Moderada	*Triangular*	*0.5*	*0.6*	*0.8*	
	Alta	*S*	*0.8*	*1*		

Free-Living Stage Model

Migration



Free-Living Stage Model



$$H_0(t) = \begin{cases} NAnimal\, 6.3\, HPG(t)\left(PatWt(w)\right) & \text{if calf's weight} = w \\ NAnimal\, 8.1\, HPG(t)\left(PatWt(w)\right) & \text{if cow's weight} = w \end{cases}$$

$$H_t(a) = \left(1 - \mu_{Pre}\left(a, t + a, R\left(t + a\right)\right)\right) H_t(a-1)$$
$$\text{if } L_t(a) \le l_{L3}\left(T_t + a\right)$$

$$L3ND(t) = H_j(\tau(j)) \quad si\ j + \tau(j) = t$$
$$L3D(t+1) = (1 - \delta_{DP}(t, R(t)))\,(1 - \mu_{ID})\,L3D(t) + L3ND(t+1)$$

$$C_t(0) = \delta_{DP}(t, R(t)\,L3D(t)$$
$$C_t(k+1) = \left(1 - \mu_p(t)\right) C_t(k)$$

Mortality in pasture

$$P_{L3}(t) = C_t(0) + \sum_{i=1}^{t-1} C_i(k-i)$$

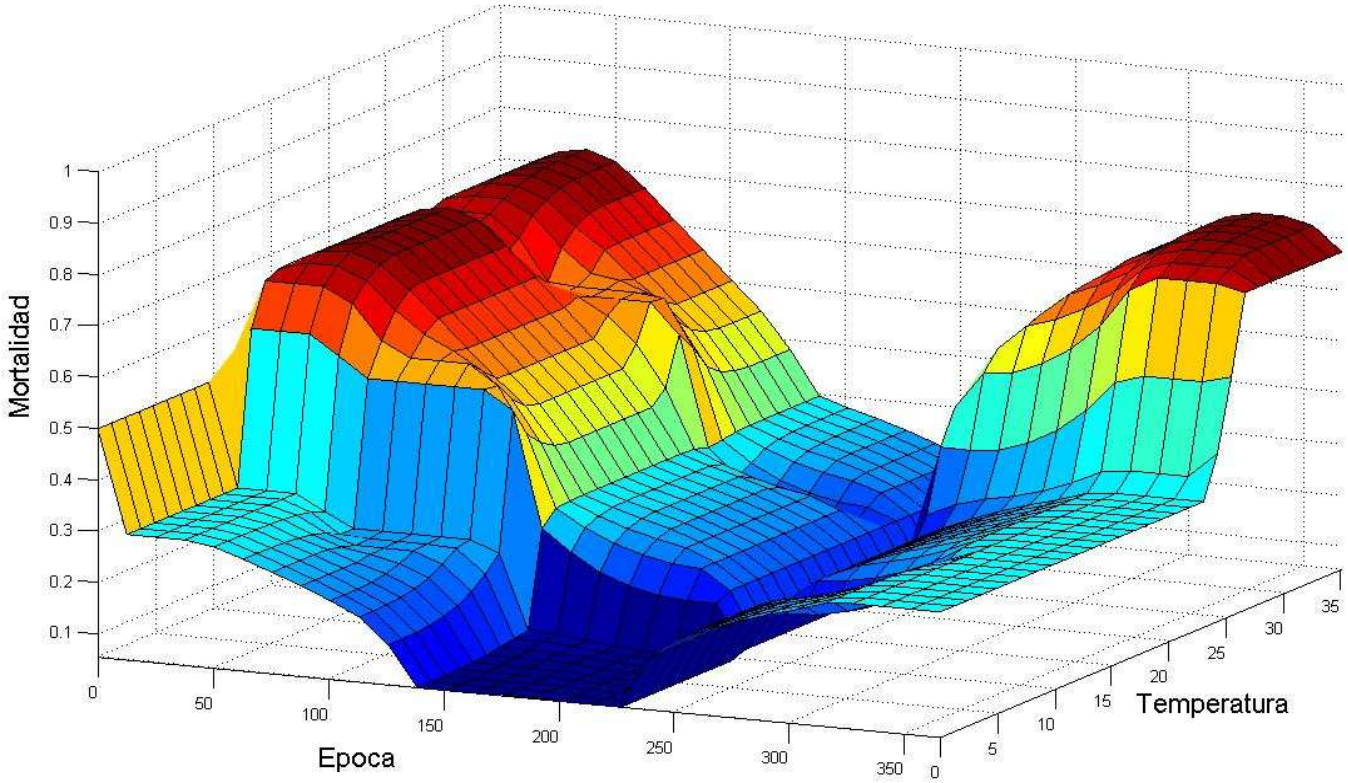
Number of infective larvae in pasture

Free-Living Stage Model

Variable Lingüística(tipo)	Nombre	Tipo	Parámetros			
			α	β	γ	η
Estación (entrada)	Verano	Z	0	136		
	Otoño	Trapezoidal	45	121	151	228
	Invierno	Trapezoidal	136	213	243	319
	Primavera	S	228	365		
Temperatura (entrada)	Baja	Z	0	14		
	Moderada	Trapezoidal	10	15	23	26
	Alta	S	23	32		
MortalidadPastura (salida)	Baja	Triangular	0	0.2		
	Moderada	Triangular	0.1	0.2	0.4	0.5
	Alta	S	0.25	0.7		

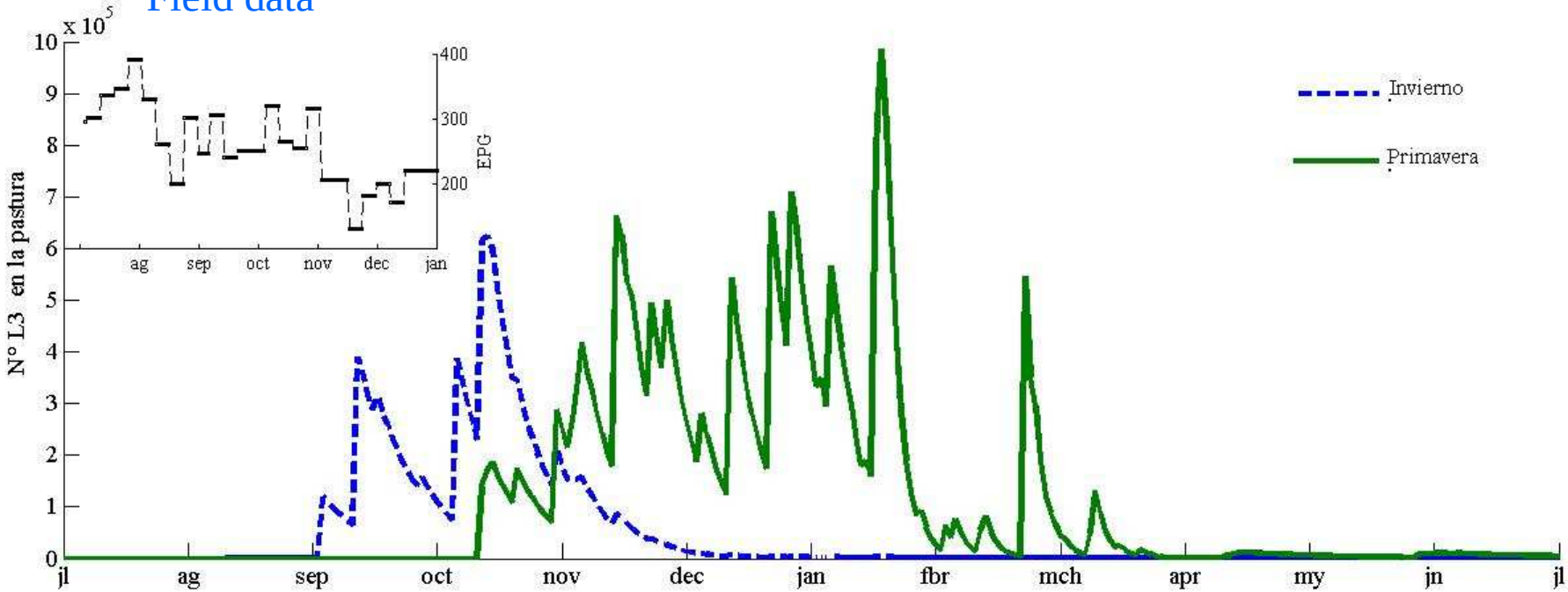
Mortality in pasture

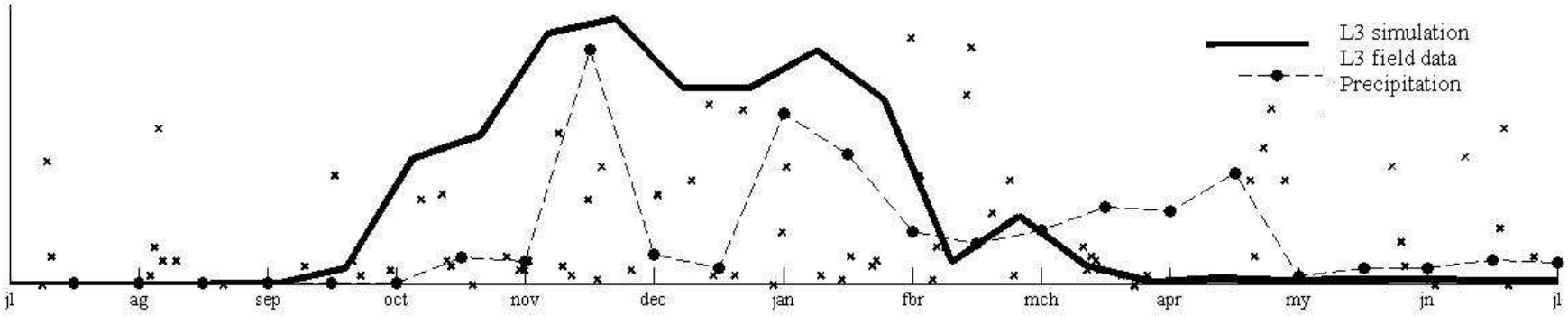
Free-Living Stage Model



Simulations: dynamics of the infective larval population

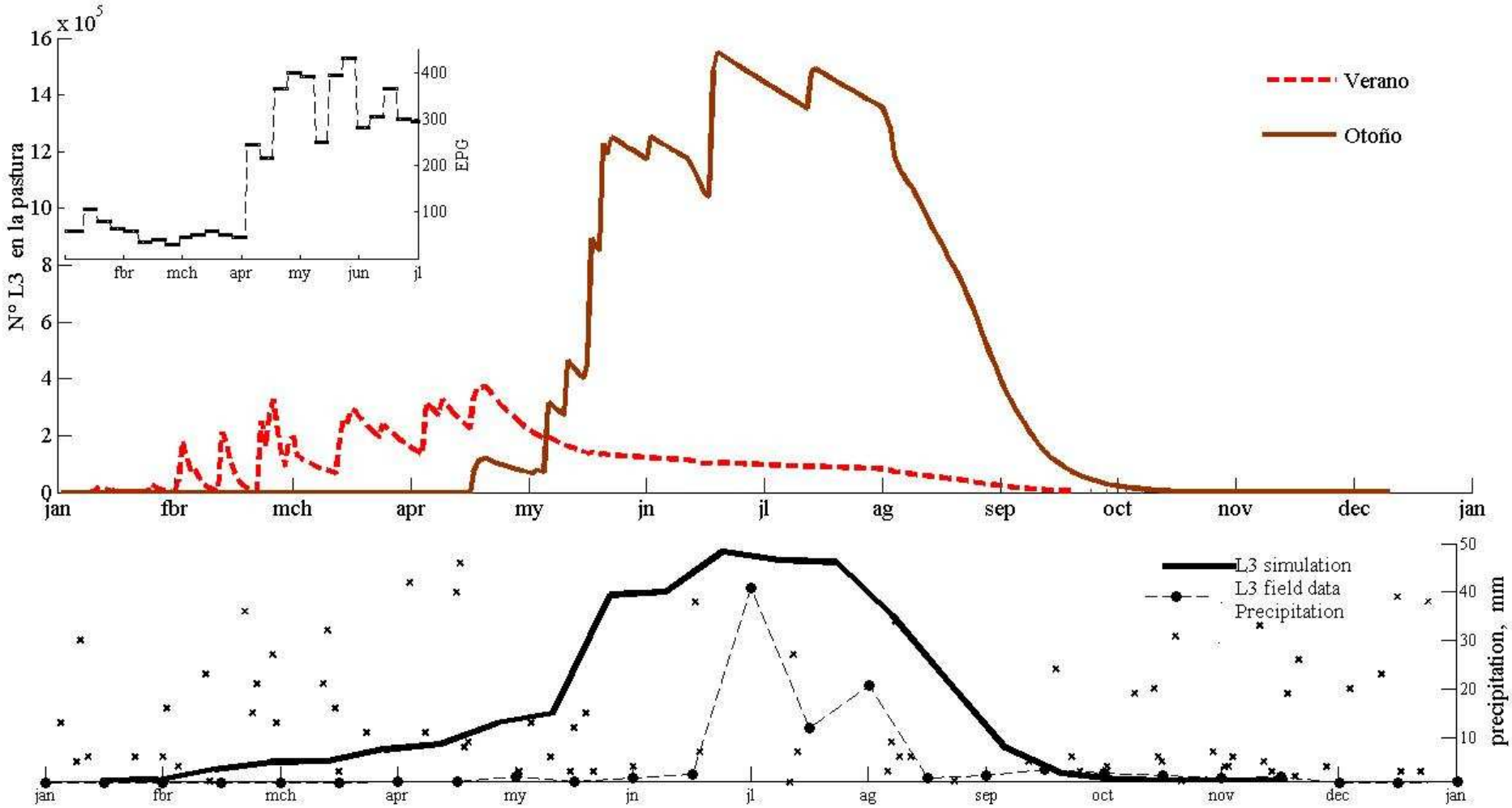
Field data





Simulations: dynamics of the infective larval population

Field data



Peak of infection

Semester: (Year)	Field data	Simulation
1:(1995)	November 1995	September 1995
2:(1995)	November-December 1995	November-December 1995
1:(1996)	July 1996	July 1996
2:(1996)	August 1997	November 1997
1:(1997)	July 1997	July 1997
2:(1997)	April 1998	December 1997 - January 1998

