Factors of phillophages’ invasion success or failure: estimation in frameworks of mathematical optimization model

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Invasion process within a new territory begins with appearance of insects. However Noah principle is not always correct and appearance of insects within a new territory is a necessary, but an insufficient condition for invasion.

Noah Principle: A pair of individuals of the same specie is enough to populate a new territory.

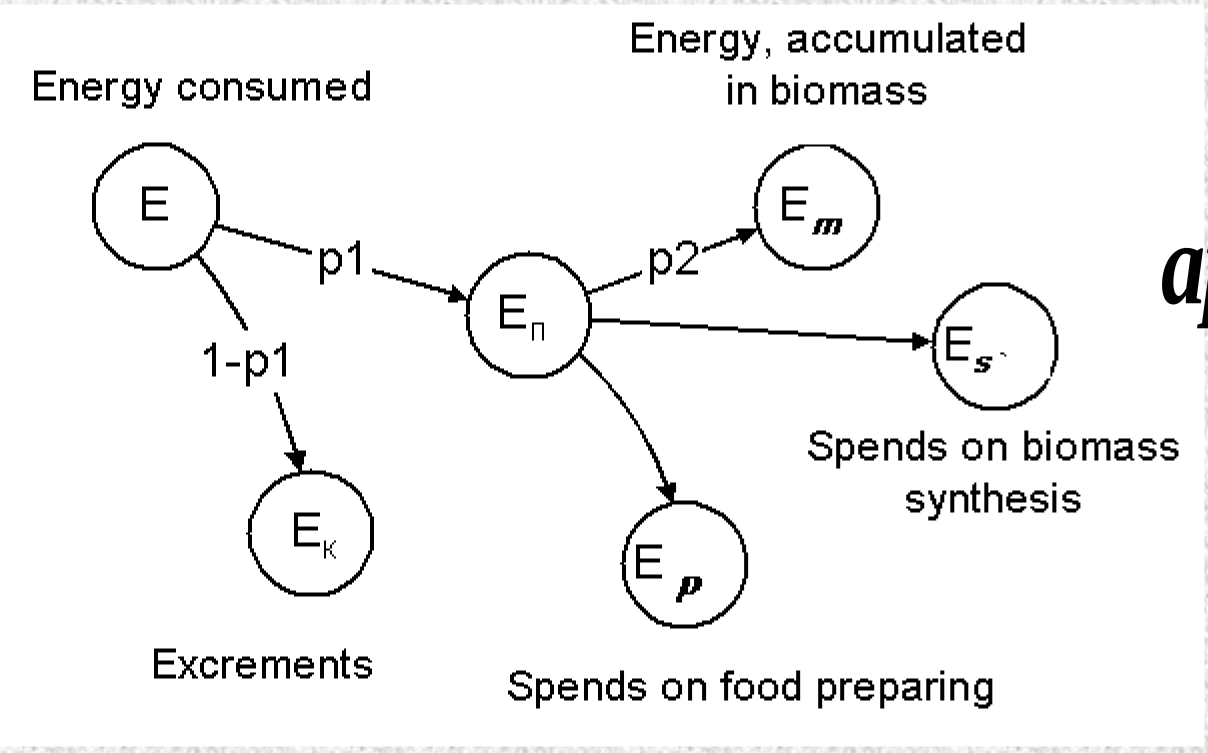
That factors promoted invasion success of some Lepidoptera insects?

I would like to compare peculiarity of ecology for two species - gypsy moth *Lymantria dispar* L. and Siberian moth *Dendrolimus sibiricus* Tschetv.
Gypsy moth invasion into North America was successful.
Aggressive Siberian silk moth stays mostly within limits of its areal.
We try to find a differences in ecological characteristics of these species connected with invasion potential.
We will to take into account the following factors:
-processes connected with food consumption;
- parameters of population dynamics;
- impact of weather;
- peculiarities of pheromone communication systems.

Optimization model of food consumption

$$\boldsymbol{E} = (1 - \boldsymbol{p}_1)\boldsymbol{E} + \boldsymbol{a}\boldsymbol{p}_1^2\boldsymbol{E} + \boldsymbol{p}_2\boldsymbol{p}_1\boldsymbol{E} + \boldsymbol{b}\boldsymbol{p}_2\boldsymbol{p}_1\boldsymbol{E}$$

