Parasites, climate and fuzzy inference systems

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Argentina

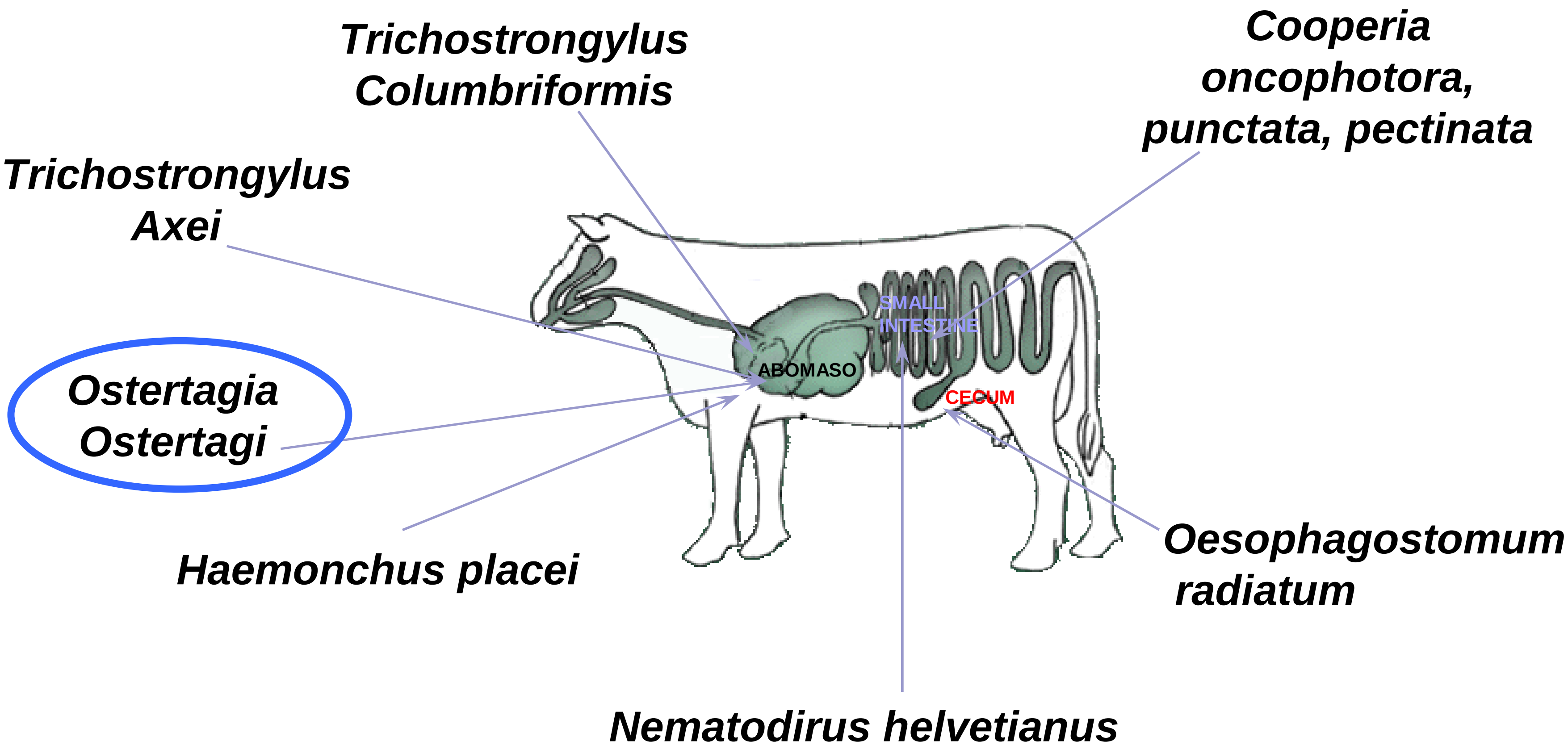
Main cattle production regions

Corrientes

Santa Fe - Cordoba

Buenos Aires

Nematodes in the Pampas region



Effects

- Diseases with high economic impact on meat production systems.

- Losses include high mortality in young individuals, antihelmintic drugs costs, and a considerable decrease in weight gain (*Entrocasso & Steffan, 1981; Steffan; et.al. 1982*)

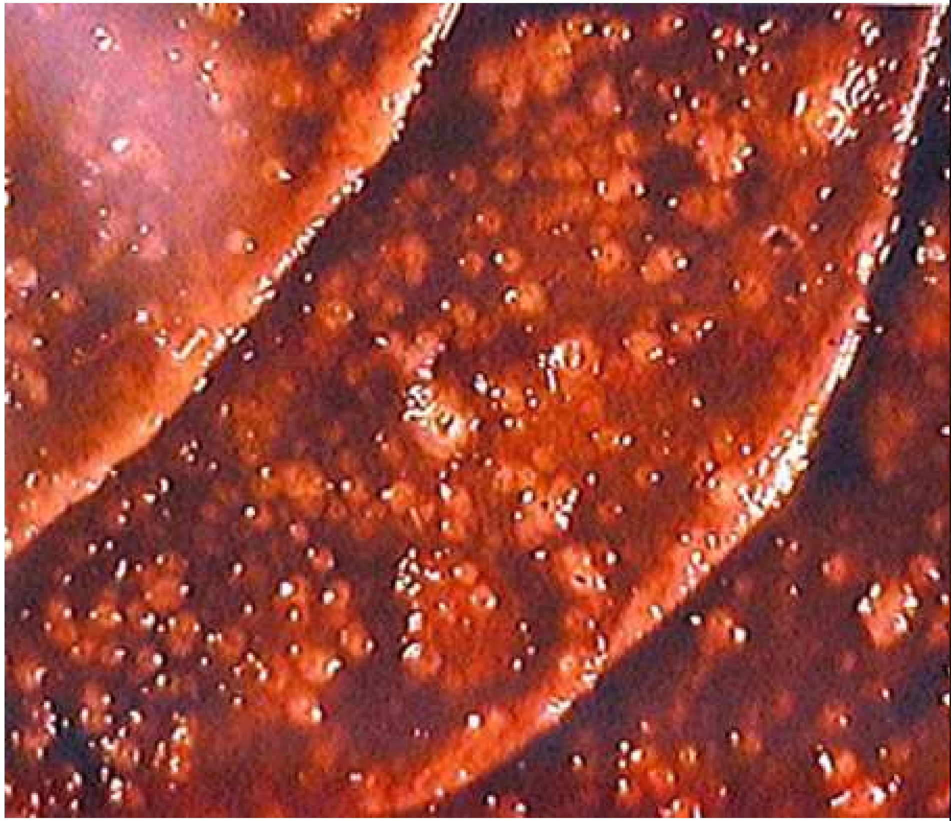
- Estimated costs added up to some 22 million dollars in annual losses due to cattle mortality, and 170 million dollars caused by subclinic problems.

Effects

- A reduction in weight gain was estimated to affect some 18% of animals feeding in natural pastures and 25% of those feeding in pens.