Beginning of infection

Semester: (Year)	Field data	Simulation
1:(1995)	April	January
2:(1995)	October	October
1:(1996)	April	January
2:(1996)	October	October
1:(1997)	March	January
2:(1997)	October	October

End of infection

Semester: (Year)	Field data	Simulation
1:(1995)	End of December 1995	End of December 1995
2:(1995)	End of June 1996	End of June 1996
1:(1996)	End of November 1996	End of October 1996
2:(1996)	End of June 1997	End of June 1997
1:(1997)	End of September 1997	End of September 1997
2:(1997)	End of October 1998	End of October 1998

Argentina

Main cattle production regions

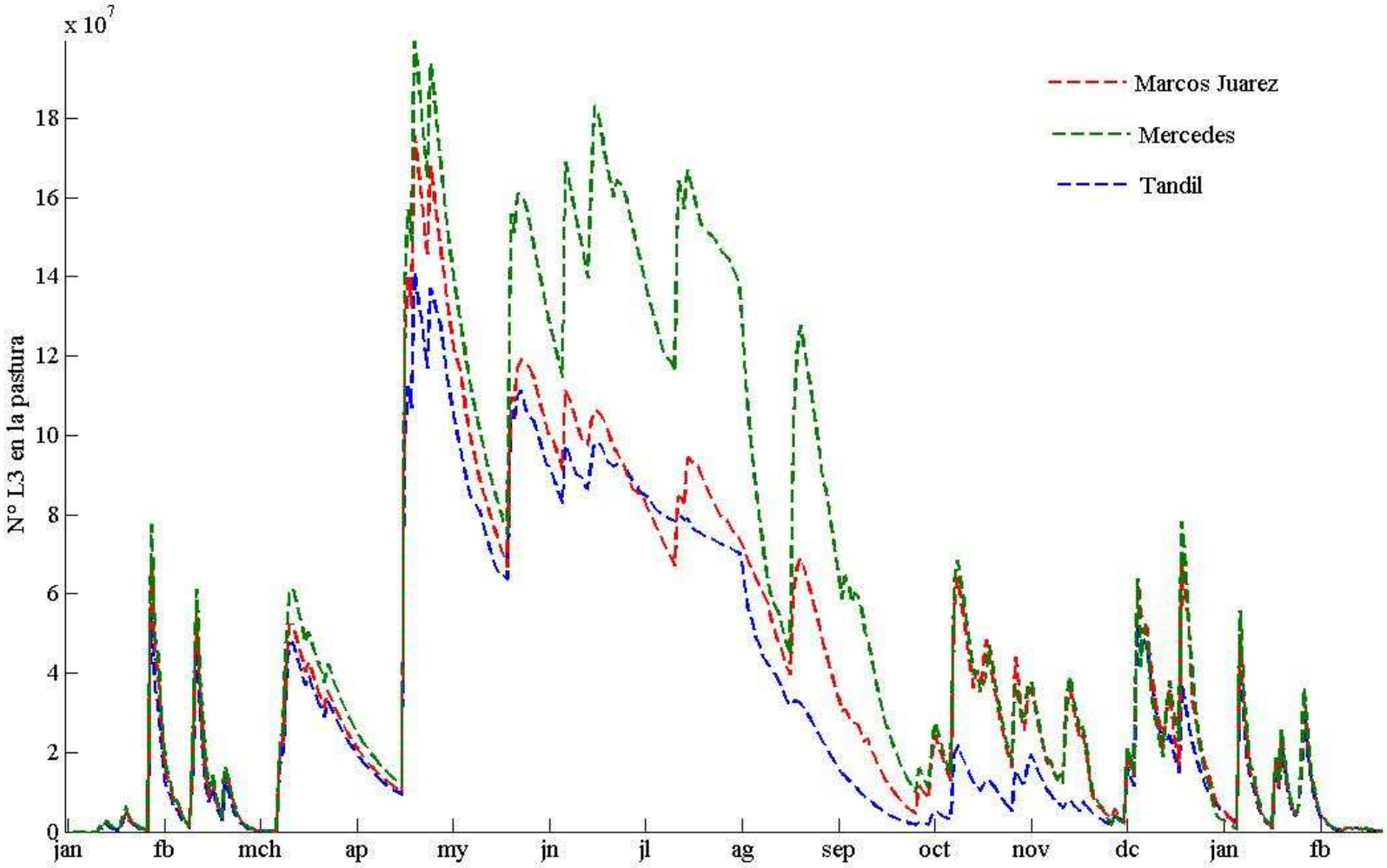
Corrientes

Santa Fe - Cordoba

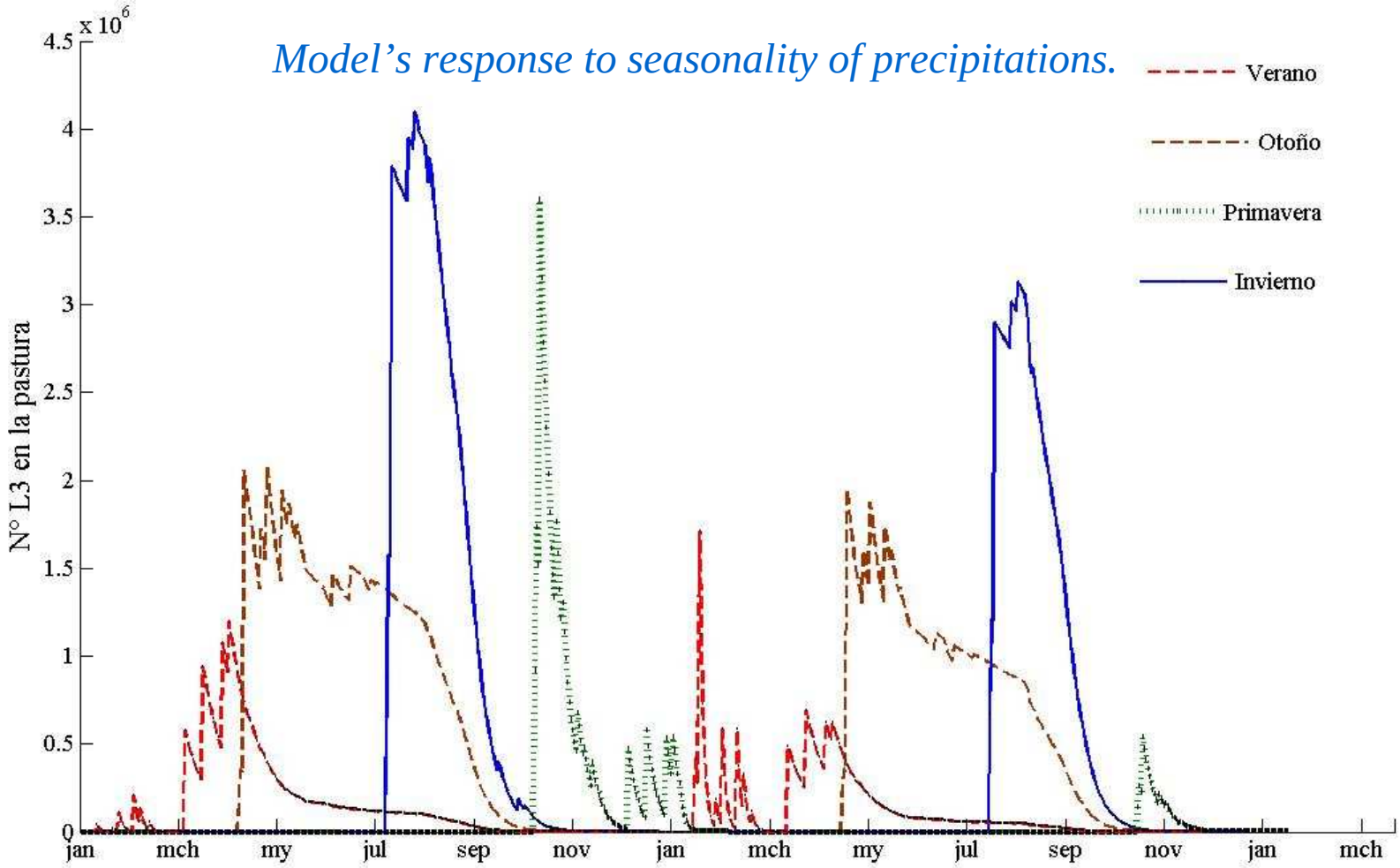
Buenos Aires

Simulations: dynamics of the infective larval population

Model response to variations in the temperature series



Simulations: dynamics of the infective larval population



Simulations: dynamics of the free-living infective larval population

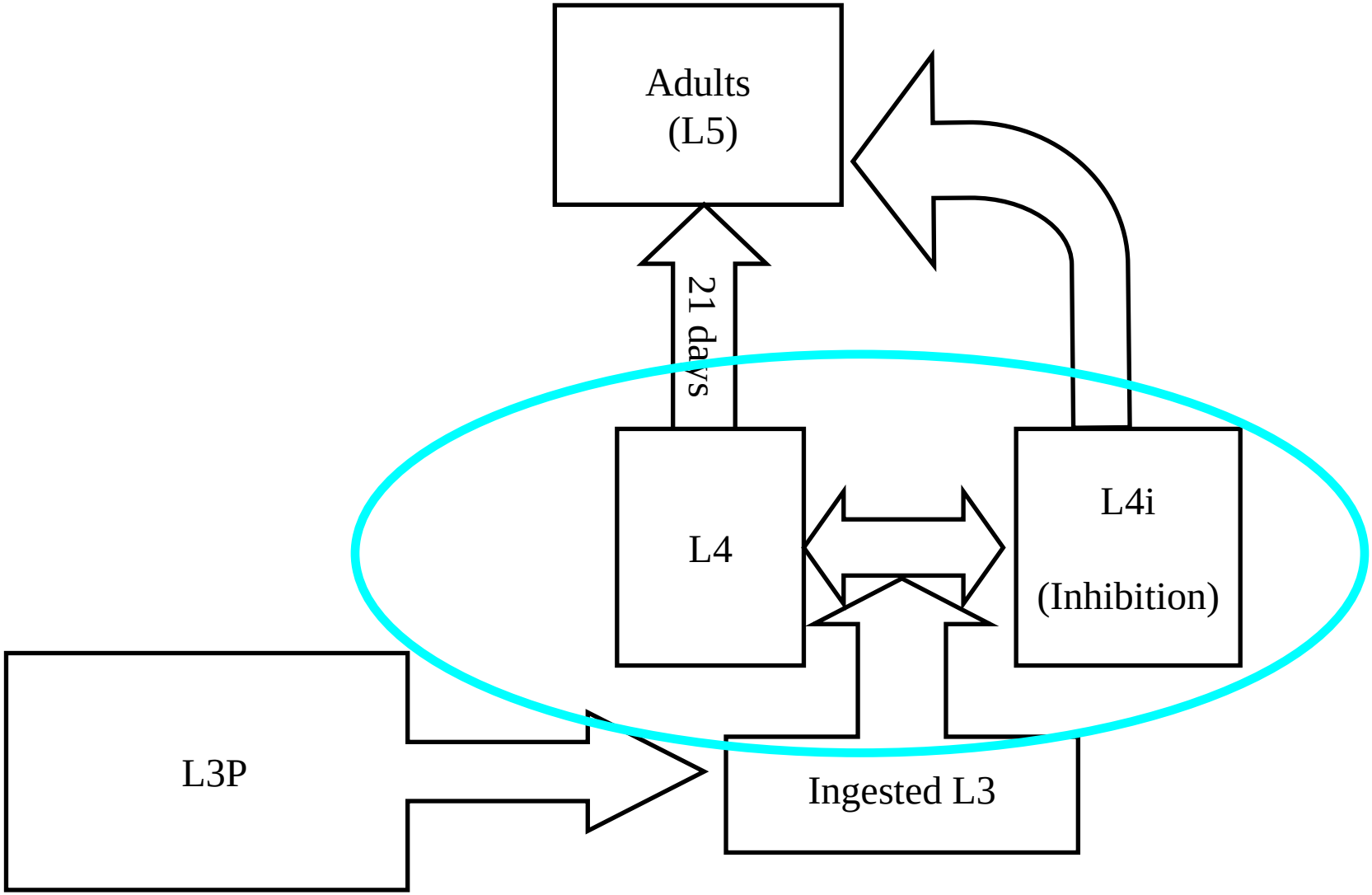
The model adequately replicates the dynamics of

- the time at which the first *L*3 larvae appear in the pasture,
- the days in which peak infections occur, and
- the duration of the infection.