$$\Downarrow$$



$$\boldsymbol{a}\boldsymbol{p}_1 + (1 + \boldsymbol{b})\boldsymbol{p}_2 = 1$$

The optimization principle

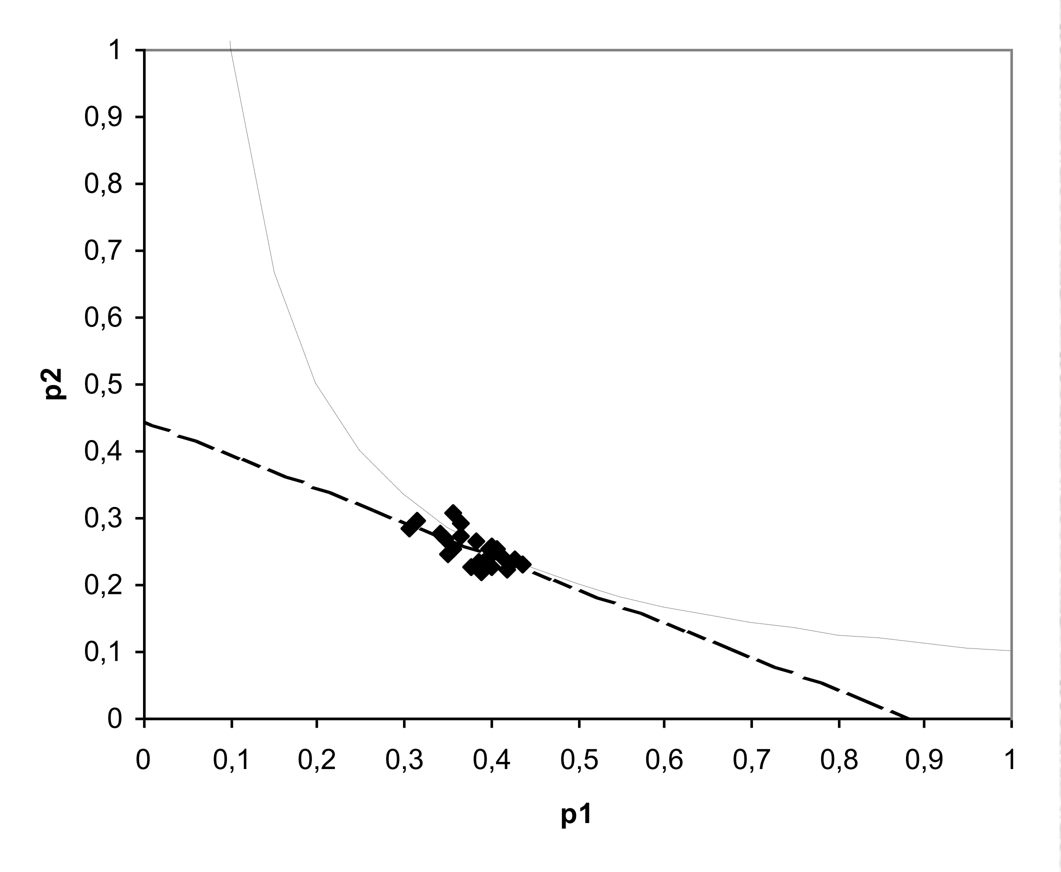
$$\frac{\mathbf{E_m}}{\mathbf{E}} = \frac{\mathbf{p_1 p_2 E}}{\mathbf{E}} = \mathbf{p_1 p_2} \Rightarrow \mathbf{max}$$

$$\mathbf{a p_1 + (1+b) p_2 = 1}$$

$$\boldsymbol{p}_1 = \frac{1}{2\boldsymbol{a}};\ \boldsymbol{p}_2 = \frac{1}{2(1+\boldsymbol{b})}$$