- The largest losses occur during the first autumn-winter grazing (INTA-EEA Anguil, Argentina). Animals suffer losses ranging from 18 to 44 kg in calves and 15 to 23 kg to steers.

- Lately, resistance to antihelmintic drugs has been detected.



Abomasum showing lesions

Adults in intestine

Life Cycle

- *Stages*

Deposition of eggs in the cow dung

Non parasitic phase:

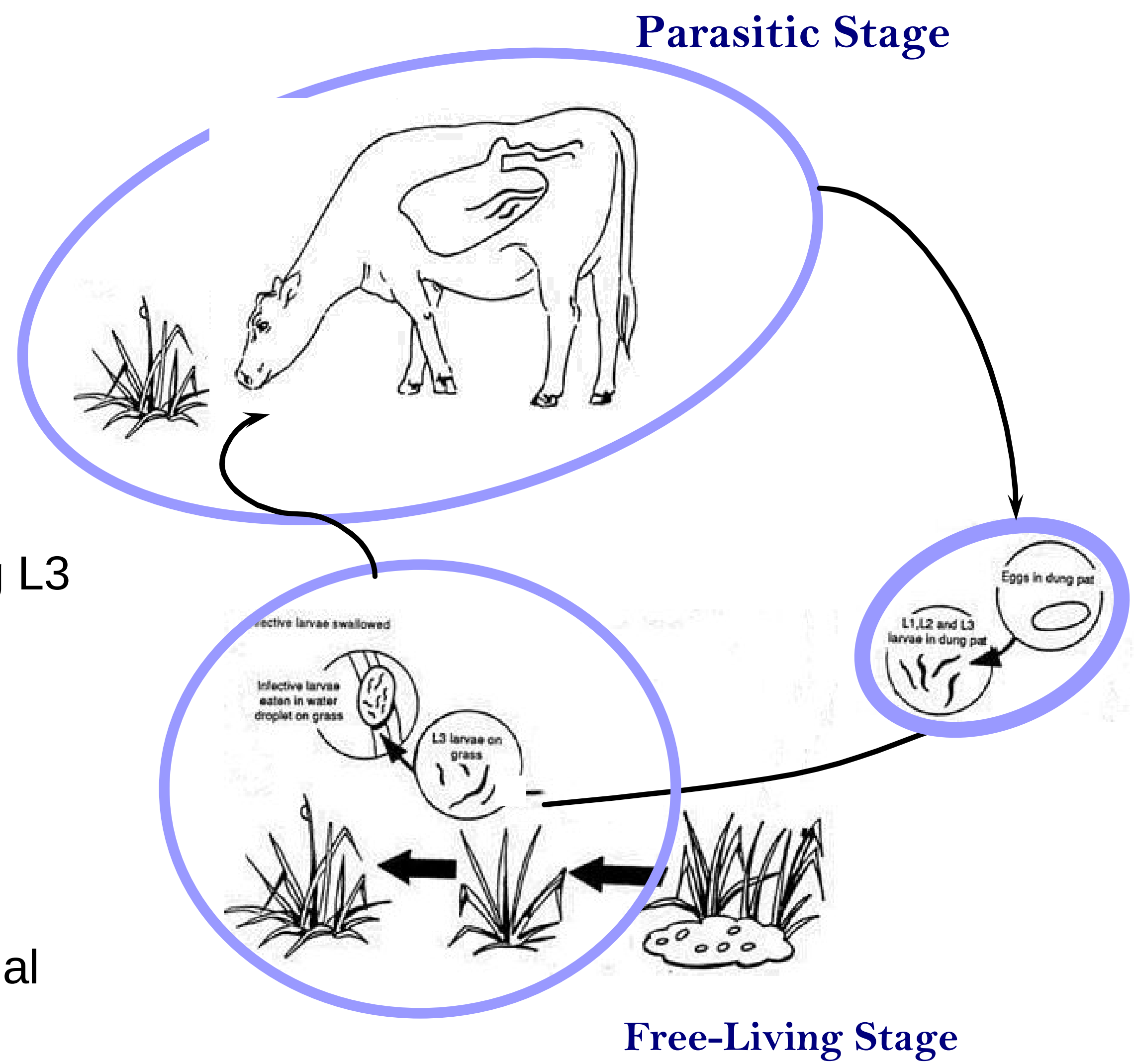
Growth from eggs to infecting L3

Migration to pastures

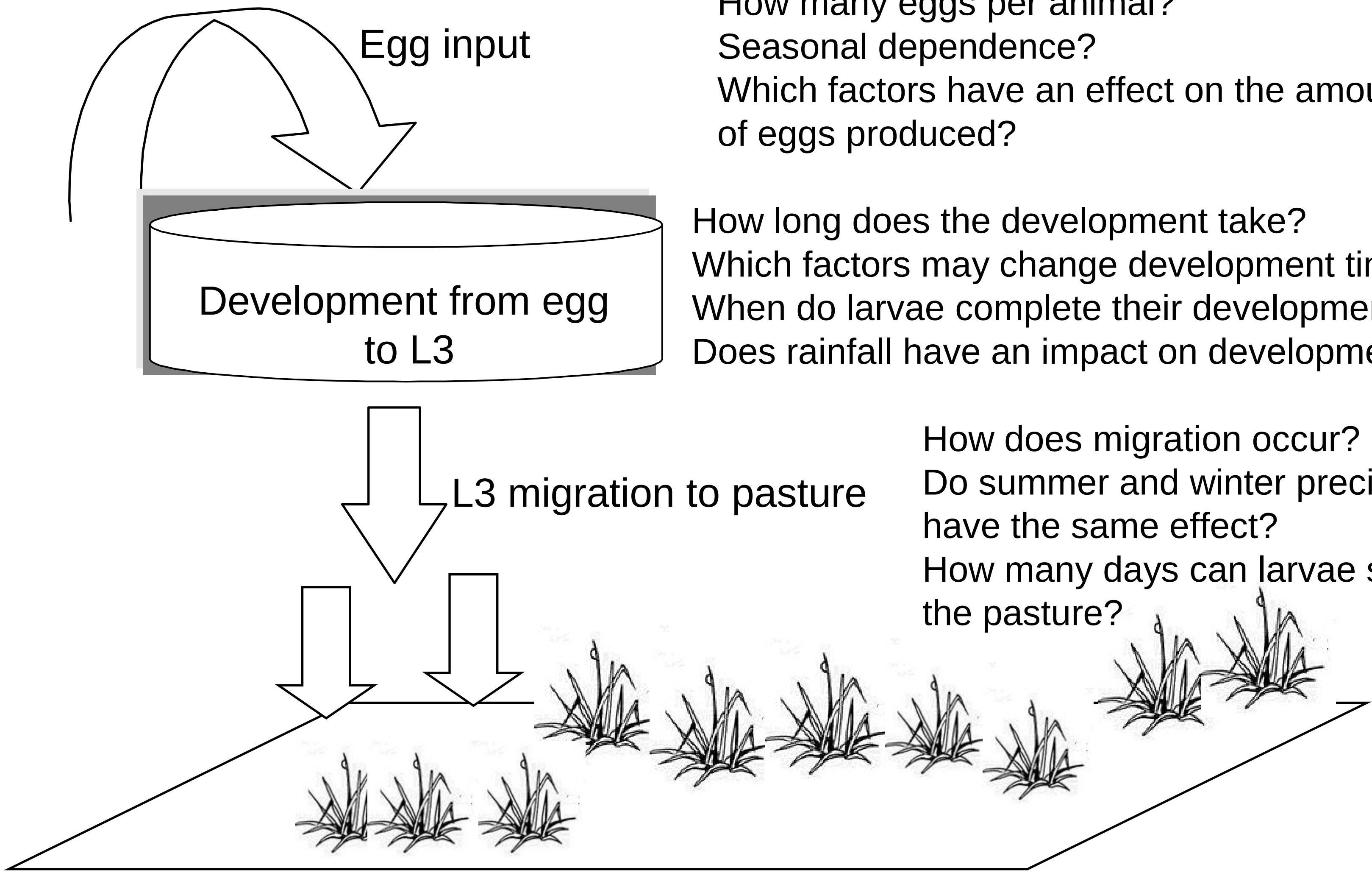
Auto-infection

Parasitic phase:

Growth of L3 to adult individual



Free-Living Stage: Conceptual Model



How many eggs per animal?
Seasonal dependence?
Which factors have an effect on the amount of eggs produced?

How long does the development take?
Which factors may change development time?
When do larvae complete their development?
Does rainfall have an impact on development time?

How does migration occur?
Do summer and winter precipitations have the same effect?
How many days can larvae survive in the pasture?

Some questions

- Is the time of appearence of L3 larvae in the pasture related to the precipitation pattern?

- How long is the delay before the first L3 larvae are found in the pasture?

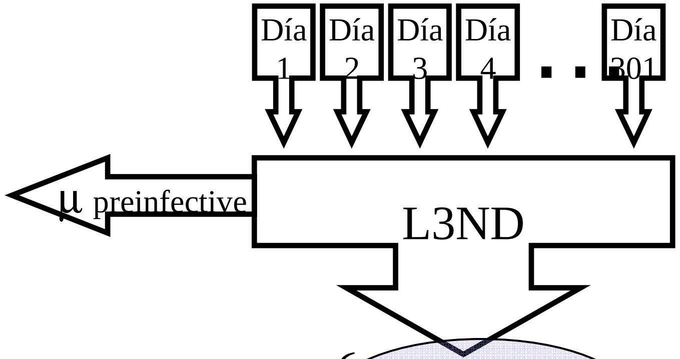
- Is it possible to determine the population dynamics of the L3 larvae in the pasture from EPG, monthly precipitation, and the time cattle enter the paddock?

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 linear interpolation of non linear systems.