The simulations results suggest diferent implications about the effects of weather conditions on the infection dynamics.

The model properly reflects the impact of seasonality (temperature and precipitation) on preinfective (in dung) and infective (in pasture), corroborating the hypothesis.

Parasitic Stage Model



Proportion of inhibited larvae

Fuzzy inference system of Mamdani type.

Variables:

- Number of days that the L3 cohort spent in the pasture
- Mean daily temperature
- Photoperiod

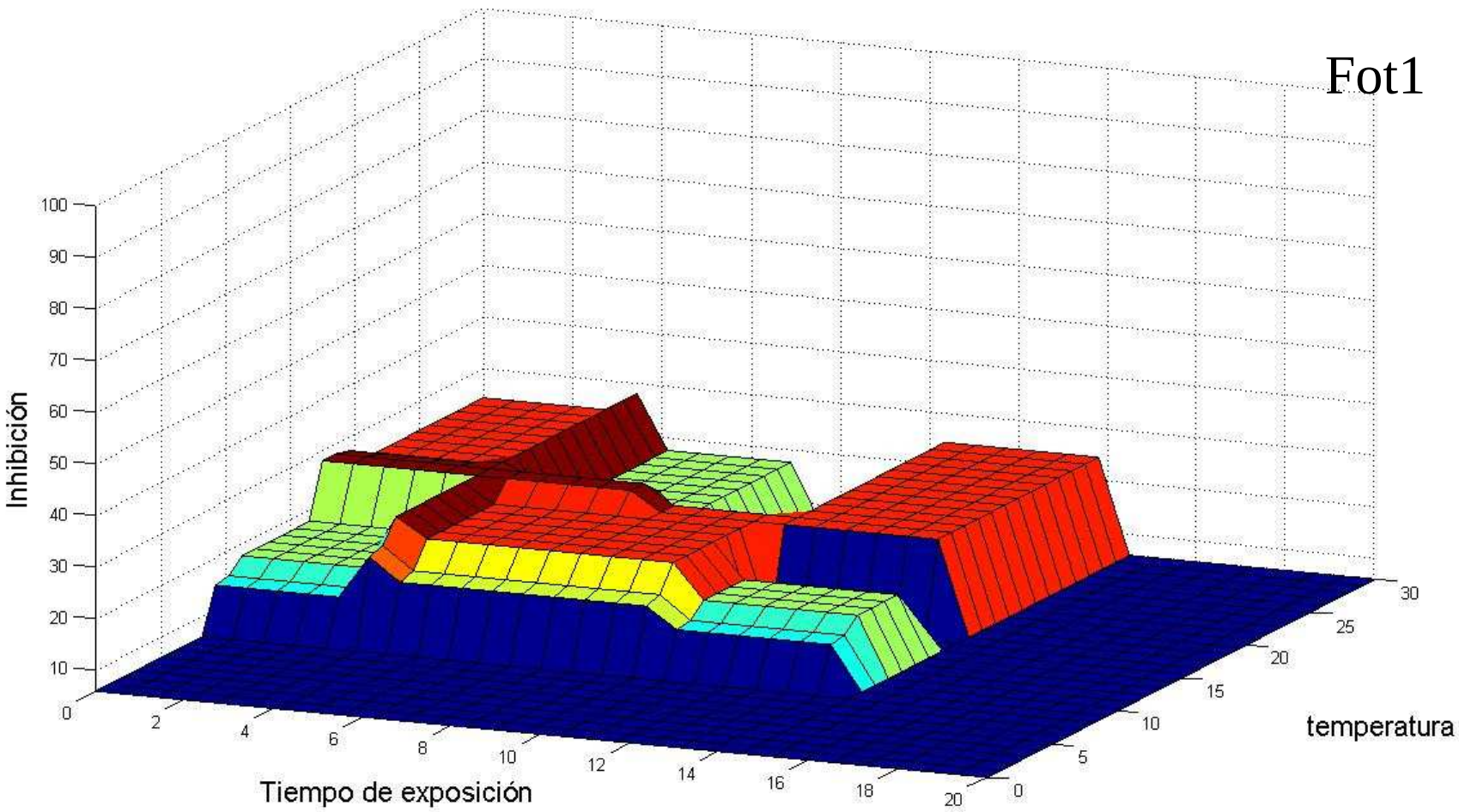
$$Phot(t) = \frac{24}{\pi} ar\cos\left(-tg(lat)\, tg\left(0.4093\, sen\left(\frac{2\pi t}{365} - 1.405\right)\right)\right)$$

Proportion of inhibited larvae

Variable Lingüística(tipo)	Nombre de la función de membresía	Tipo	Valor de los parámetros			
			a	b	c	d
Tiempo de exposición (entrada)	T-m	*Z(x;a;b)*	3	4		
	F1	*Tri(x;a,b,c)*	3	6	7	
	F2	*Tri(x;a,b,c)*	6.5	8	10	
	F3	*Tri(x;a,b,c)*	9.9	12	14	
	T-M	*S(x;a,b)*	13.5	16		
Temperatura (entrada)	*D2*	*Z(x;a,b)*	9.1	12.5		
	D4	*Tri(x;a,b)*	9.1	12.5	15.5	
	D6	*Tri(x;a,b)*	12.5	16	19.8	
	D8	*S(x;a,b)*	16.5	19.8		
Fotoperíodo (entrada)	*Fot1*	*Z(x;a,b)*				
	Fot2	*Trap(x;a,b)*	11.1	13	14.4	14.55
	Fot3	*S(x;a,b)*	14	14.7		
Proporción de larvas inhibidas (salida)	*Baja*	*Tri(x;a,b)*	0	6	12	
	Moderada	*Tri(x;a,b)*	10	25	60	
	Alto	*Tri(x;a,b)*	50	75	90	

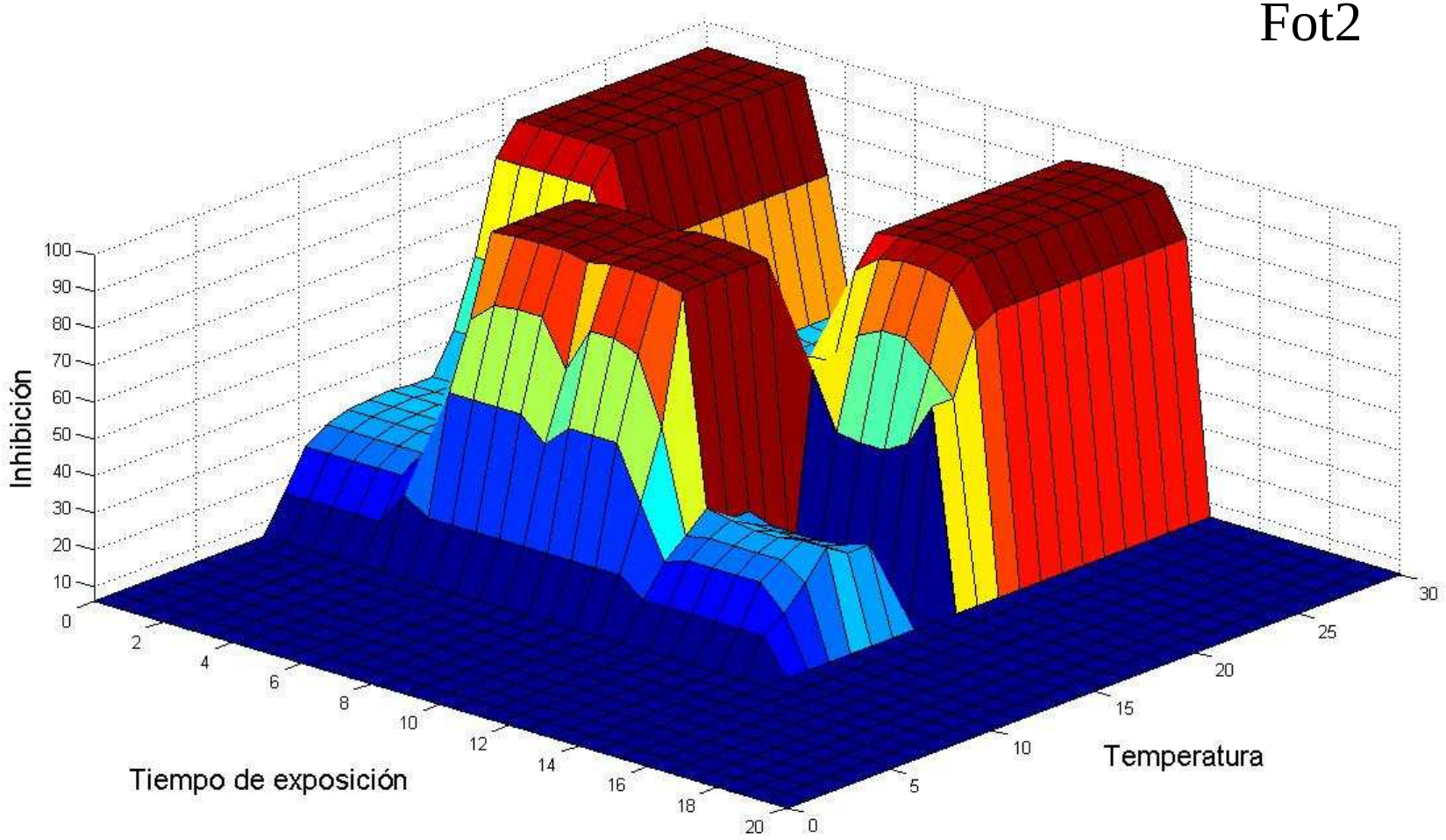
Proporción de larvas inhibidas.