The solution is an point of intersection

a – price of food decomposition; (1+b) – price of biomass growth

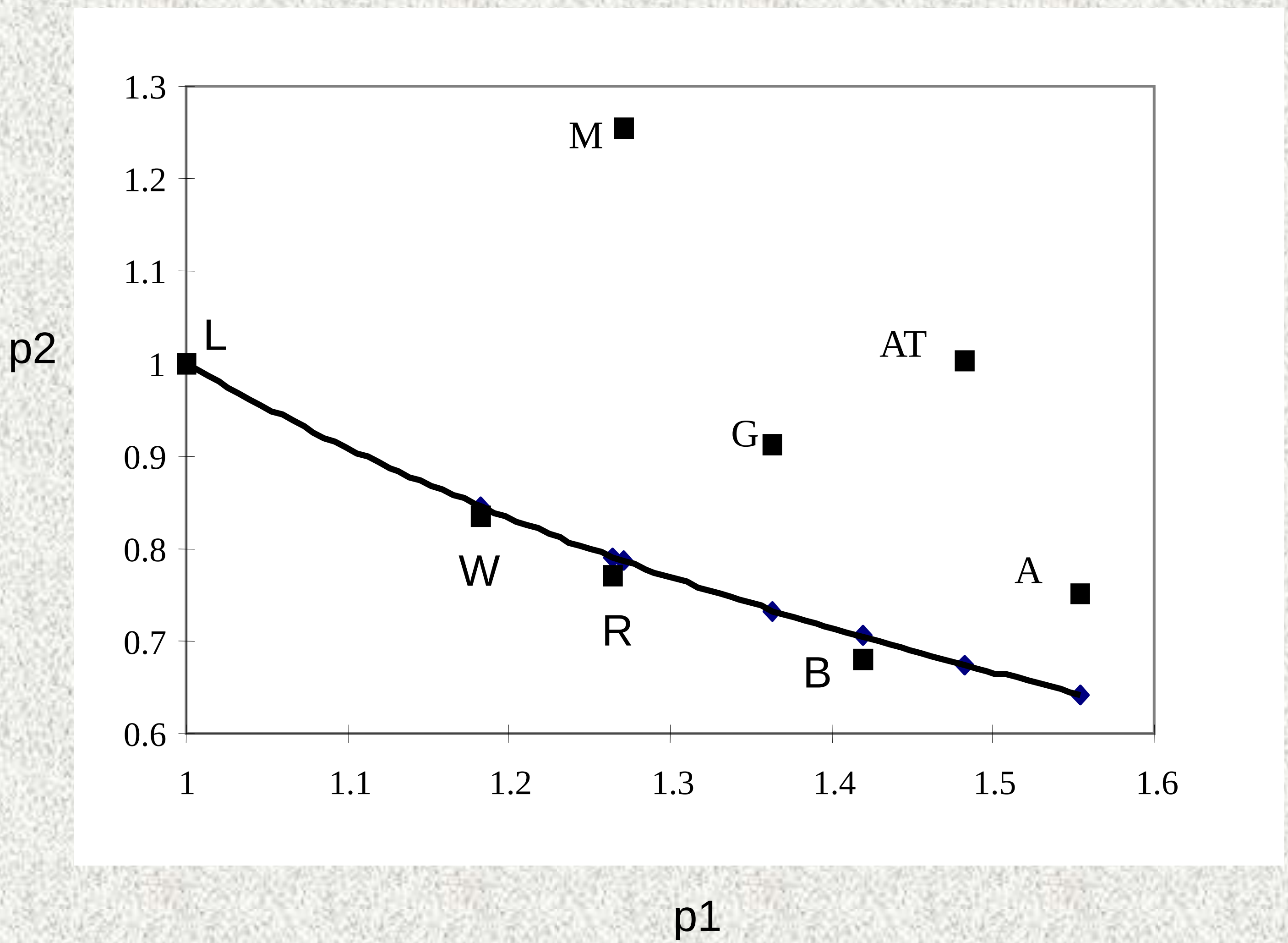


Ecological prices of food consumption

species	**Food trees**	**a**	**1+b**
Siberian moth	*Larix sibirica* Ldb.	0,92	4,26
	Abies sibirica Ldb.	1,17	4,93
	Pinus sylvestris L.	1,91	5,59
Gypsy moth	*Larix sibirica* Ldb	0,91	2,46

Recalculated data from (Baranchikov, Kirichenko, 2011)