  - Mamdani: allows representing empirical knowledge when the system’s behavior is not known.

Free-Living Stage Model



$H_t(a)$ = amount of preinfective larvae (eggs, L1 and L2) aged a, which "started" on julian day t.

$$H_t(0) = \begin{cases} NAnimal\ 6.3\ EPG(t)\ \left(PatW(w)\right) & \text{if calf's weight} = w \\ NAnimal\ 8.1\ EPG(t)\ \left(PatW(w)\right) & \text{if cow's weight} = w \end{cases}$$

$$PatW(w) = 0.3795\ w^{1.361}$$

Weight of animal's dung in grams

Number of animals

Number of eggs per gram of fecal matter per day

Animal's weight in grams

$$\boxed{H_t(a) = \left(1 - \mu_{Pre}\left(a,\ t+a,\ R(t+a)\right)\right) H_t(a-1)}$$

When do larvae reach the L3 stage?

Stromberg, B.E., 1997. Environmental factors influencing transmission. Vet. Parasitol. 72, 247-264.

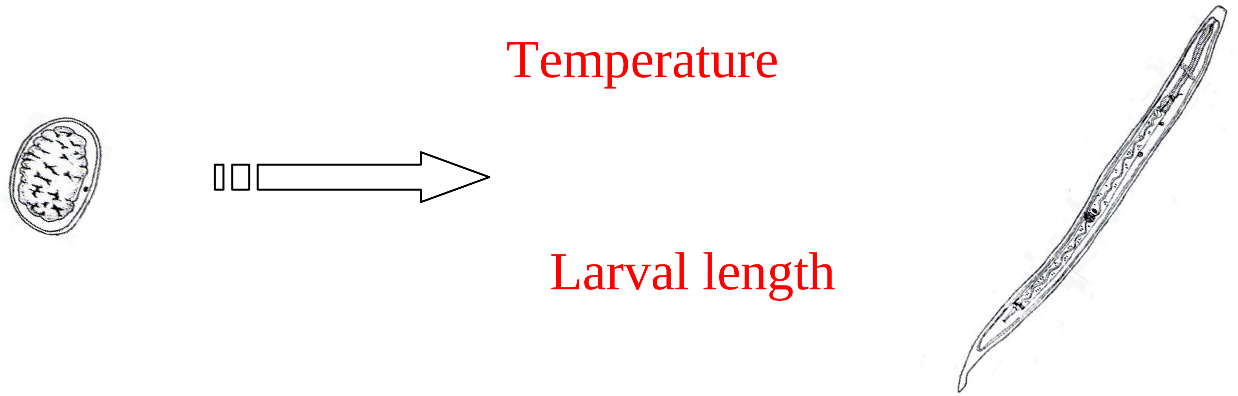
First step

- Estimation of development time from egg to infecting larva L3 taking into account weather conditions.
- Estimation of availability of infecting larva L3 ready to migrate to pastures at any given time.

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

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

$$IC\text{: } L_t(0)=l_0(T_t)$$

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

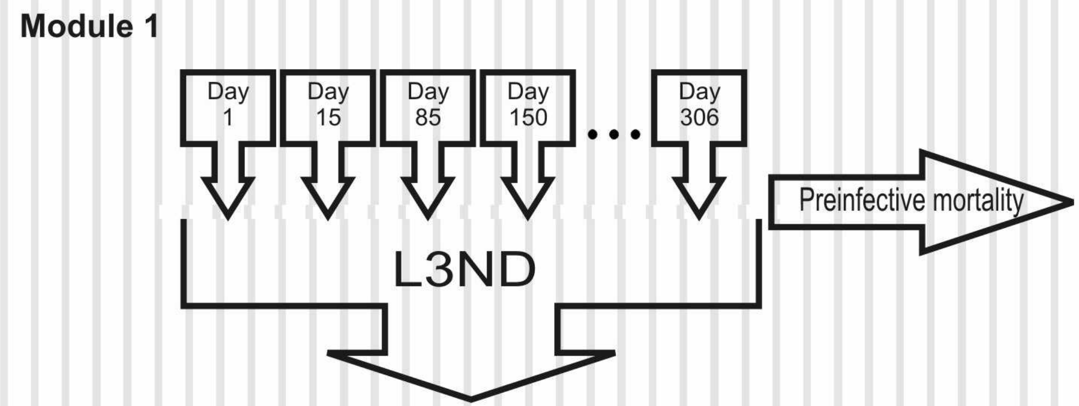
$r(T_t)$ growth rate,

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

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

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

Free-Living Stage Model



Module 1: Pre-infective stages in dung (waiting to migrate to pasture)