Proportion of inhibited larvae

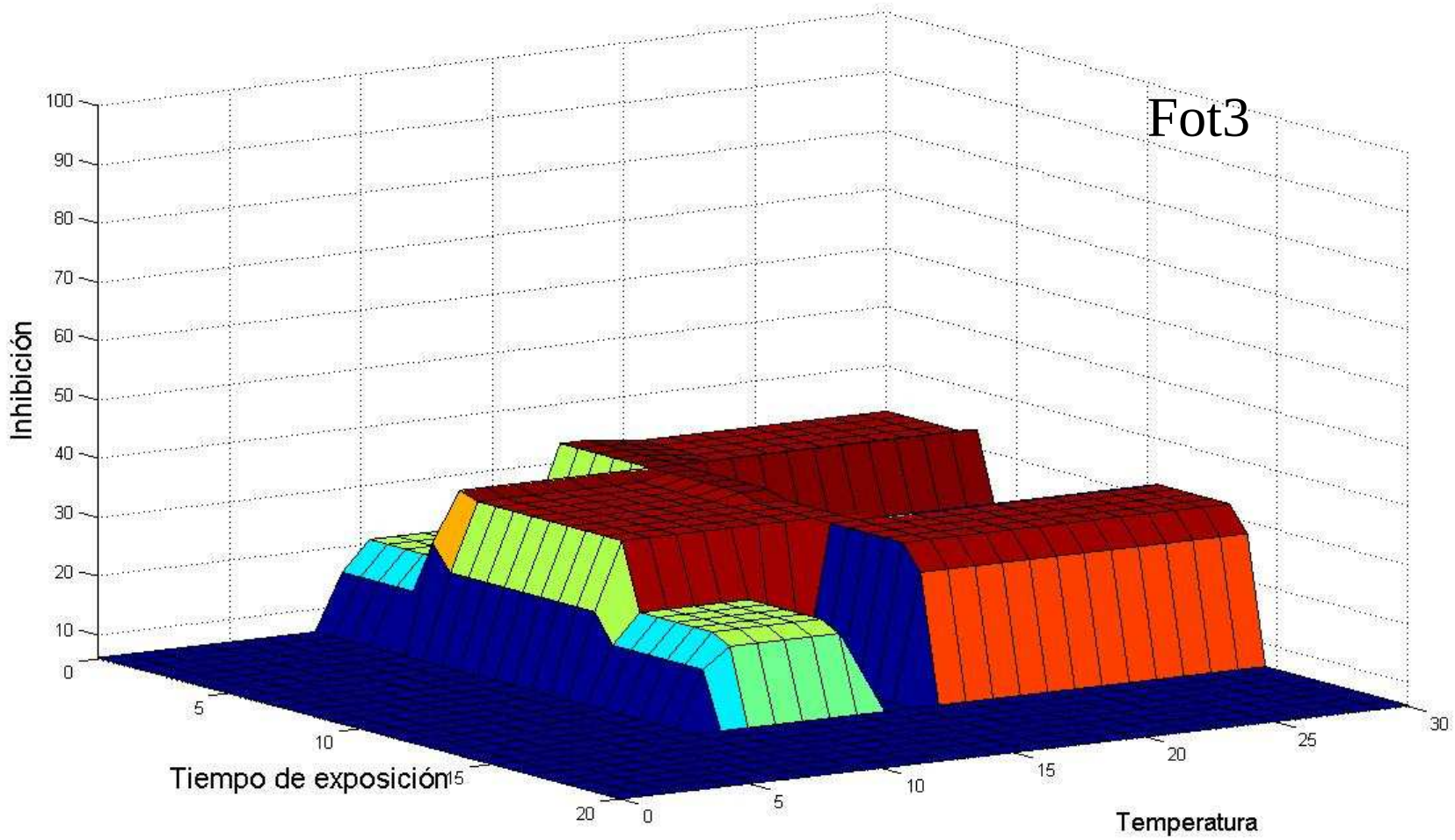


Proportion of inhibited larvae

Fot2

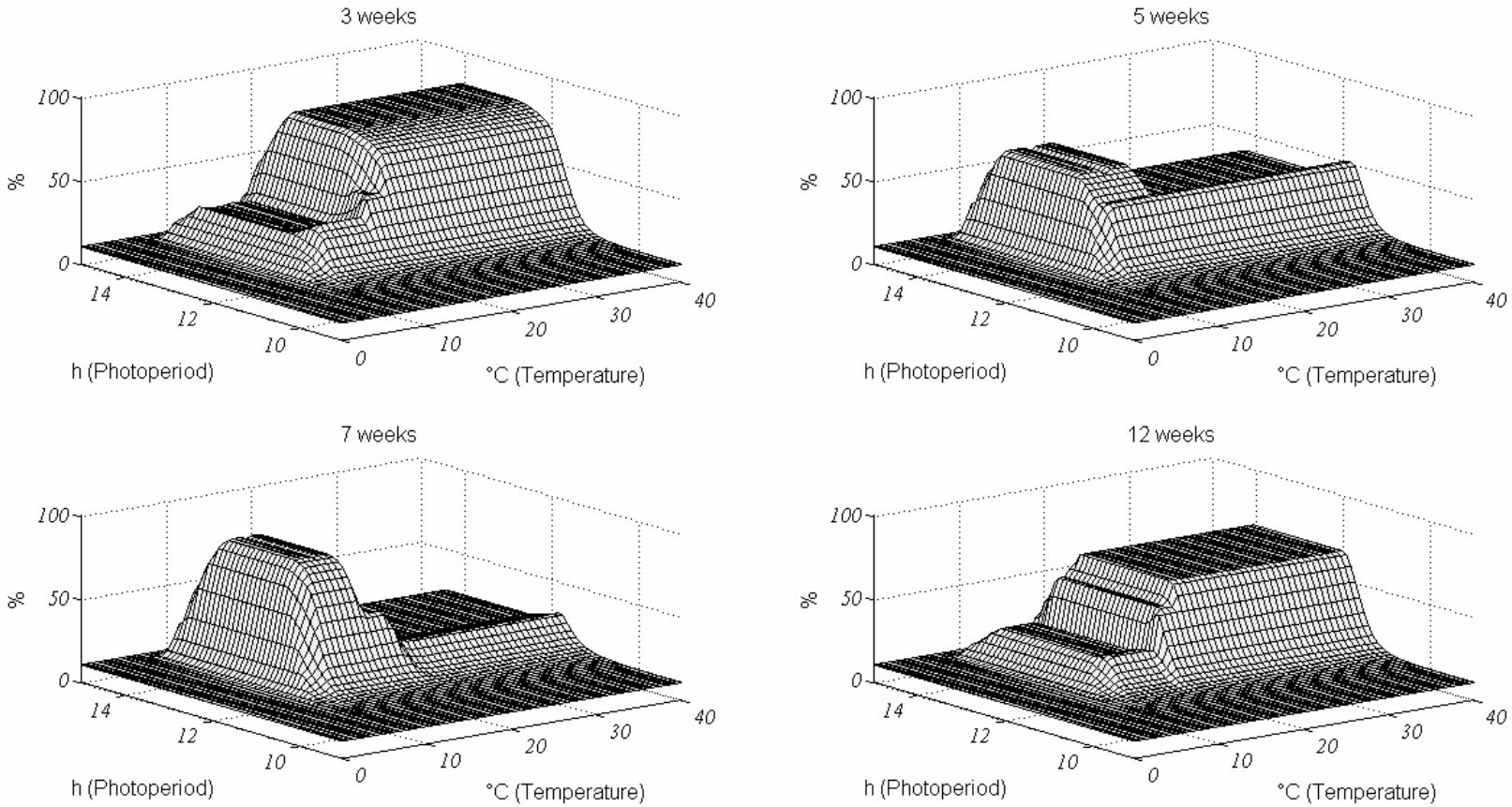


Proportion of inhibited larvae

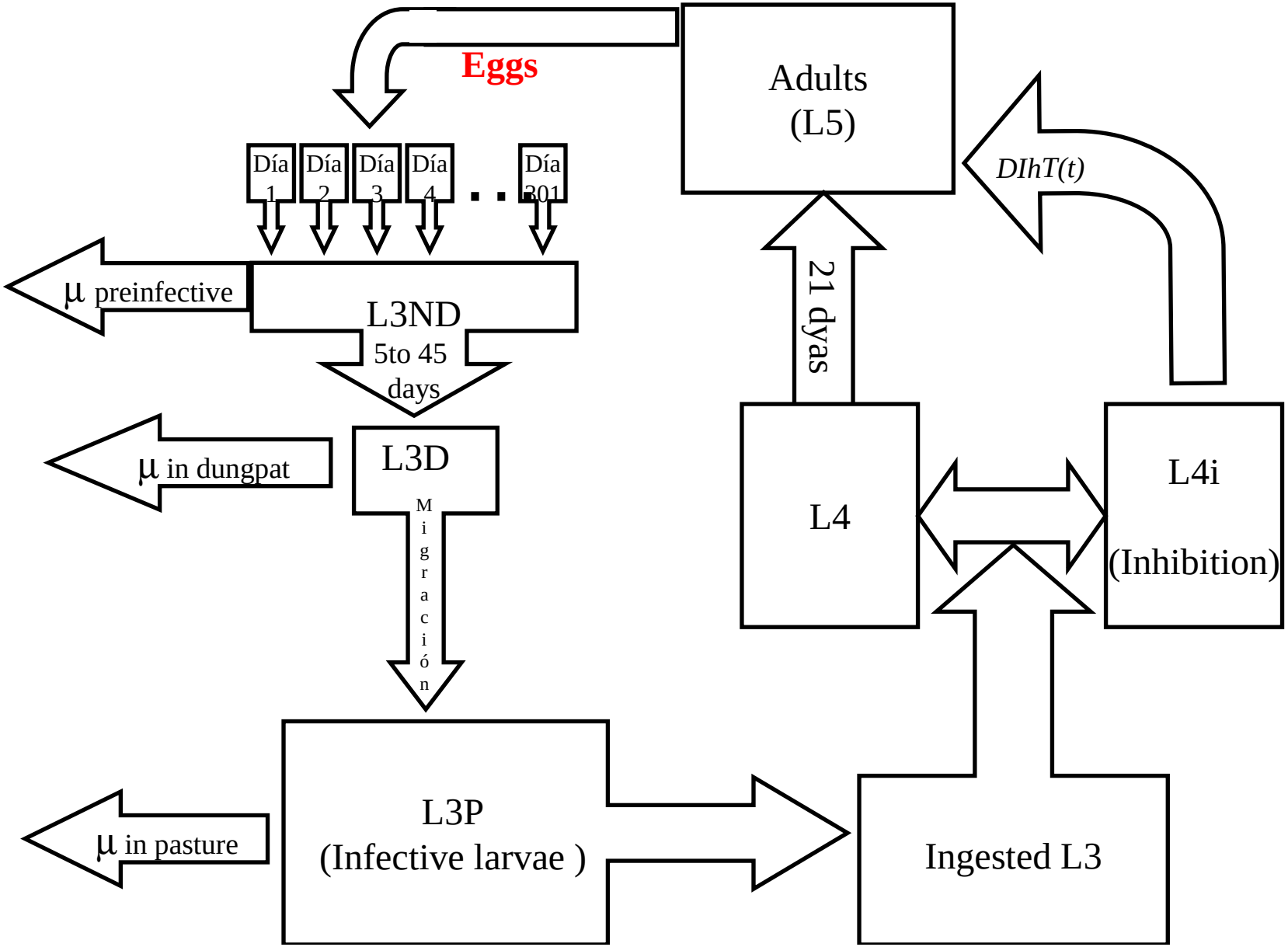


Proportion of inhibited larvae

Output of the fuzzy inference system (proportion of ingested larvae that arrest their development) depending on time of exposure to environmental conditions.



Estimation of number of eggs depending of parasite load in the host



Estimation of number of eggs depending of parasite load in the host

The model is a fuzzy inference system of Mamdani type.

The components, membership functions and rules are based on the hypotheses:

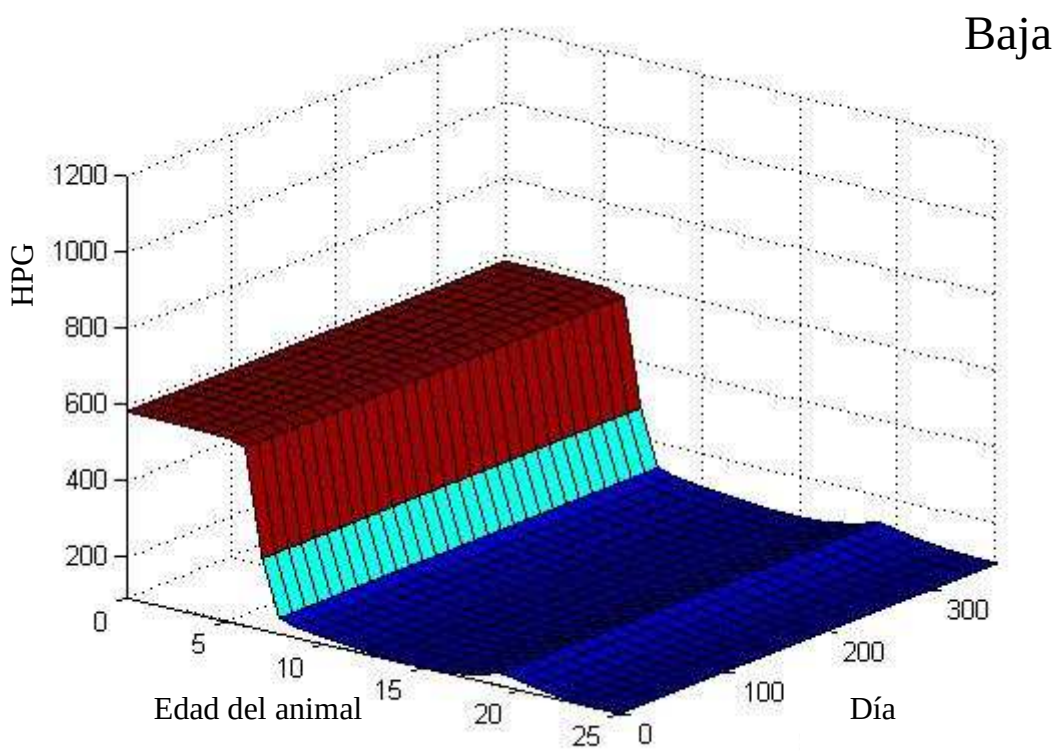
EPG is regulated by three variables:

- *Parasite load (carga sanitaria).*
- *Host's age (edad).*
- *Season (epoca del año).*

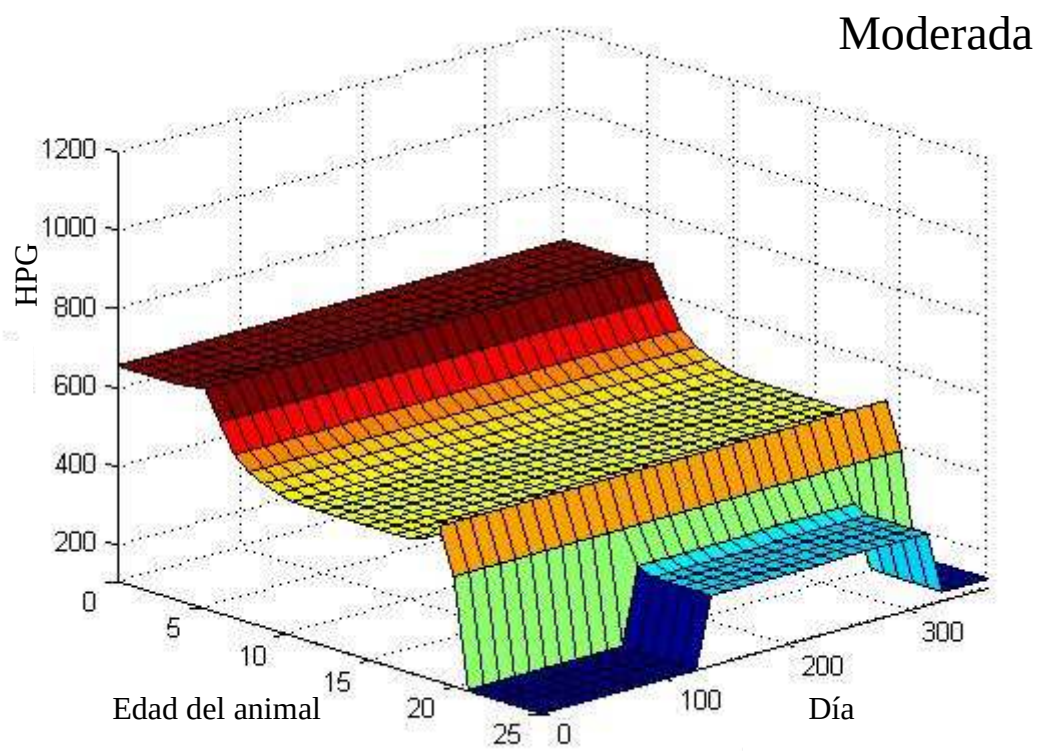
Estimation of number of eggs depending of parasite load in the host