Comparative prices of food consumption for gypsy moth



L – larch

W – willow

R – rose

B – birch

A – aspen

AT - Alder tree

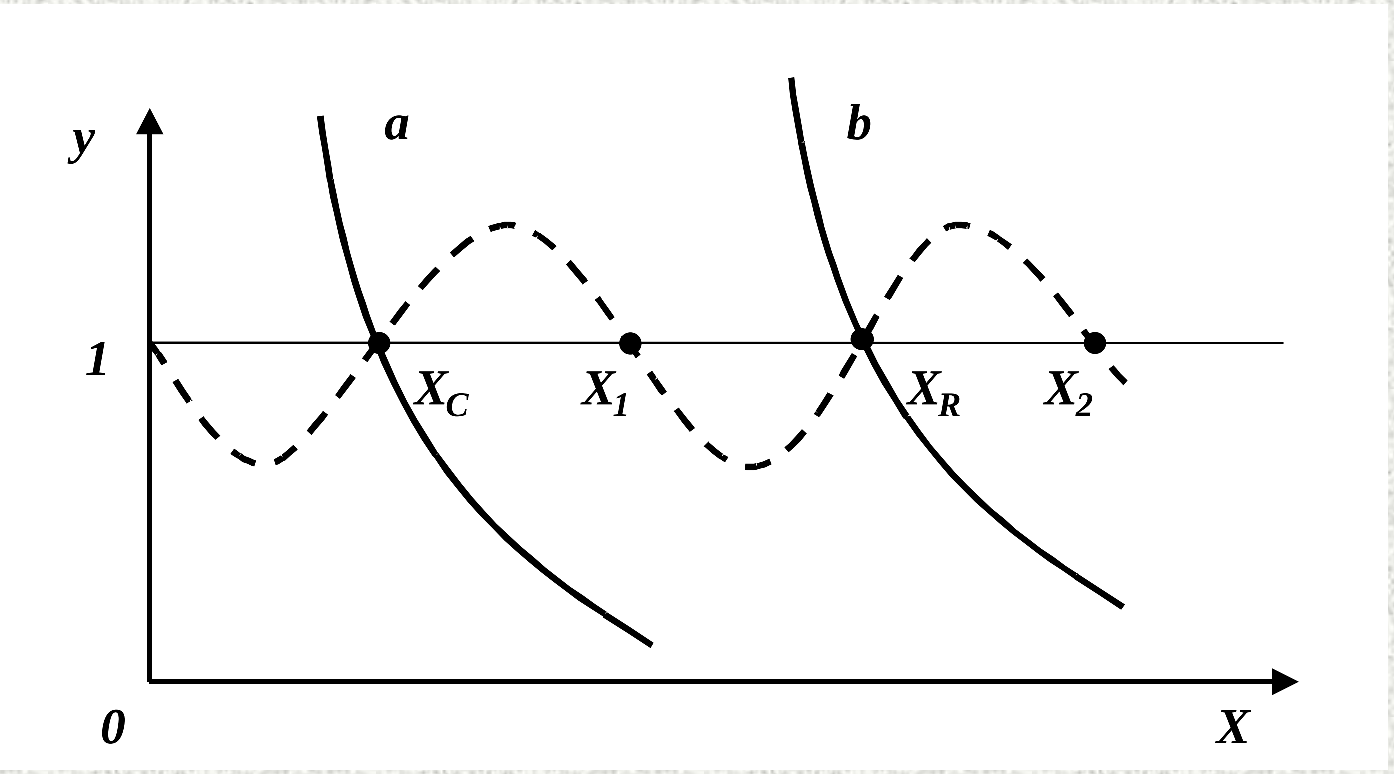
G – Glossy Black Chokecherry

M - Mountain ash

Population dynamics differences for studied species

Two variables characterize a population dynamics:

population density X(i) and reproduction coefficient
y(i) =X(i+1)/X(i)



Modeling of outbreaks as second-order phase transitions

$$G = G_0 + a(X - X_r)q^2 + Bq^4$$

$$G \Rightarrow \min$$

$$\frac{\partial G}{\partial q} = 2a(X - X_r)q + 4Bq^3 = 0$$

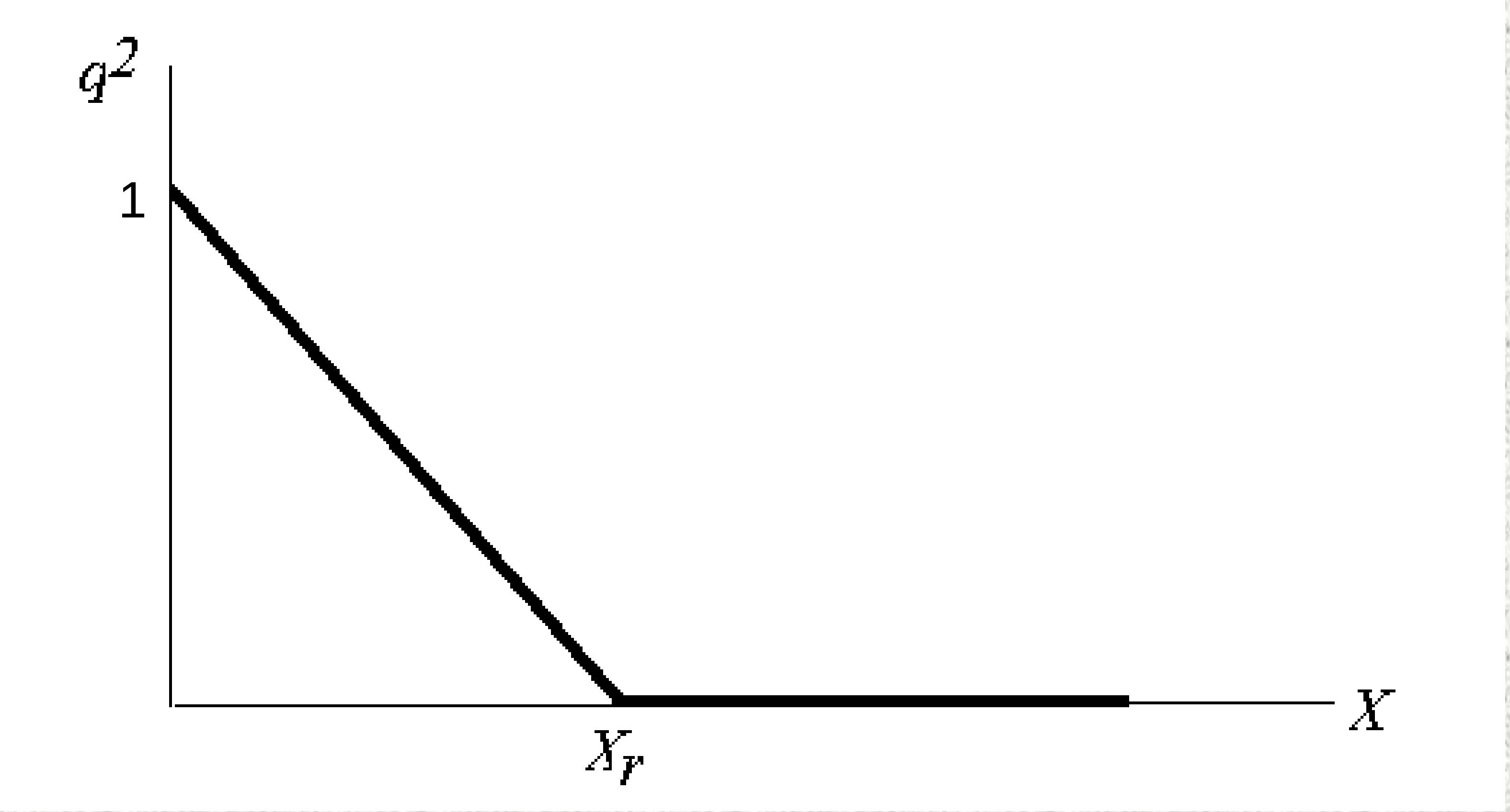
$$\frac{\partial^2 G}{\partial q^2} = 2a(X - X_r) + 12Bq^2 > 0$$