$$H(t+a,a+1) = (1-\mu_P)H((t-1)+(a-1),a)$$

$$si\ a+1 \leq \tau(t)$$

Module 1+1/2: Migration to pasture

Module 2: Larval dynamics in pasture

$$L3D(t+1) = (1-\delta_D)(1-\mu_{ID})L3D(t) + L3ND(t+1)$$

$$L3P(t) = (1-\mu_P)L3P(t-1) + \delta_{DP}(1-\mu_{ID})L3D(t)$$

Free-Living Stage Model

Three equations:

$$H(t+a,\ a)=(1-\mu_{Pr})H((t+a-1,a-1) \quad \text{if } a \leq t(t)$$

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

$$L3P(t) = (1-\mu_{P})\ L3P(t-1)+\ \delta_{DP}\ (1-\mu_{ID})\ L3ND(t)$$

μ_{Pr} = rate of preinfective mortality;

μ_{ID} = rate of mortality inside dung;

μ_{P} = rate of mortality in pasture;

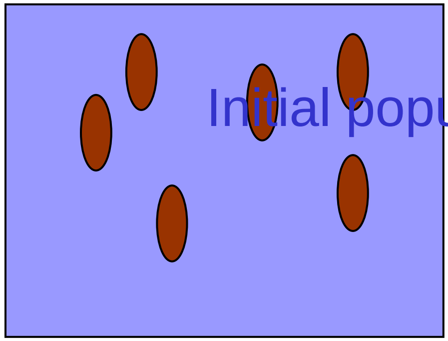
δ_{DP} = rate of migration from dung to pasture.

Larvae in the pasture

$P_{L3}(k)$ is the total number of L3 larvae in the pasture after *k* days since the beginning of infection

Day 1

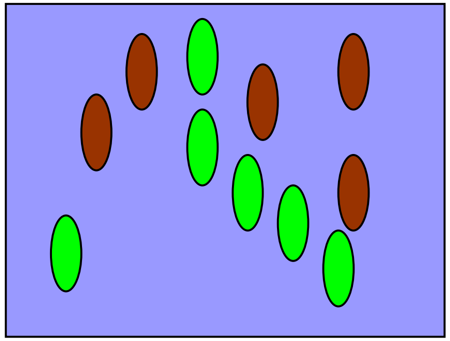
$$P_{L3}(1) = C_1(0)$$



Initial population in cohort *j* $C_j(0)$

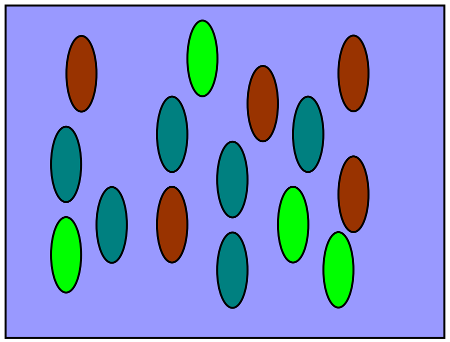
$$P_{L3}(2) = C_2(0) + C_1(1)$$
$$C_1(1) = \big(1 - \mu_p(0,1)\big)C_1(0)$$

Day 2



$$P_{L3}(3) = C_3(0) + C_2(1) + C_1(2)$$
$$C_1(2) = \big(1 - \mu_p(0,2)\big)C_1(1)$$
$$C_2(1) = \big(1 - \mu_p(1,1)\big)C_2(0)$$

Day 3



Cohort 1 $C_1(0)$

Cohort 2 $C_2(0)$

Cohort 3 $C_3(0)$

Larvae in the pasture

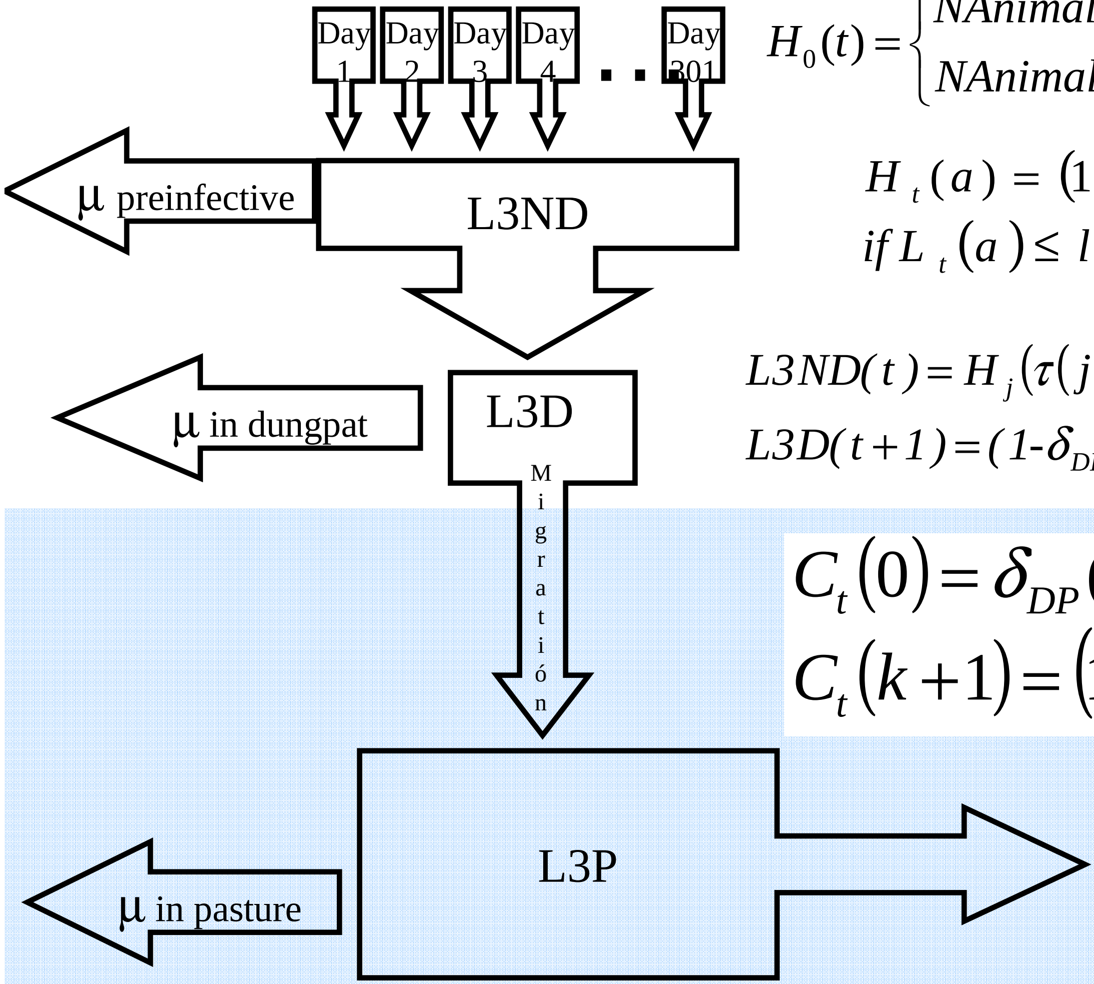
$$C_t(0) = \delta_{DP}(t)\; L3D(t)$$
$$C_t(k+1) = \left(1 - \mu_p(t)\right) C_t(k)$$

where $\mu_P(t)$ is mortality in pasture

Hence the number of infective larvae in pasture is:

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

Free-Living Stage Model



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

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

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

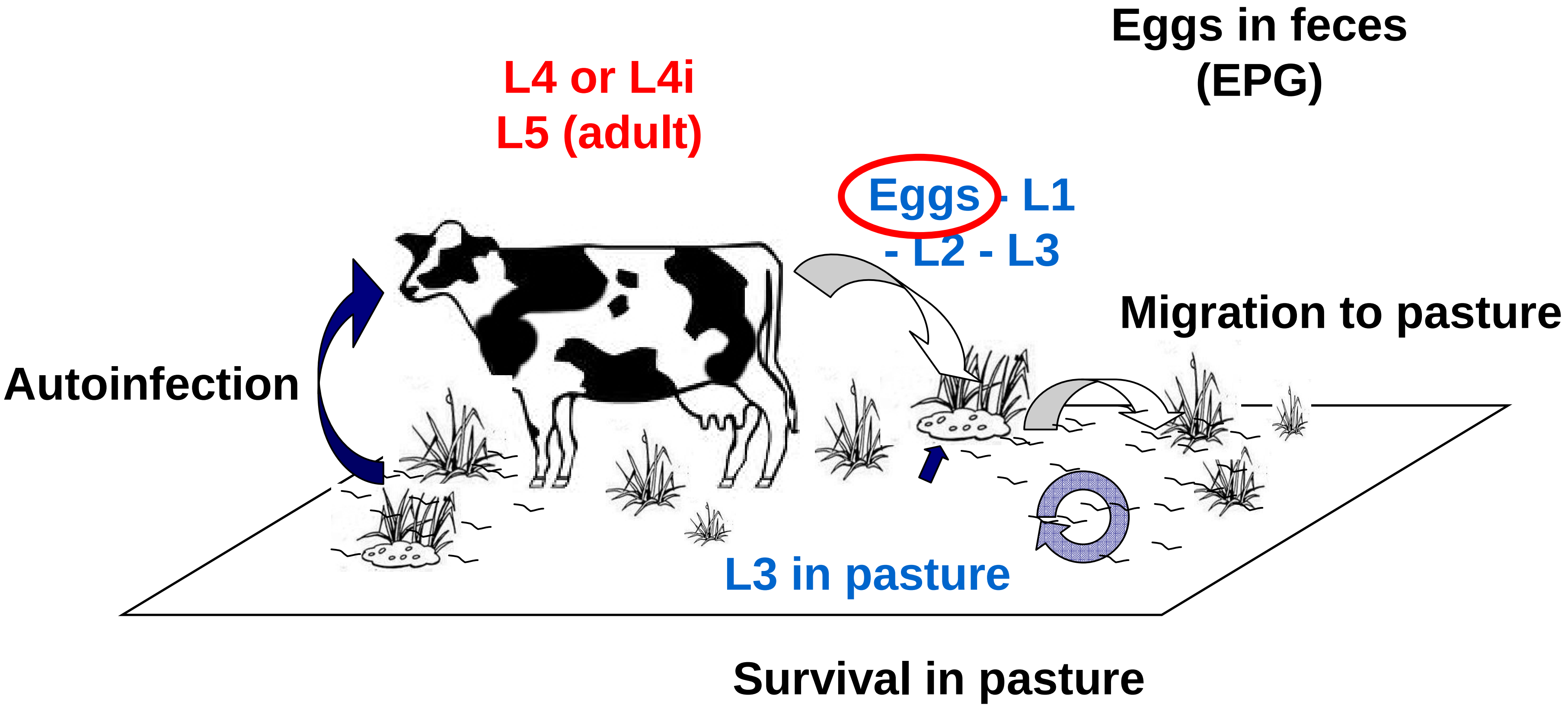
$$C_t(0) = \delta_{DP}(t)\,L3D(t)$$
$$C_t(k+1) = \left(1-\mu_p(t)\right)C_t(k)$$