Variable Lingüística (tipo)	Nombre	Tipo	Parámetros			
			α	β	γ	η
Edad del hospedador (entrada)	Terneros de destete	Z	0	8		
	Novillitos	Gaussiana	2.2	9		
	Novillo	S	10	15		
Carga parasitaria (entrada)	Bajo	Z	0	7500		
	Moderado	Trapecio	3500	7500	18500	22500
	Alto	S	18000	50000		
Época del año (entrada)	Verano	Z	0	136		
	Otoño	Trapecio	45	121	151	228
	Invierno	Trapecio	136	213	243	319
	Primavera	S	228	365		
Huevos por gramo de materia fecal (salida)	Bajo	Z	0	350		
	Moderado	Trapecio	200	350	550	700
	Alto	S	550	850		

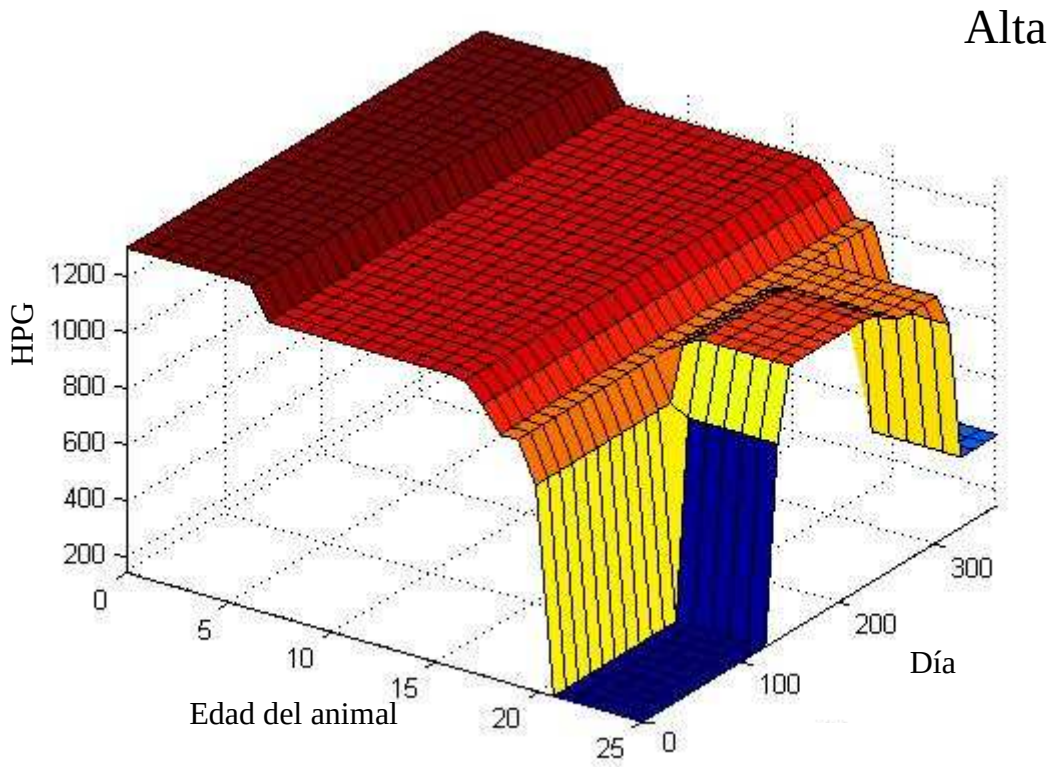
Estimation of number of eggs depending of parasite load in the host



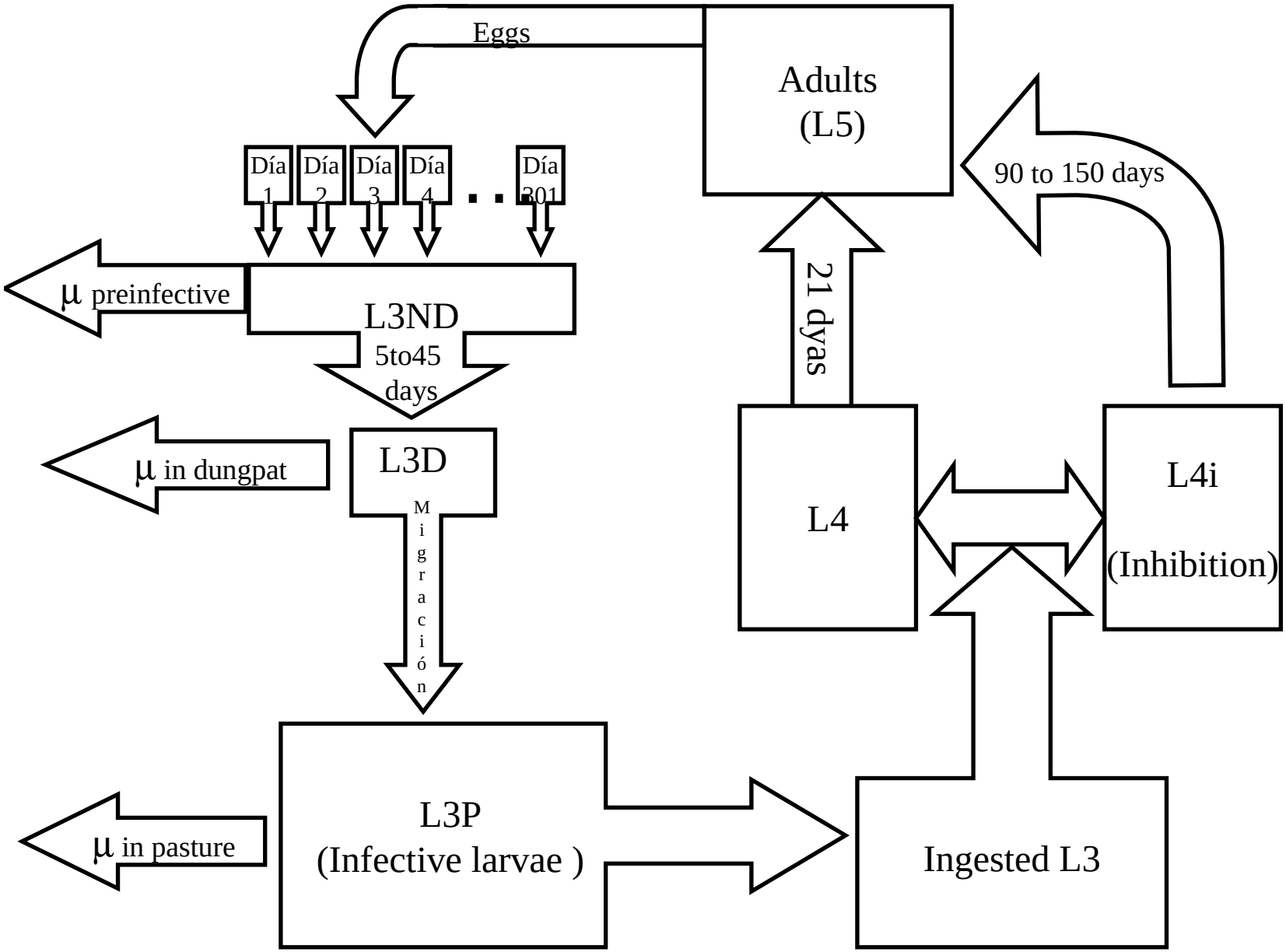
Estimation of number of eggs depending of parasite load in the host



Estimation of number of eggs depending of parasite load in the host



The complete model



The complete model

μ_b: adult mortality

$$A(t) = (1-\mu_b(t))A(t-1) + F_{NI}(t-21) + \sum_{\forall k / k+DIhT(k)=t} F_I(k + DIhT(k))$$

EPG: number of eggs per gram (FISM)

$$H(t,0,w) = \begin{cases} NAnimal\ 6.3\ EPG(t)\ (1000PatWt(w)) & \text{if animal is calf} \\ NAnimal\ 8.1\ EPG(t)\ (1000PatWt(w)) & \text{if animal is cow,} \end{cases}$$

$$H(t+a, a) = (1-\mu_{Pre}(a, t+a, R(t+a)))\, H(t+a-1, a-1)$$
$$si\ L_t(a) \le l_{L3}(T_t + a)$$

$$DIhT(t) = \begin{cases} 240 - \frac{t}{2} & if \quad Phot(180) \le Phot(t) \le Phot(265) \\ 270 - \frac{t}{2} & if \quad Phot(t) \ge Phot(265) \\ 120 & if \quad other\ case \end{cases}$$

μ_{pre}: preinfective mortality (FISM)

$$L_t(a) = \begin{cases} (1+r(T_{t+a}))L_t(a-1) & si \quad L_t(a) < l_{L3}(T_t + a) \\ l_{L3}(T_t + a) & si \quad L_t(a) \ge l_{L3}(T_t + a) \end{cases}$$

$$F_{NI}(k) = F(k) - F_I(k)$$

$$F_{Inhi}(k) = \sum_{j=1}^{k} p_{inhi}(j,k) F(j,k)$$

$p_{inhi}(j,k)$= proportion of inhibited larvae of cohort "j" aged "k" (FISM)

$$L3ND(t) = \sum_{\forall k / k+k+\tau(k)=t} H(k+\tau(k), k+\tau(k))$$

$$\tau(k) / L_k(\tau(k)) \le l_{L3}(T_k + \tau(k)) \le L_k(\tau(k)+1)$$

$$L3D(t+1) = (1-\delta_{DP}(t, R(t)))\,(1-\mu_{ID})L3D(t) + L3ND(t+1)$$

δ_{DP}: migration rate (FISM)

$$F(k) = \sum_{j=1}^{k} F(j,k) = F_{NI}(k) + F_I(k)$$

$$F(j,k) = F(k)p(j,k)$$

$$p(j,k) = \frac{C_j(k)}{P_{L3}(k)}$$

$$P_{L3}(k) = C_k(0) + \sum_{i=1}^{k-1} C_i(k-i)$$

μ_P: L3 mortality in pasture (FISM)

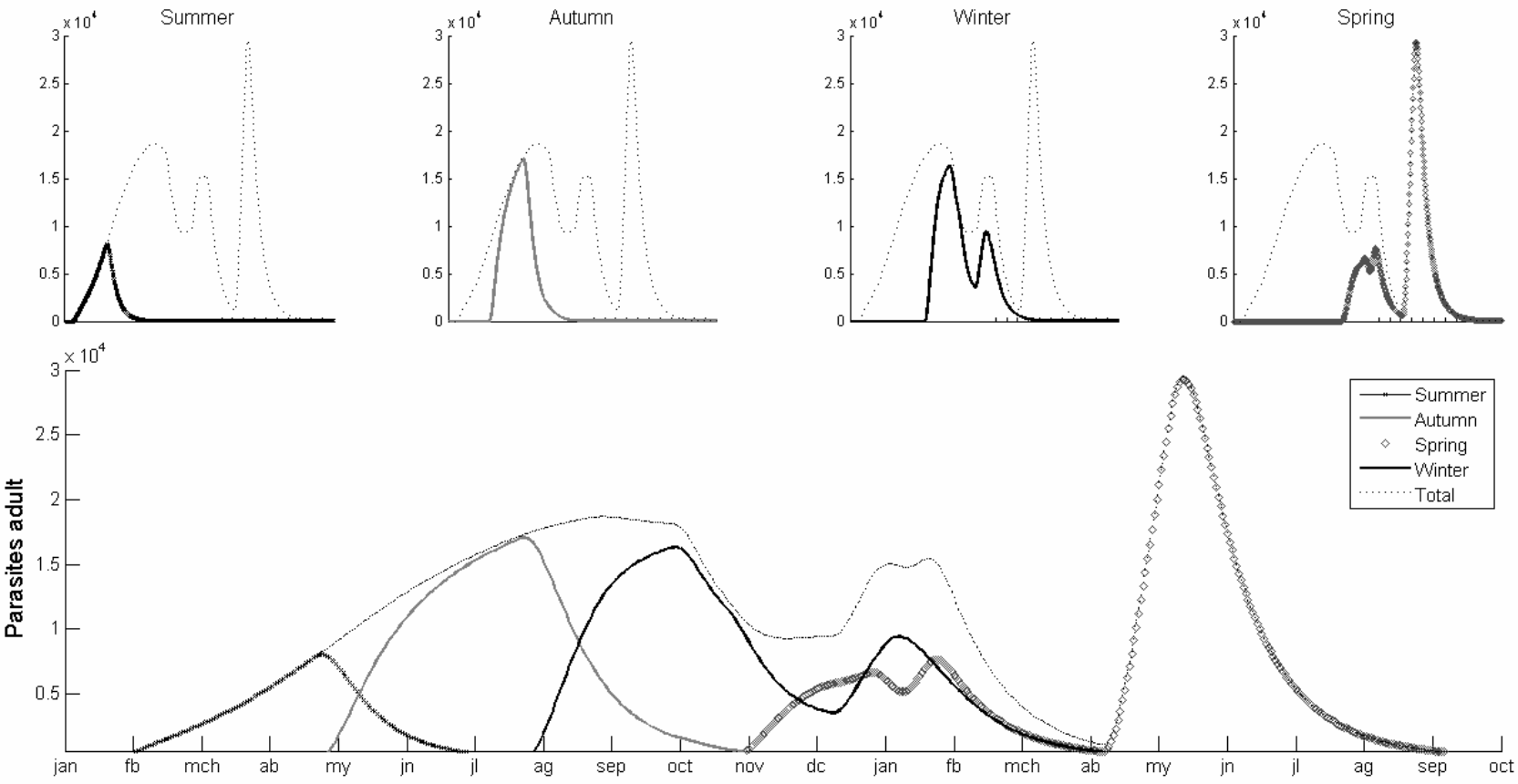
$$C_j(k+1) = (1-\mu_p(j,k))C_j(k) - p(j,k)F(k)$$
$$C_j(0) = \delta_{DP}(t+1, R(t+1))L3D(t+1)$$

$$Phot(t) = \frac{24}{\pi} ar\cos\left(-tg(lat)\, tg\left(0.4093\ sen\left(\frac{2\pi t}{365} - 1.405\right)\right)\right)$$