Two non-negative solutions:

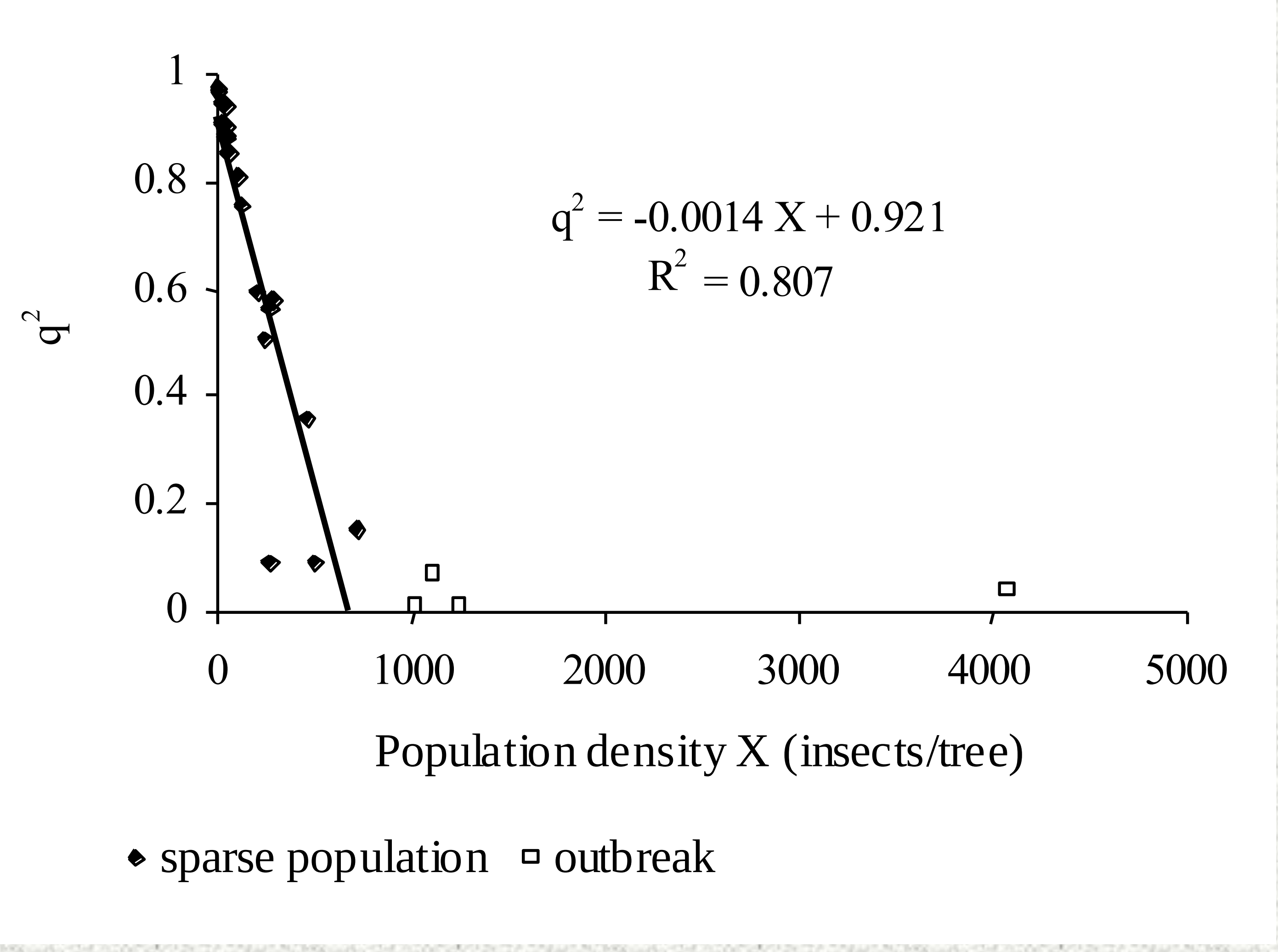
$$If \;\; X \geq X_r, q = 0$$

$$If \;\; X < X_r, q^2 = \frac{a(X_r - X)}{2B}$$

The solutions of equation: “hockey stick”



The comparison with field data: Siberian moth



Critical population density for Siberian moth ≈ 650 individuals on tree;

Critical population density for gypsy moth – less then 100 individuals on tree.