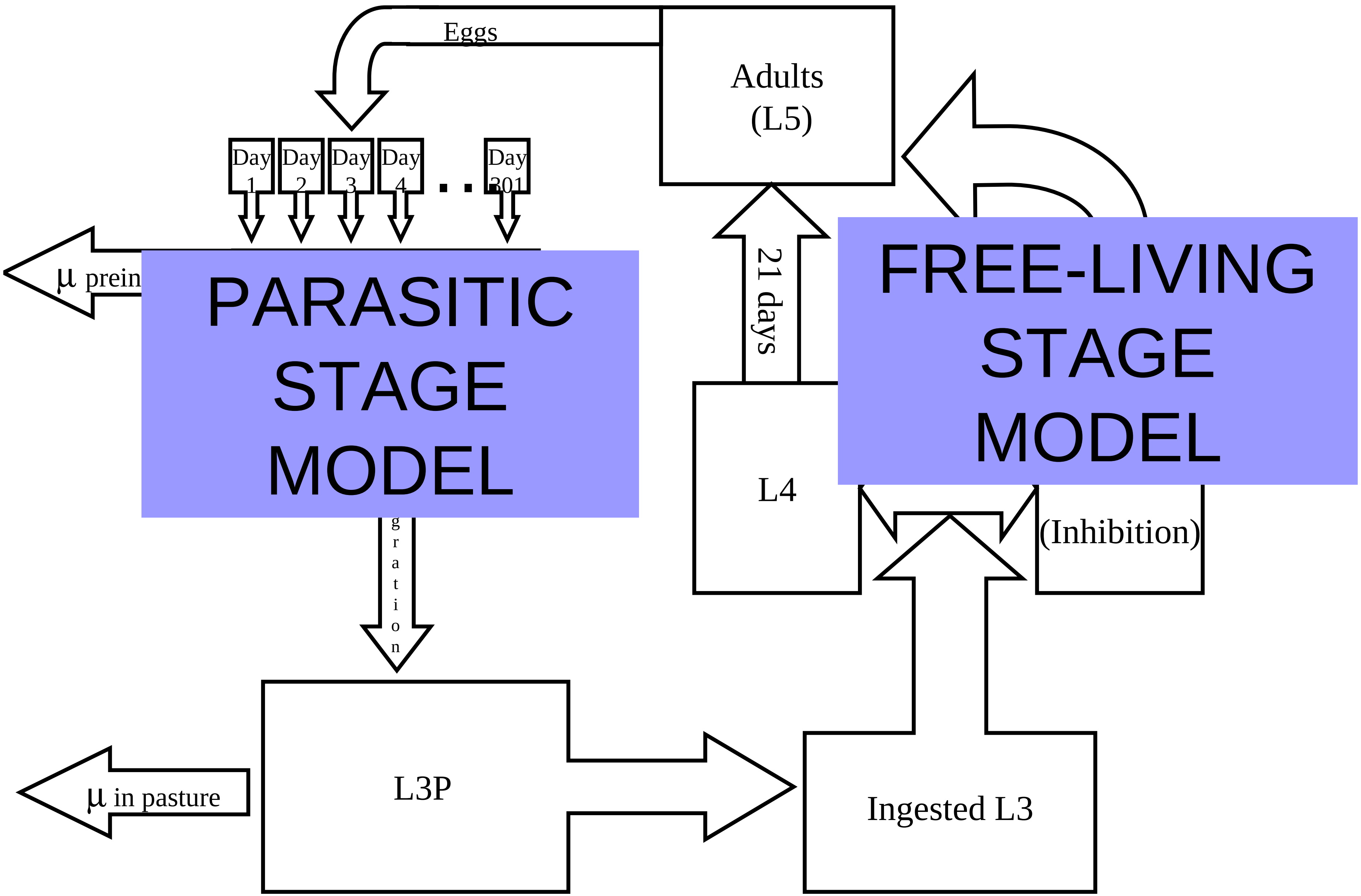
Mortality in pasture

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

Number of infective larvae in pasture

Ostertagia ostertagi life cycle




Eggs
Adults
(L5)
Day 1
Day 2
Day 3
Day 4
. . .
Day 301
μ prein
PARASITIC STAGE MODEL
21 days
FREE-LIVING STAGE MODEL
L4
(Inhibition)
gration
L3P
μ in pasture
Ingested L3