Simulations

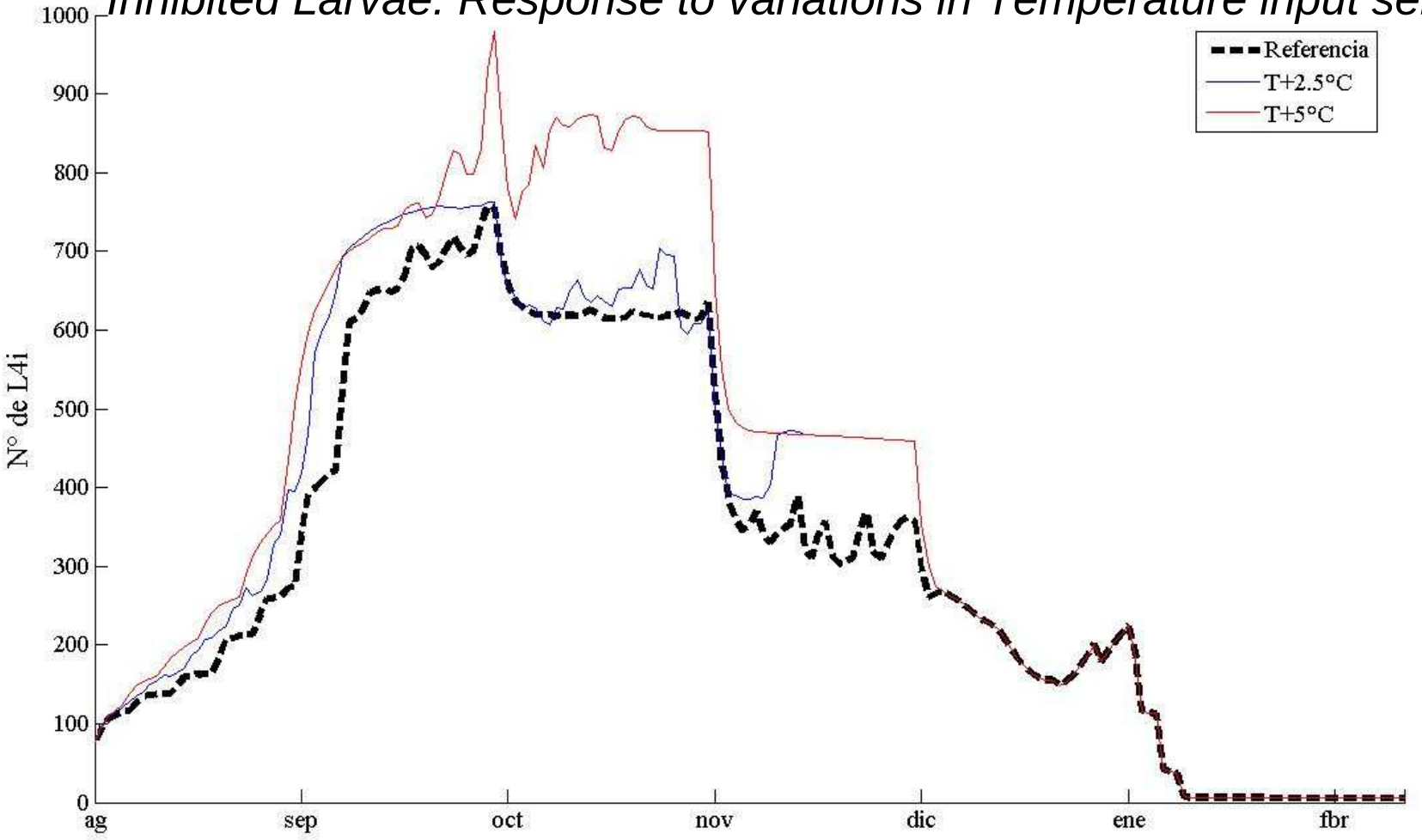
Parasitic stage dynamics

Seasonal availability of L3 larvae on pasture



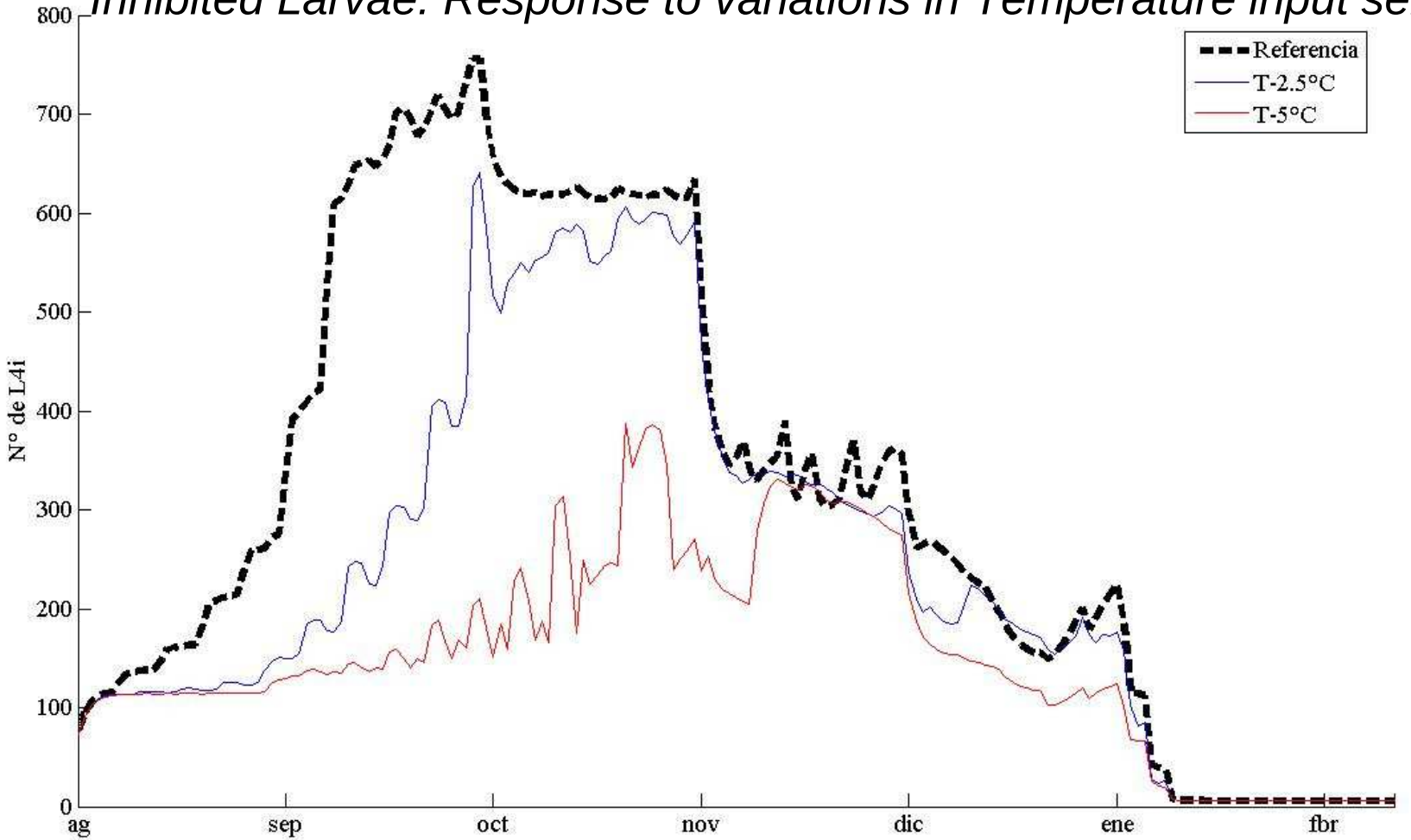
Parasitic stage dynamics

Inhibited Larvae: Response to variations in Temperature input series

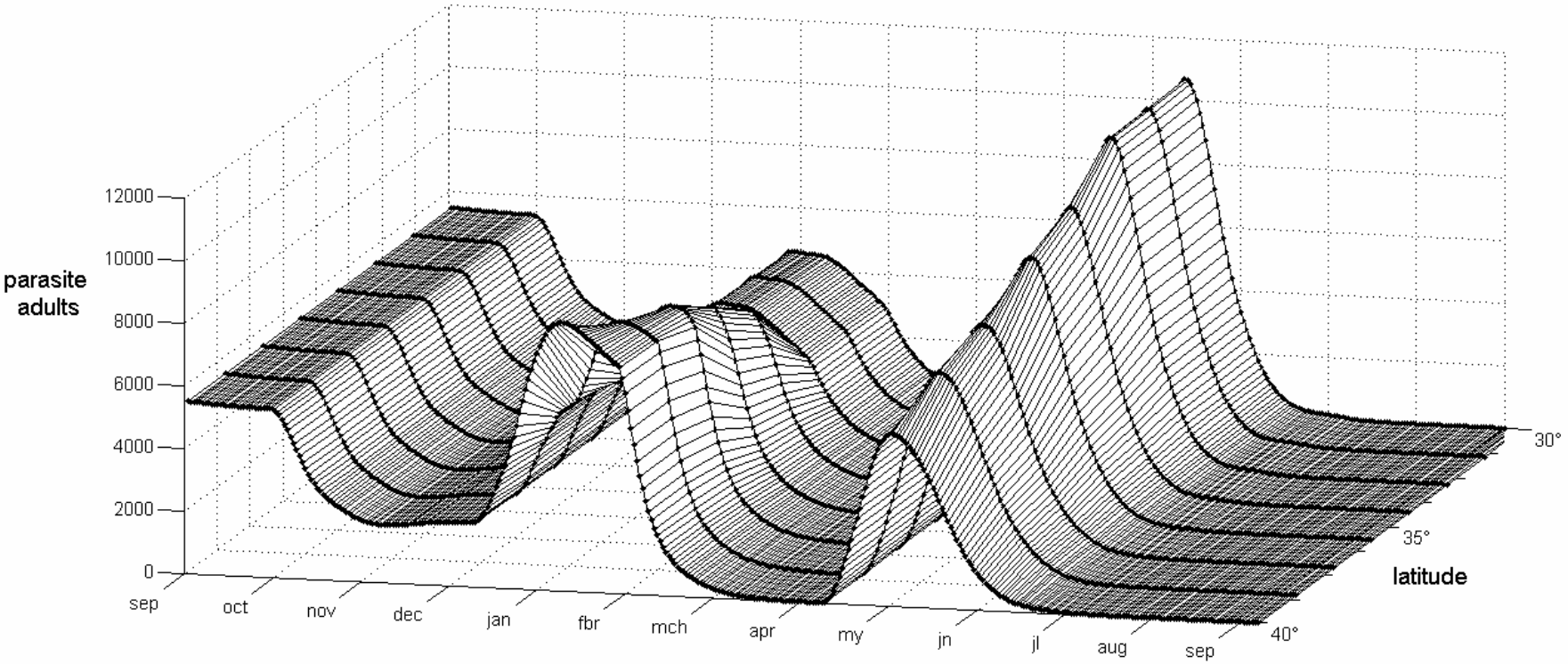


Parasitic stage dynamics

Inhibited Larvae: Response to variations in Temperature input series

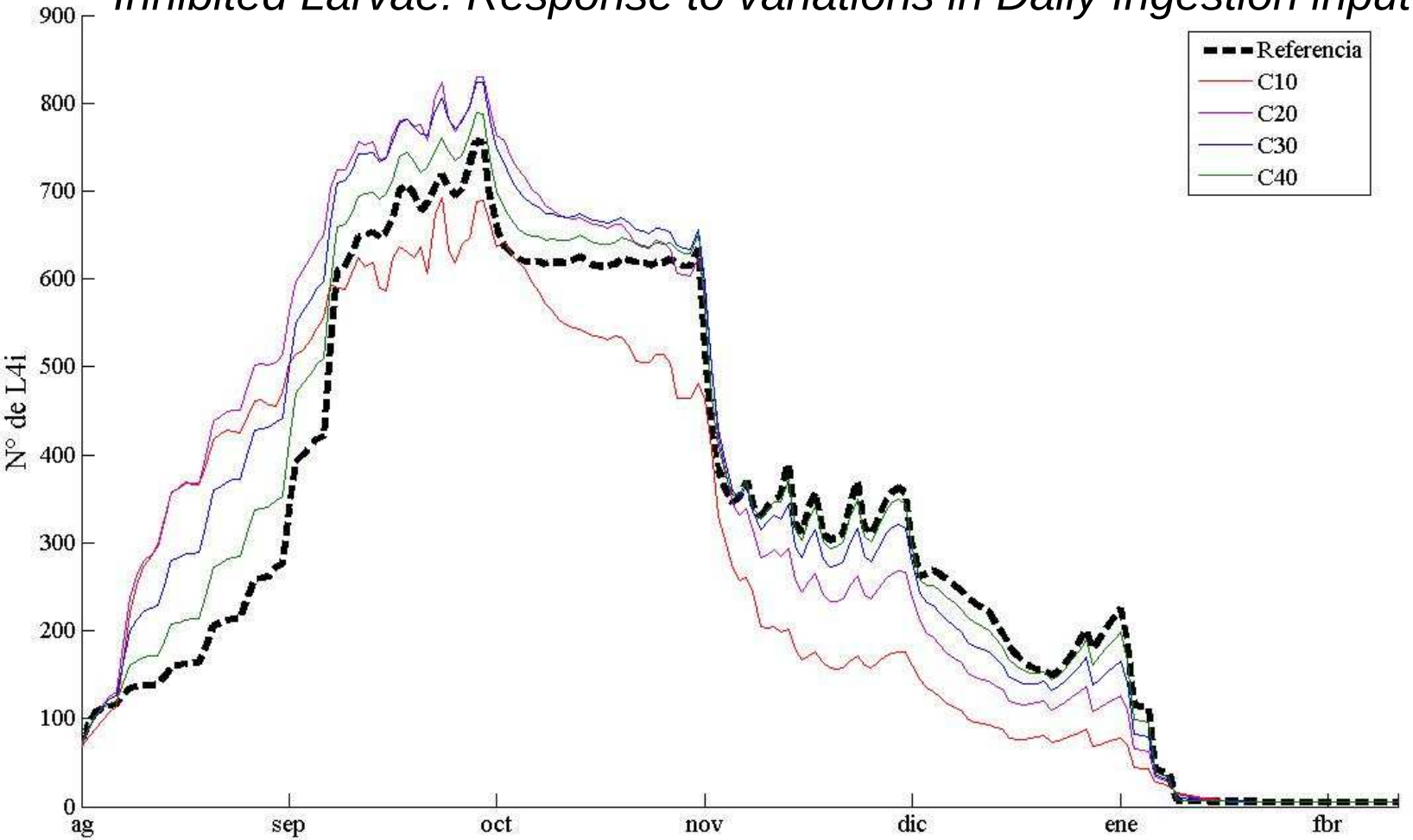


Parasitic stage dynamics



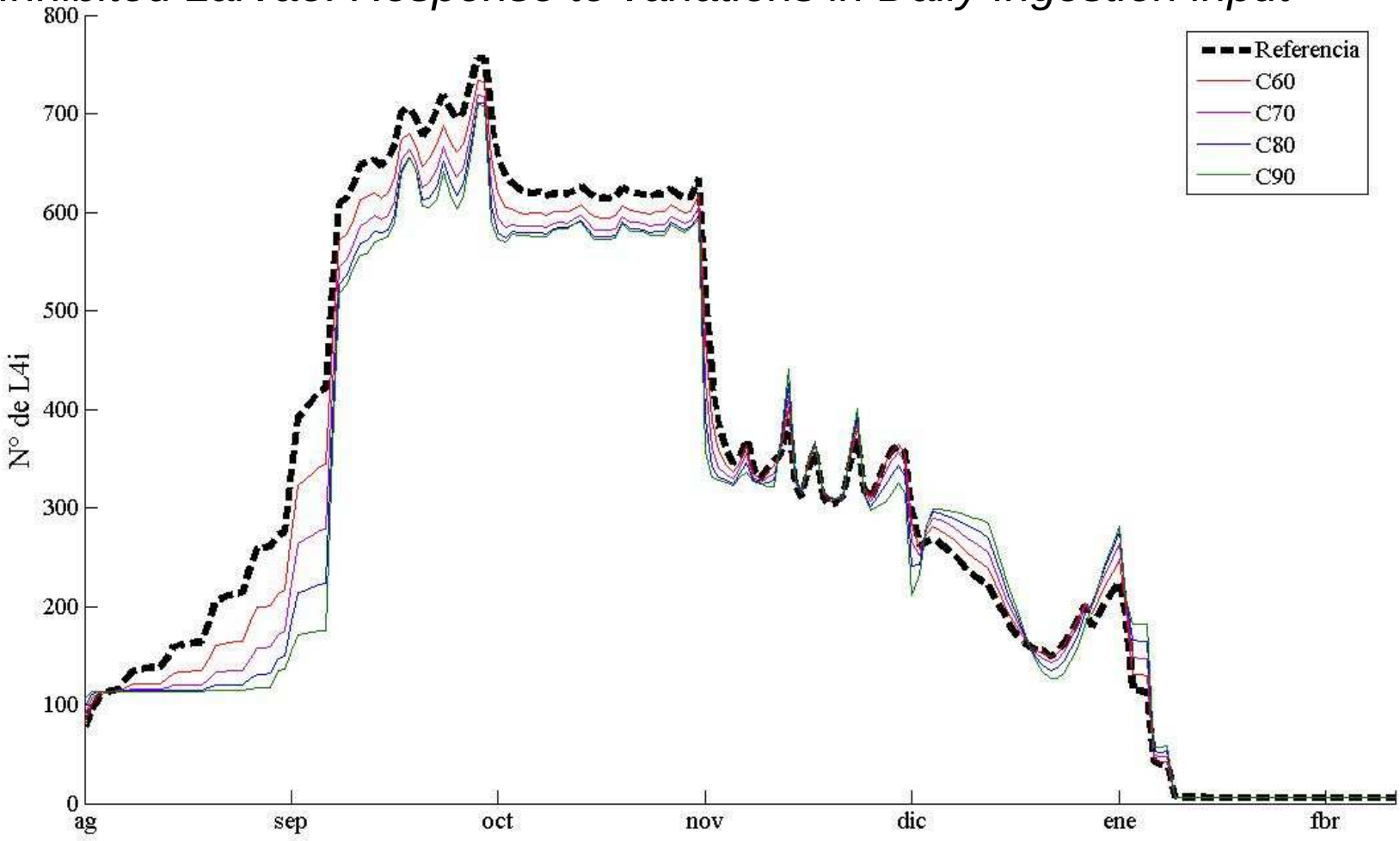
Parasitic stage dynamics

Inhibited Larvae: Response to variations in Daily Ingestion input