The impact of modifying factors

$$G = G_0 + a(X - X_r)q^2 + Bq^4 - qH$$

$$\mathrm{H} = \frac{\mathbf{precipitation}}{\mathbf{temperatute}}$$

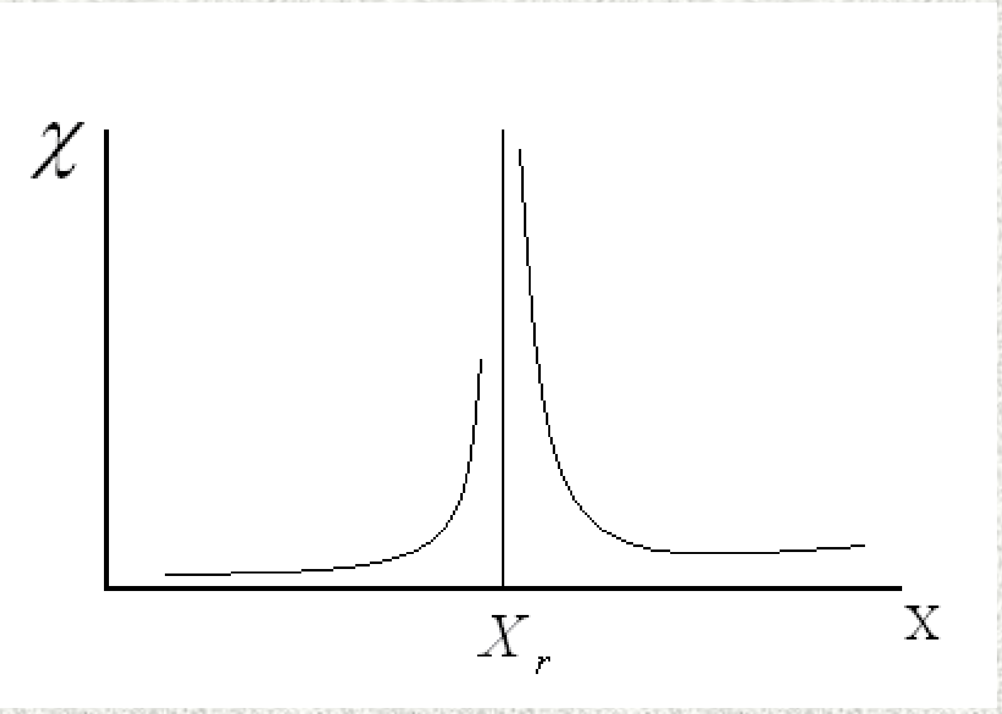
$$H \Rightarrow 0 : \textit{dry and hot weather}$$

If *H* is high, outbreak don’t realized

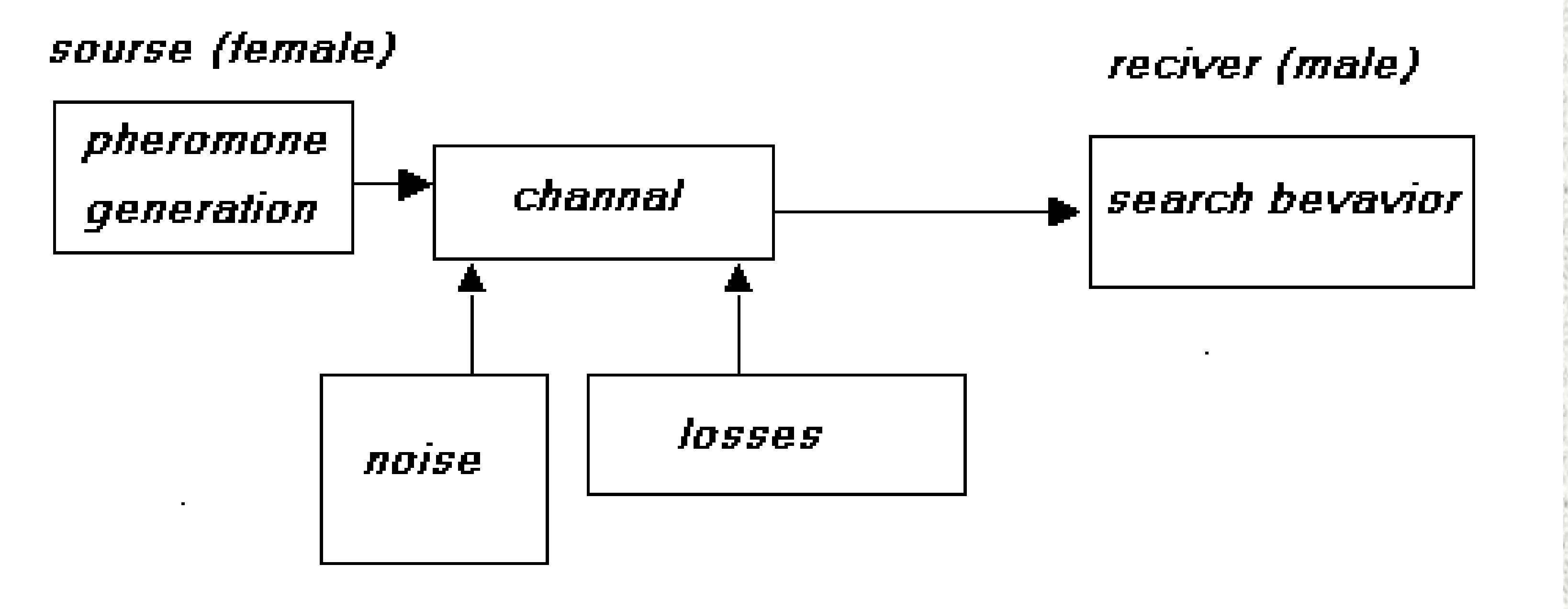
Susceptibility χ to weather factors

$$\chi = \frac{\partial q}{\partial H}$$

$$\chi = \frac{1}{4a(X_r - X)} \; when \; X < X_r; \quad \chi = \frac{1}{2a(X - X_r)} \; when \quad X > X_r$$