Parasitic Stage Model

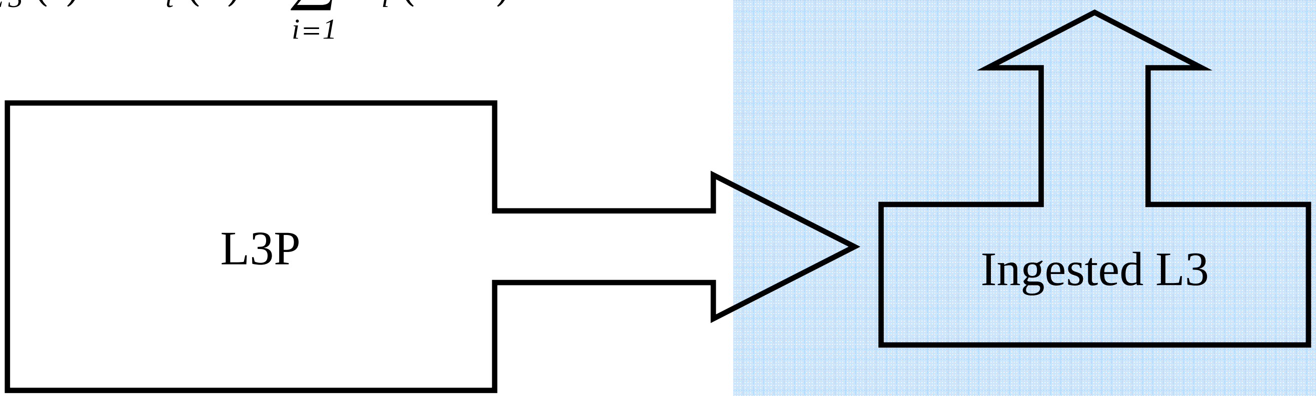
$$p(j,t) = \frac{C_j(t)}{P_{L3}(t)}$$

$$F(t) = \sum_{j=1}^{t} F_j(t)$$

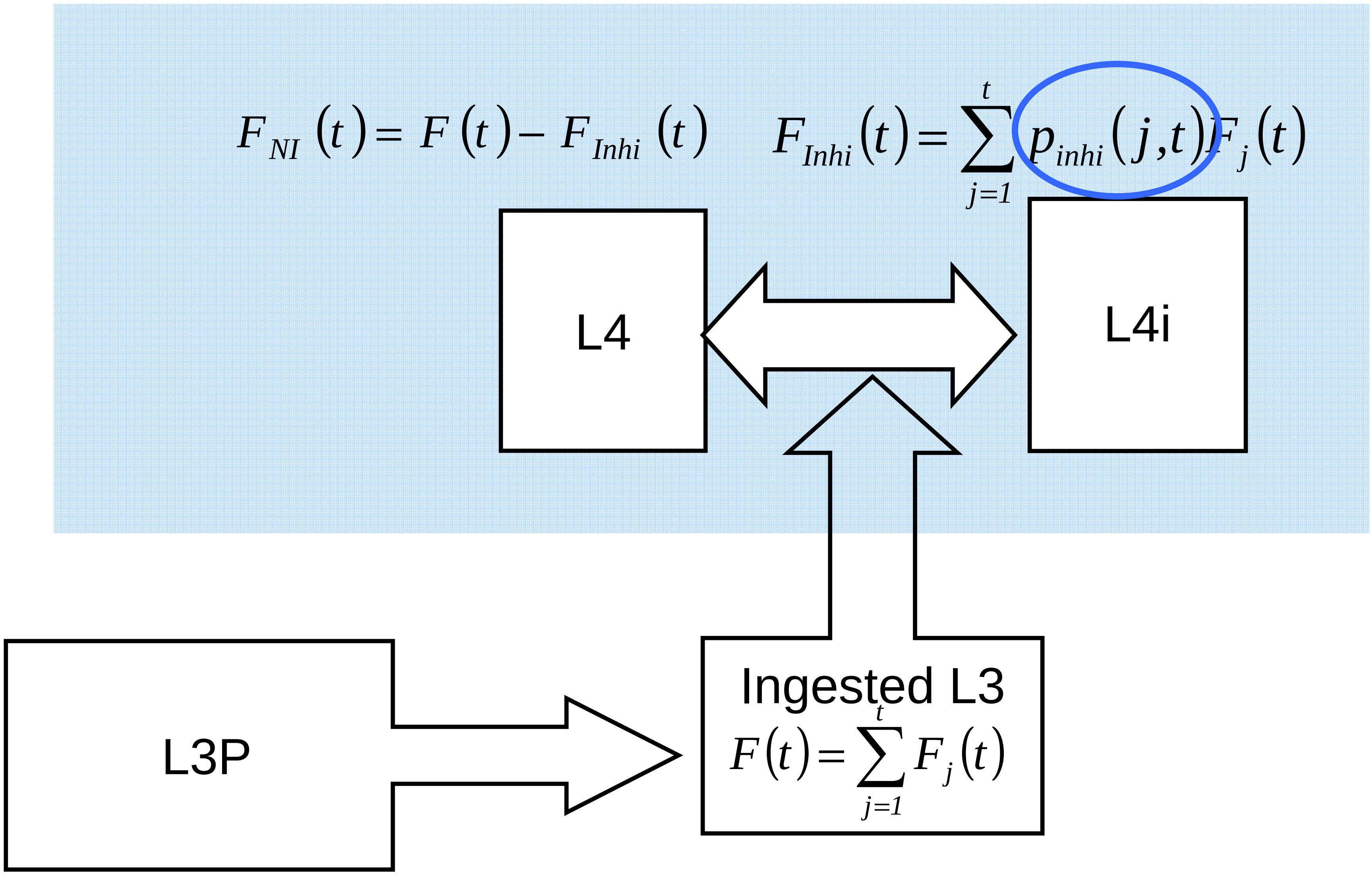
$$F_j(t) = p(j,t)\,C_j(t)$$

$$C_j(k+1) = \left(1 - \mu_p(j,k)\right)C_j(k) - F_j(k)$$

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



Parasitic Stage Model



Proportion of inhibited larvae $p_{inhi}(j, t)$

Depends on:

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

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

Hypobiosis

The desinhibition process in the Pampean region shows two phases, depending on the season in which the L3 larvae reach the pasture.

The hypothesis is that photoperiod is the main factor determining the moment in which desinhibition occurs.

Hypobiosis

Field experiments show that:

- L3 ingested before Spring end inhibition before the beginning of Summer.
- L3 ingested after the beginning of Spring end inhibition at the beginning of Autumn.

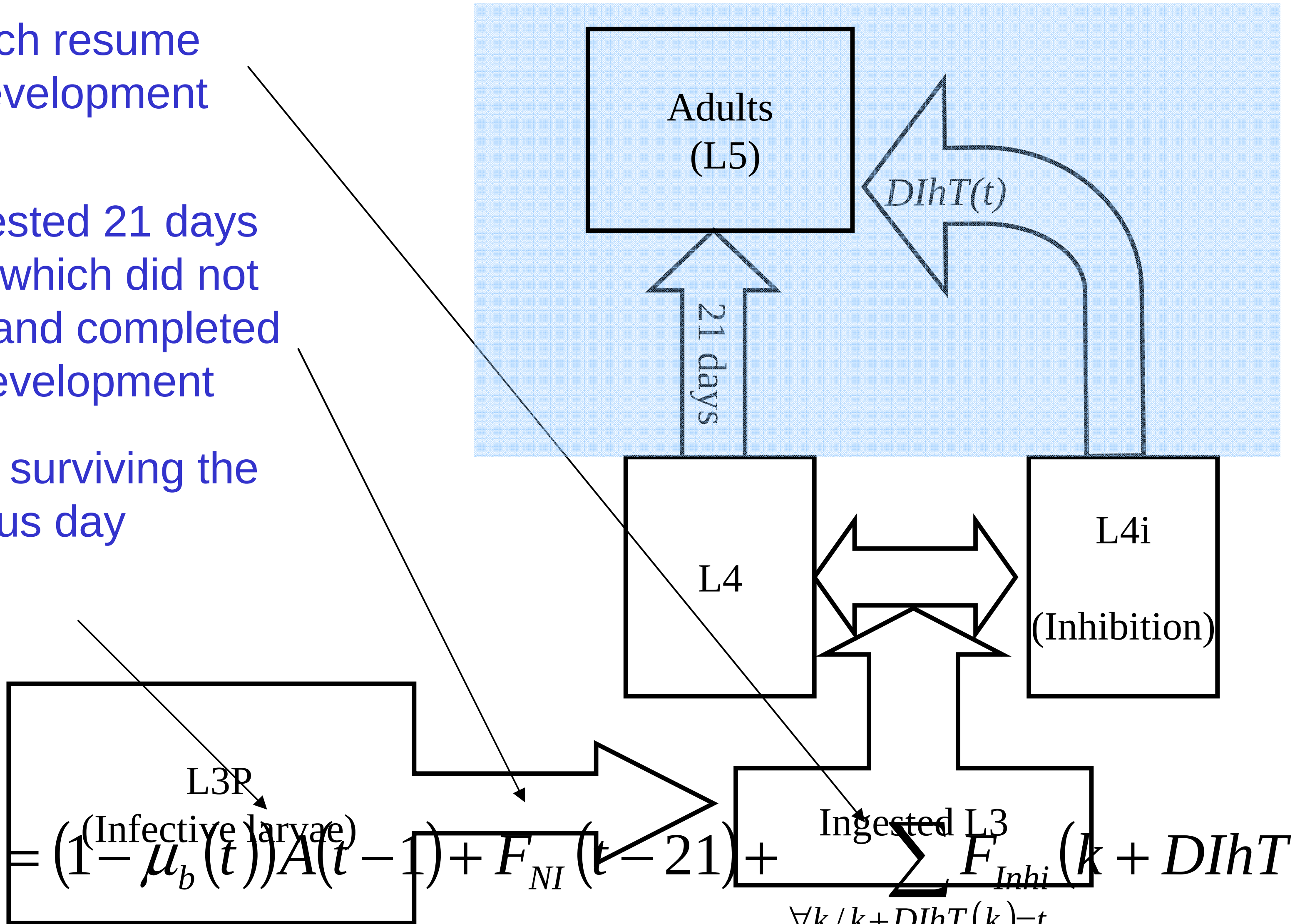
$$DIhT(t) = \begin{cases} 240 - \dfrac{t}{2} & \text{if} \quad Phot(180) \le Phot(t) \le Phot(265) \\ 270 - \dfrac{t}{2} & \text{if} \quad Phot(t) \ge Phot(265) \\ 120 & \text{if} \quad other \quad case \end{cases}$$