Parasitic stage dynamics

Inhibited Larvae: Response to variations in Daily Ingestion input

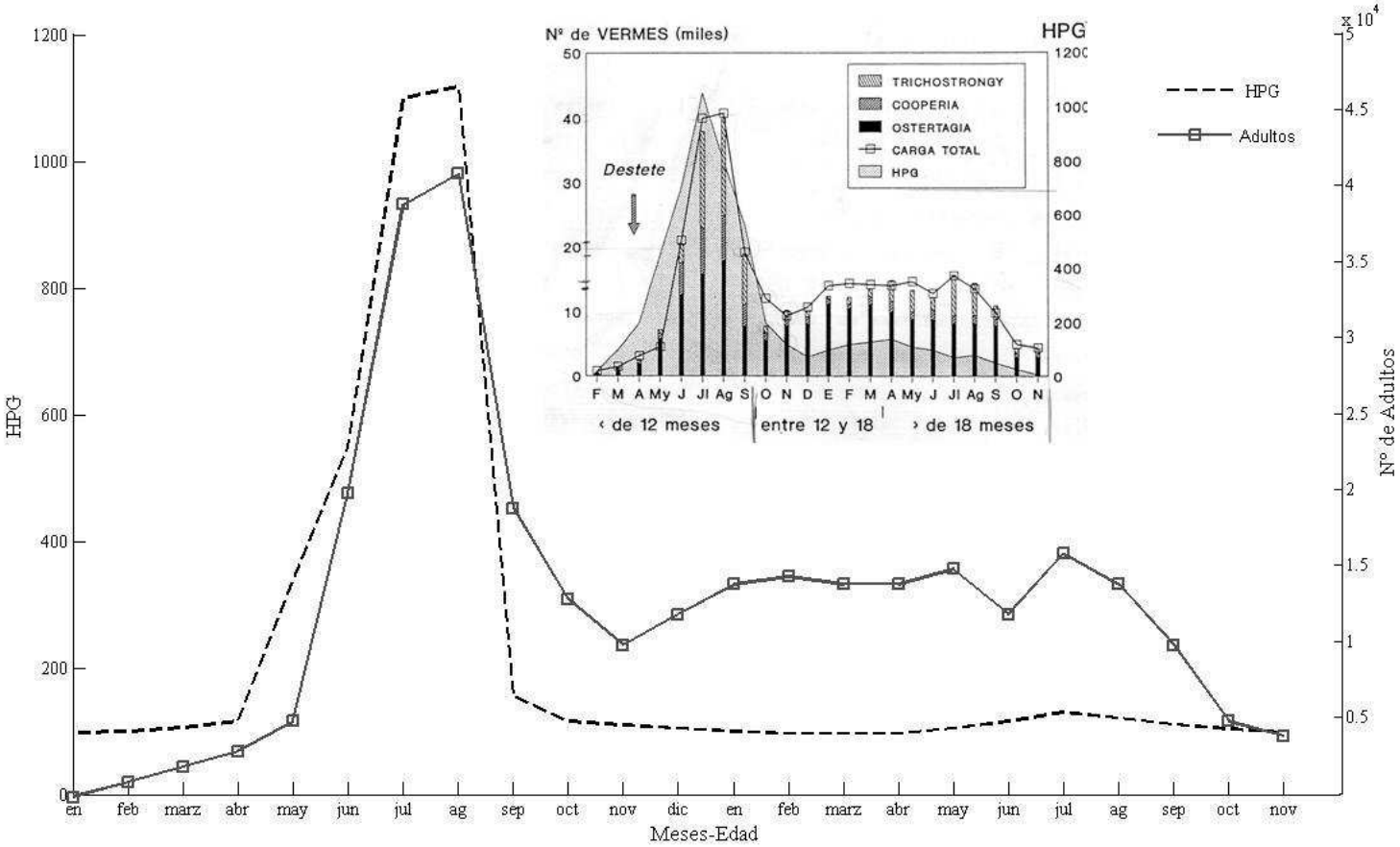


Parasitic stage dynamics

- The results coincide with the observed effects of the photoperiod variations in Tandil during Spring and Summer.
- The model reflects an inverse relationship between temperature and the proportion of inhibited larvae.
- Wider amplitude in amount of light hours resulted in a decreasing numbers of inhibited larvae.
- Higher grazing presure resulted in lower proportion of inhibited larvae in Spring.