Pheromone communication



If population density is low, a system of pheromone communication must be reliable

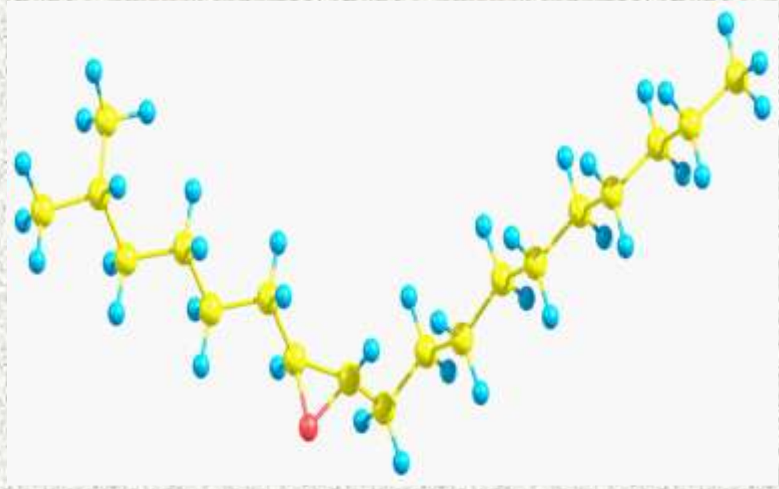
Reliability of pheromone communication is determined by noise level and losses of information in the channel.

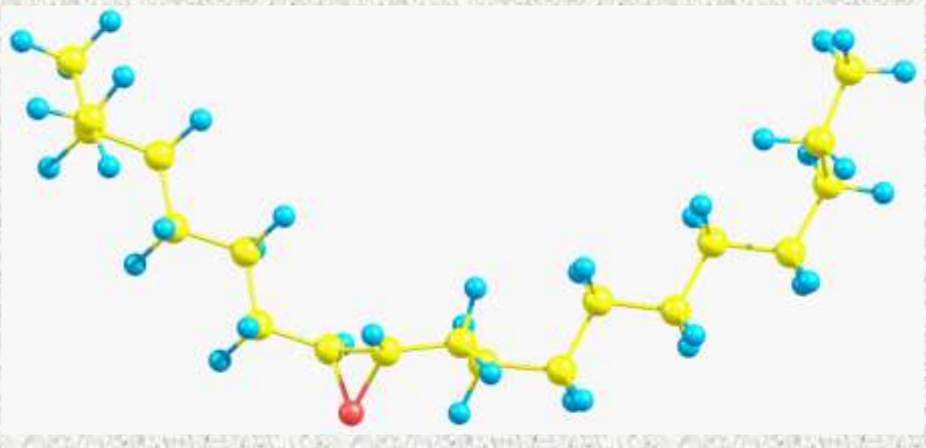
The losses of information in communication channel depended from stability of pheromone molecules to impact of environmental factors

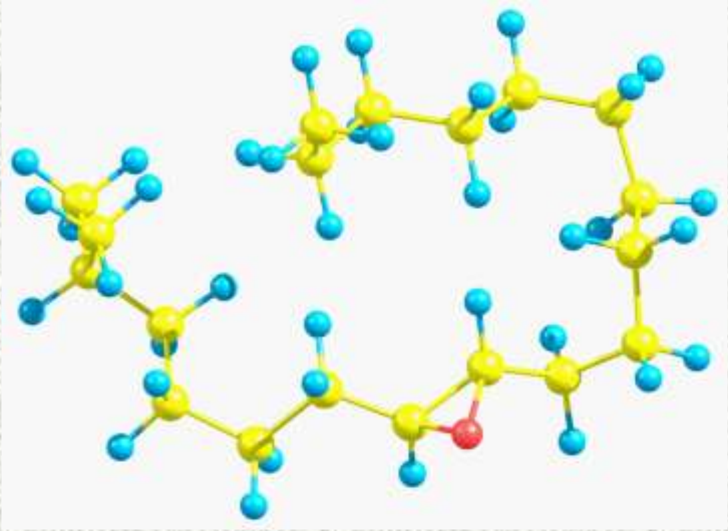
We used for calculations of stability methods of Time-Dependent Density-Functional Theory..

Using special computer programs OpenMopac 2007 and HyperChem 7.52, we calculated energy E_{total}, polarization P, oscillator strength, wave-length λ и energy E_{abs} for electron's transitions in pheromone molecules of gypsy moth and Siberian moth..