Parasitic Stage Model

L4i which resume their development

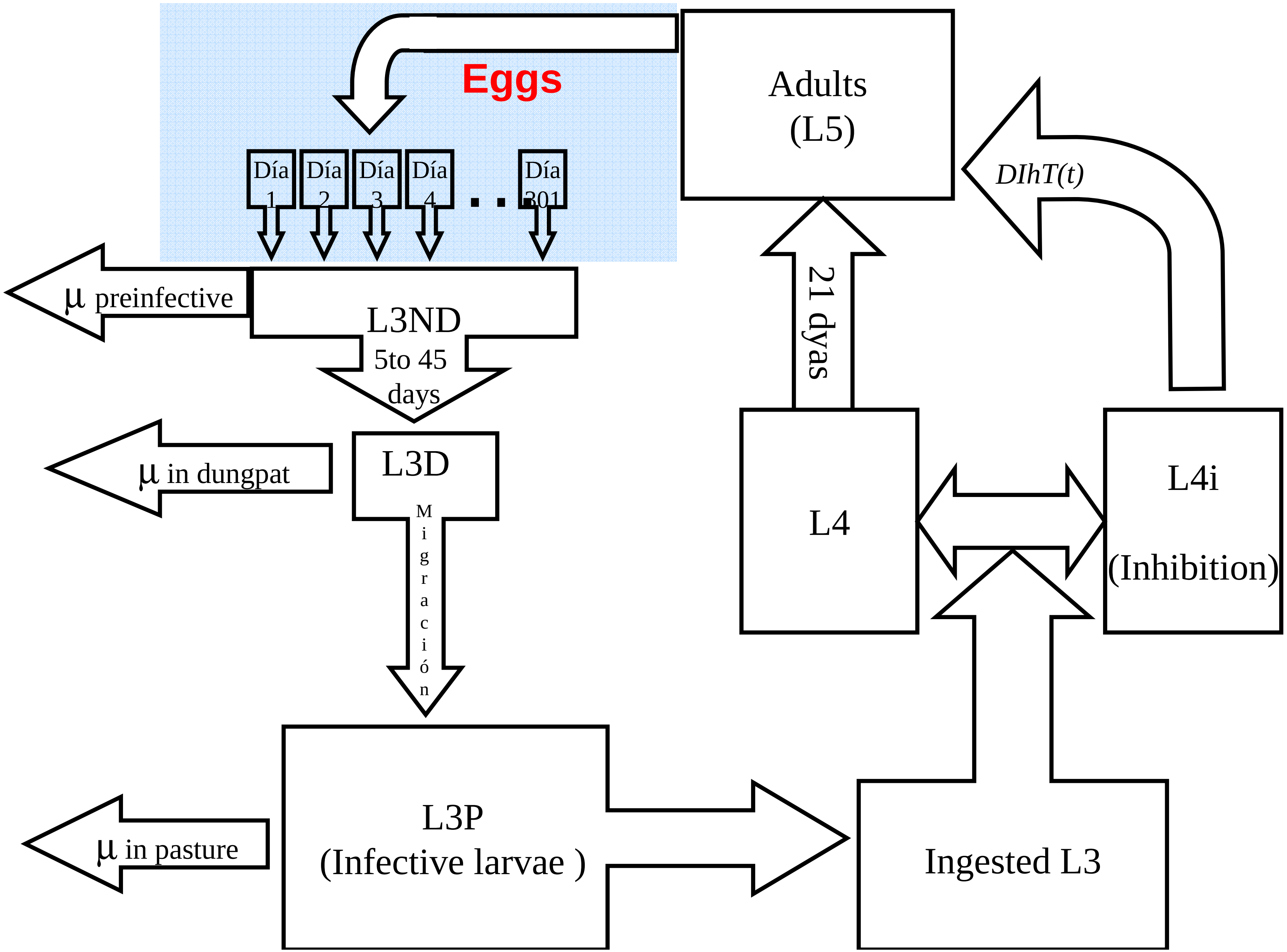
L3 ingested 21 days before which did not inhibit and completed their development

Adults surviving the previous day

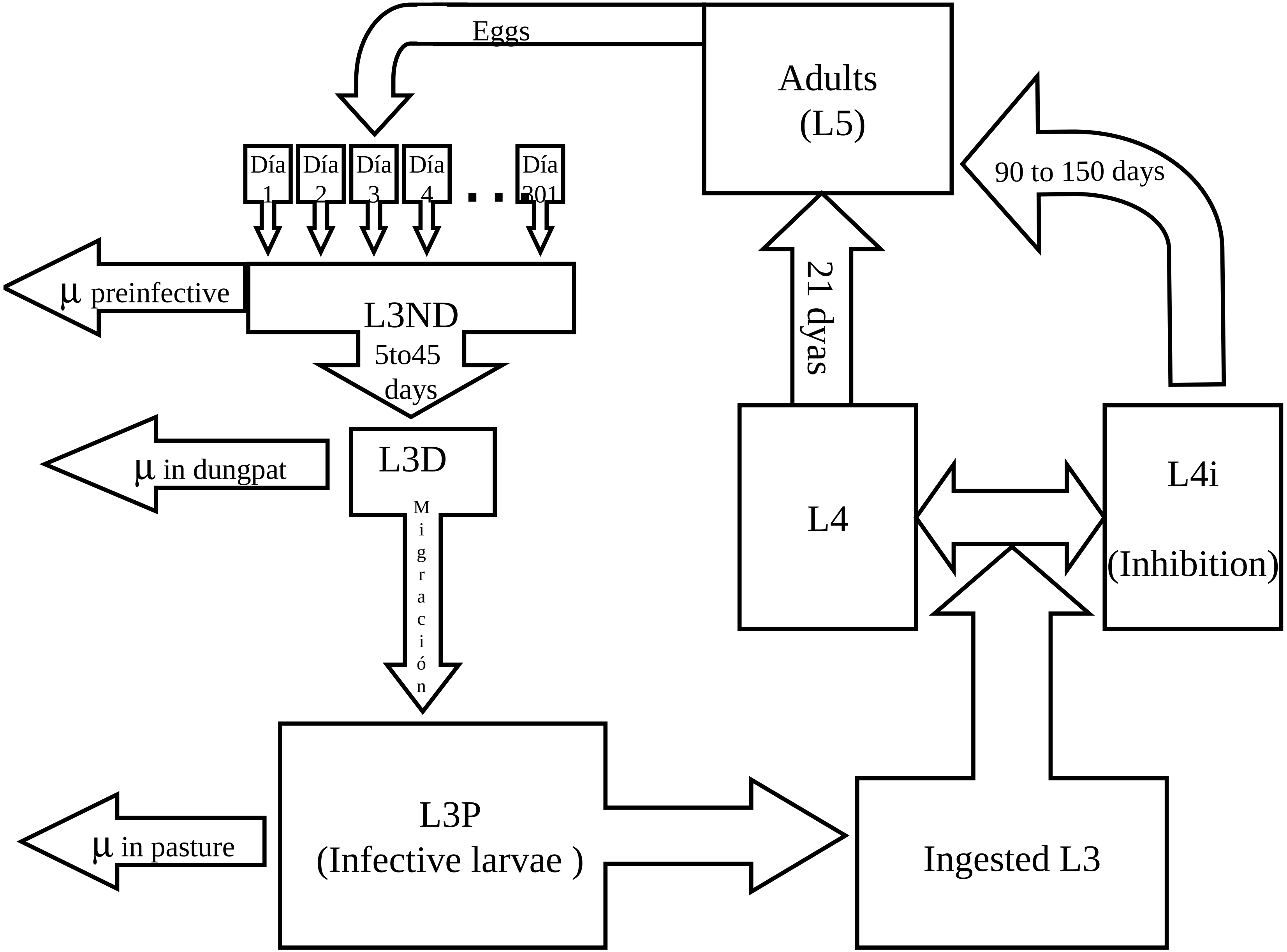


$$A(t) = \left(1 - \mu_b(t)\right) A(t-1) + F_{NI}(t-21) + \sum_{\forall k / k + DIhT(k) = t} F_{Inhi}\left(k + DIhT(k)\right)$$

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)

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

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

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

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)

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

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

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

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)

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

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


TO BE
CONTINUED
Ostertagia ostertagi