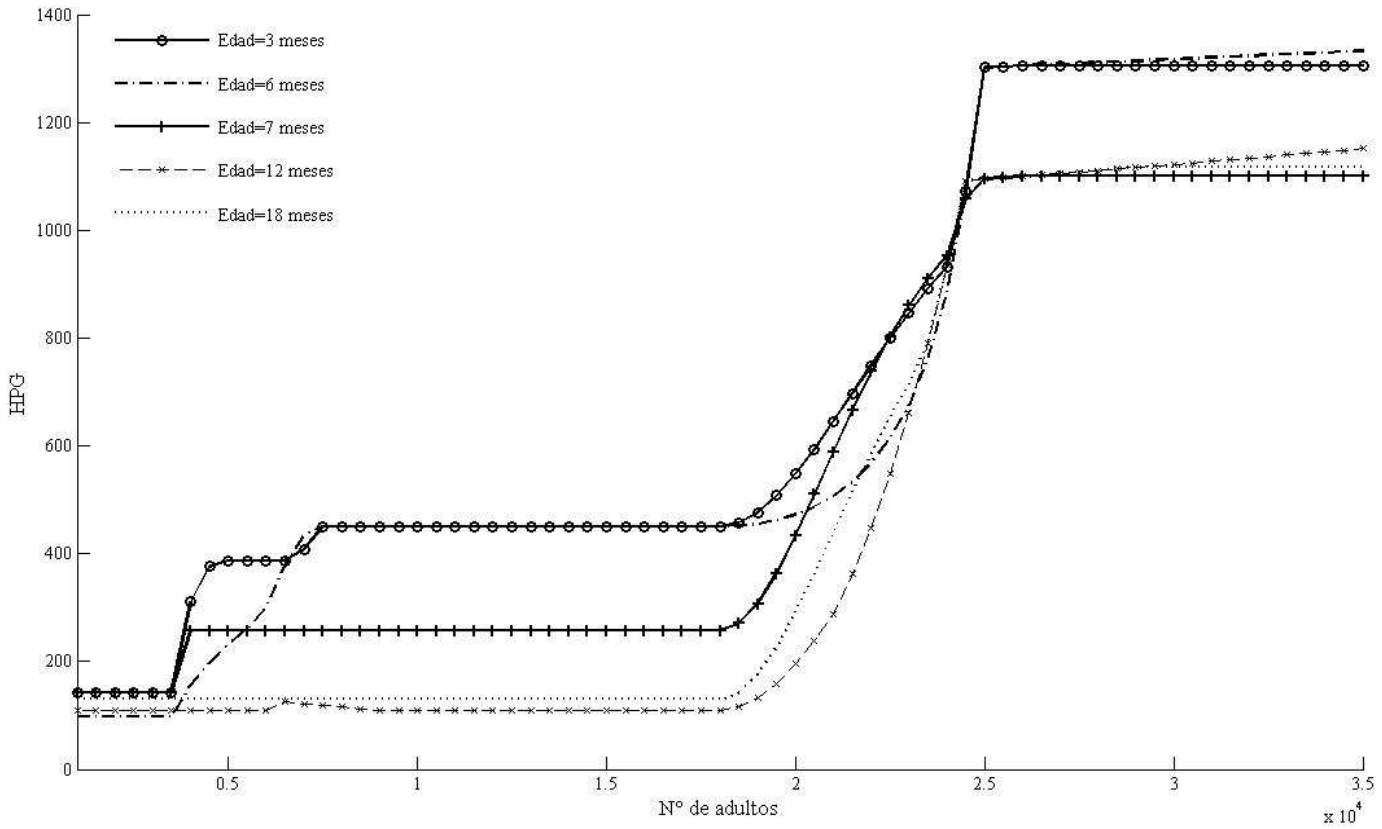
Estimation of number of eggs depending of parasite load in the host

Simulation with parasite load data reported in Suárez et al. (1994)



Estimation of number of eggs depending of parasite load in the host

Variable parasite load and host's age



Estimation of number of eggs depending of parasite load in the host

- The model accurately estimates EPG depending on the host's parasite load and age.
- The estimation of the maximum EPG value and the time of occurrence is a good indicator of the herd's state.
- There is a non linear relationship between the parasite load and the EPG estimation.

Simulations of Parasite Load Control

Control of Parasite Load

Usually herd's treatments are either:

- Scheduled in advance (Tactic Treatment).
- When weight loss occurs (Symptomatic Treatment).
- Defined by parasitological and/or production parameters (Strategic Treatment).

Initial Conditions

- The paddock is initialy free of infective larvae.
- The herd has 25 animals remaining in the paddock during 20 months beginning on January 1st.
- The animals enter the paddock with a low level of infection (5000 adults per animal).
- Grazing presure is simulated with a *L*3 ingestion rate fixed at 0.3.

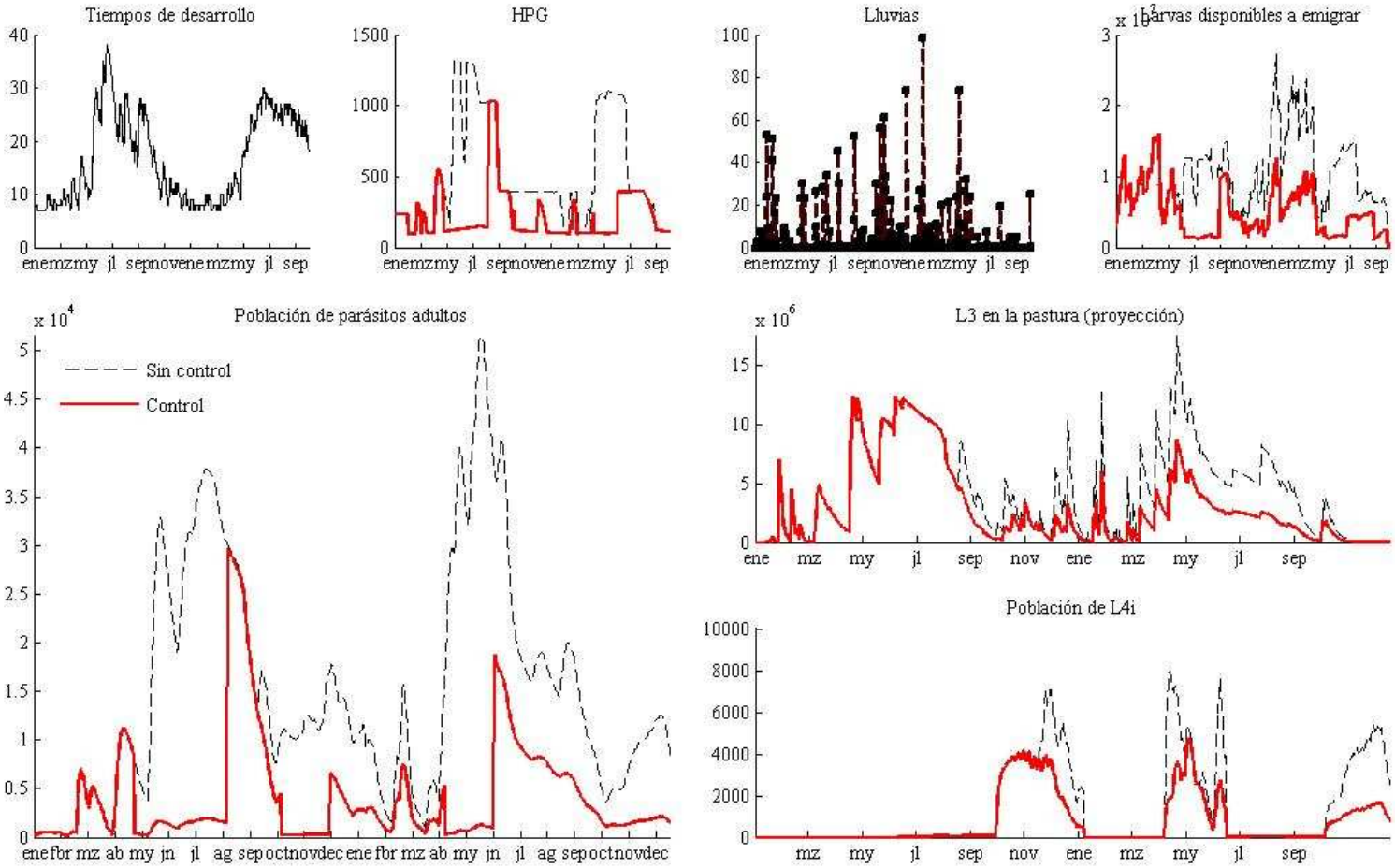
Control of Parasite Load
Strategic treatments

Tandil, province of Buenos Aires ($\bar{X}$=14℃; R=888 mm):

Drug treatment calendar:
1st application: 20/04/06. Action period : 56 days.
2nd application: 10/06/06. Action period : 56 days.
3rd application: 01/10/06. Action period : 56 days.
4th application: 01/04/07. Action period : 56 days.

Control of Parasite Load

Strategic treatments



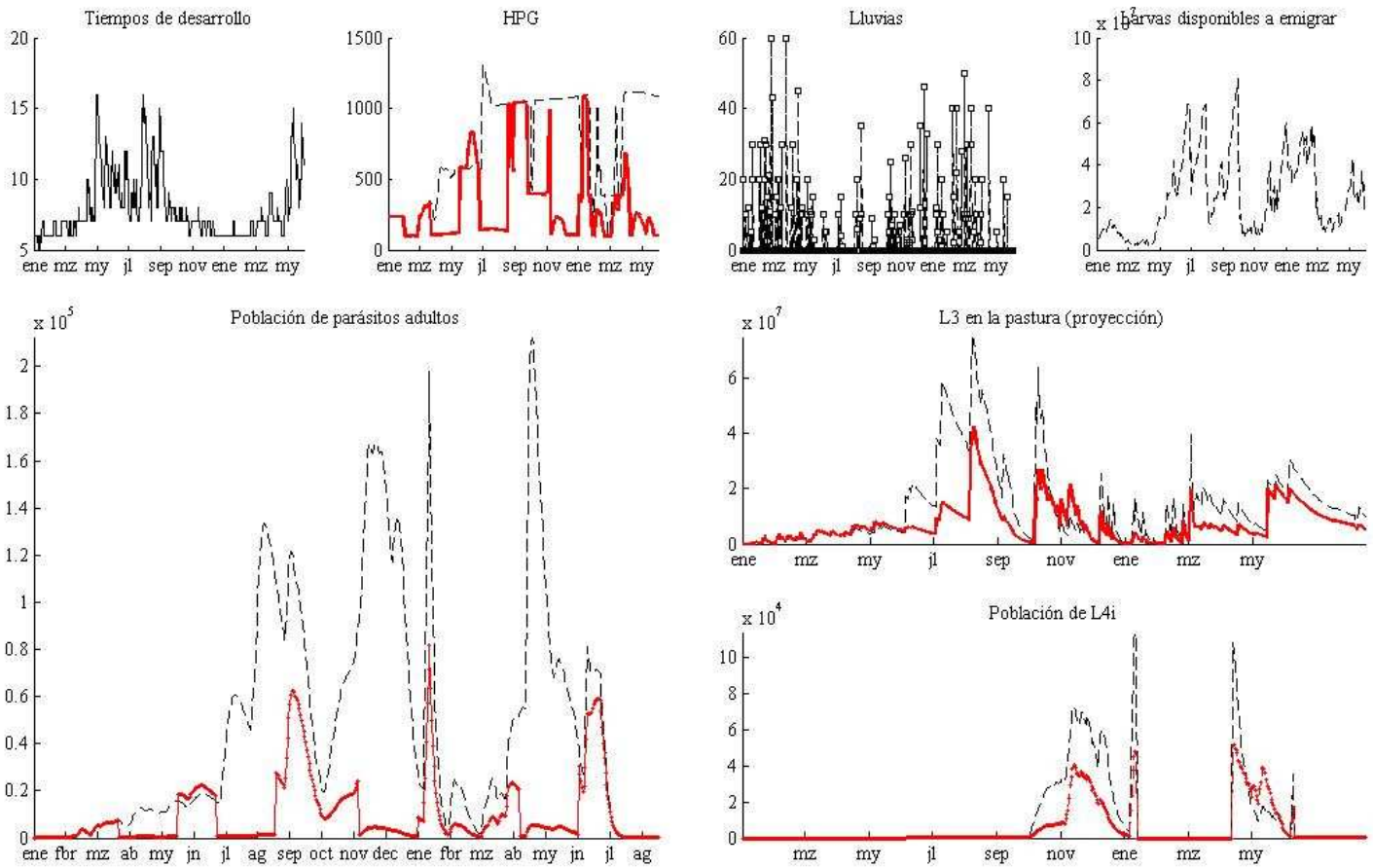
Control of Parasite Load
Strategic treatments

Reconquista, province of Santa Fe ($\bar{X}$=19.5℃; R=1408 mm):

Drug treatment calendar:
1st application: 21/03/06. Action period : 56 days.
2nd application: 21/06/06. Action period : 56 days.
3rd application: 01/11/06. Action period : 56 days.
4th application: 01/04/07. Action period : 56 days.

Control of Parasite Load
Strategic treatments

Reconquista, province of Santa Fe ($\bar{X}$=19.5°C; R=1408 mm):



Control of Parasite Load

Strategic treatments

- Controls intended to avoid high infection levels in pasture should be done between April and June.
- Preventive treatments can be done between September and October.
- Controls in January, February, July, August, November and December <u>are not</u> convenient since their effects are minimal.
- Treatments in March, April, May, June, September and October are strongly related to pasture dynamics.

Current Research

Parasite counts at different stages (egg, L3, adults) are being recorded over a period of two years in fields in the district of Olavarrìa, Province of Buenos Aires.

The model is run with temperature and precipitation time series obtained from the National Meteorological Service.

Final Comments

- The model incorporates aspects that have not been previously implemented in other models.
- The advantages of this model are:
  - its modular construction,
  - the use of difference equations, and
  - parameterization using fuzzy inference systems.

Final Comments

- The use of fuzzy inference systems in the parameterization of models permits an adequate description of complex dynamics involving large numbers of variables and information that is not easily quantifiable and that could not have been included using clasic mathematical tools.

Publications

Chaparro, M.; Canziani, G. (2010) *A discrete model for estimating the development time from egg to infecting larva of Ostertagia ostertagi parametrized using a fuzzy rulebased system.* Ecological Modelling 221: 2582–2589.

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