Conformers of disparlure

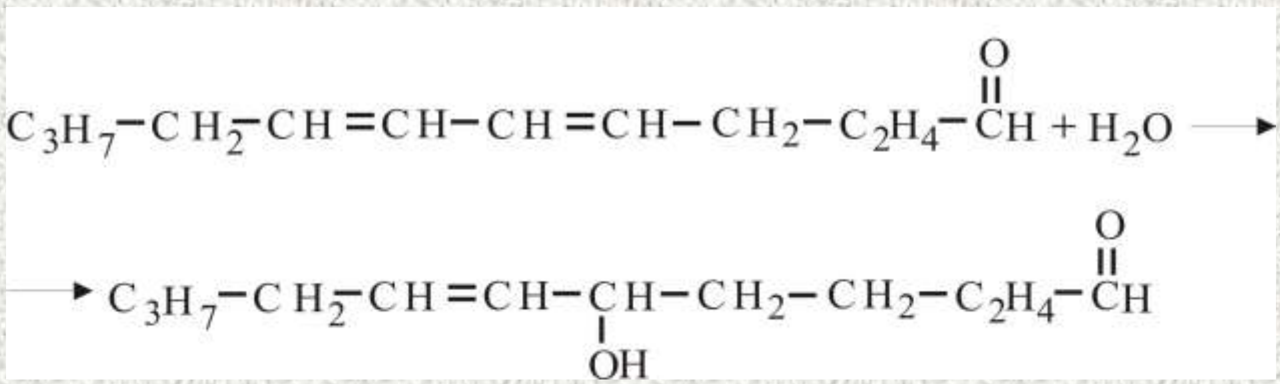


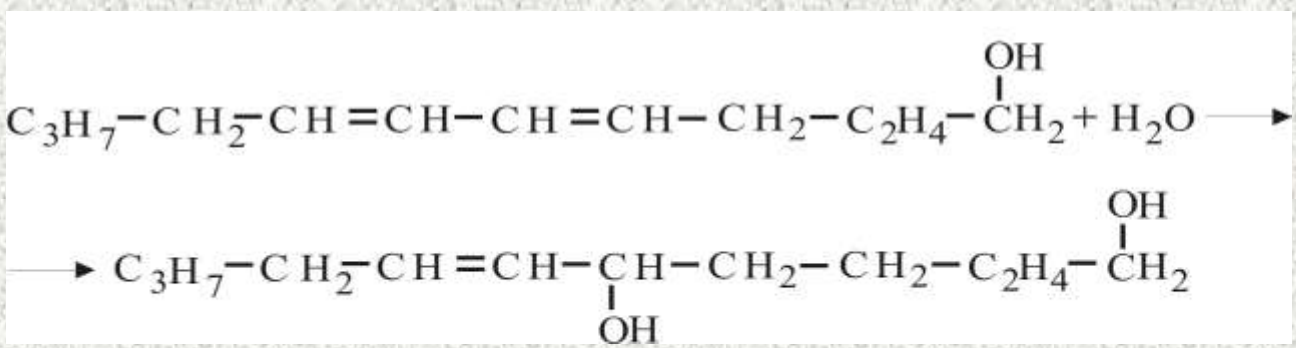




There are 3 conformers of *L.dispar* pheromone and 7 conformers of *D. sibiricus* pheromons

Siberian moth pheromones: reaction with H_2O





Gypsy moth pheromone: reaction with H_2O vapor

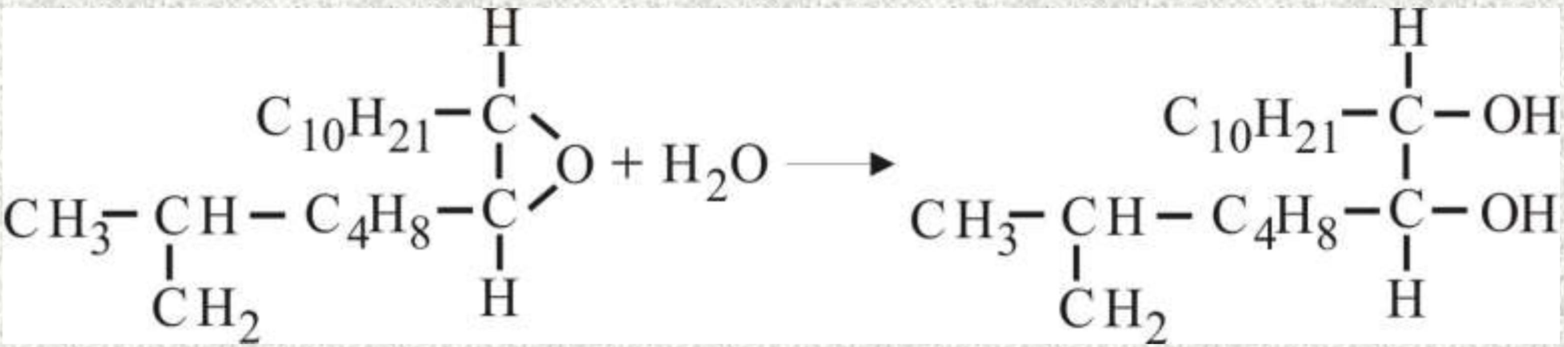
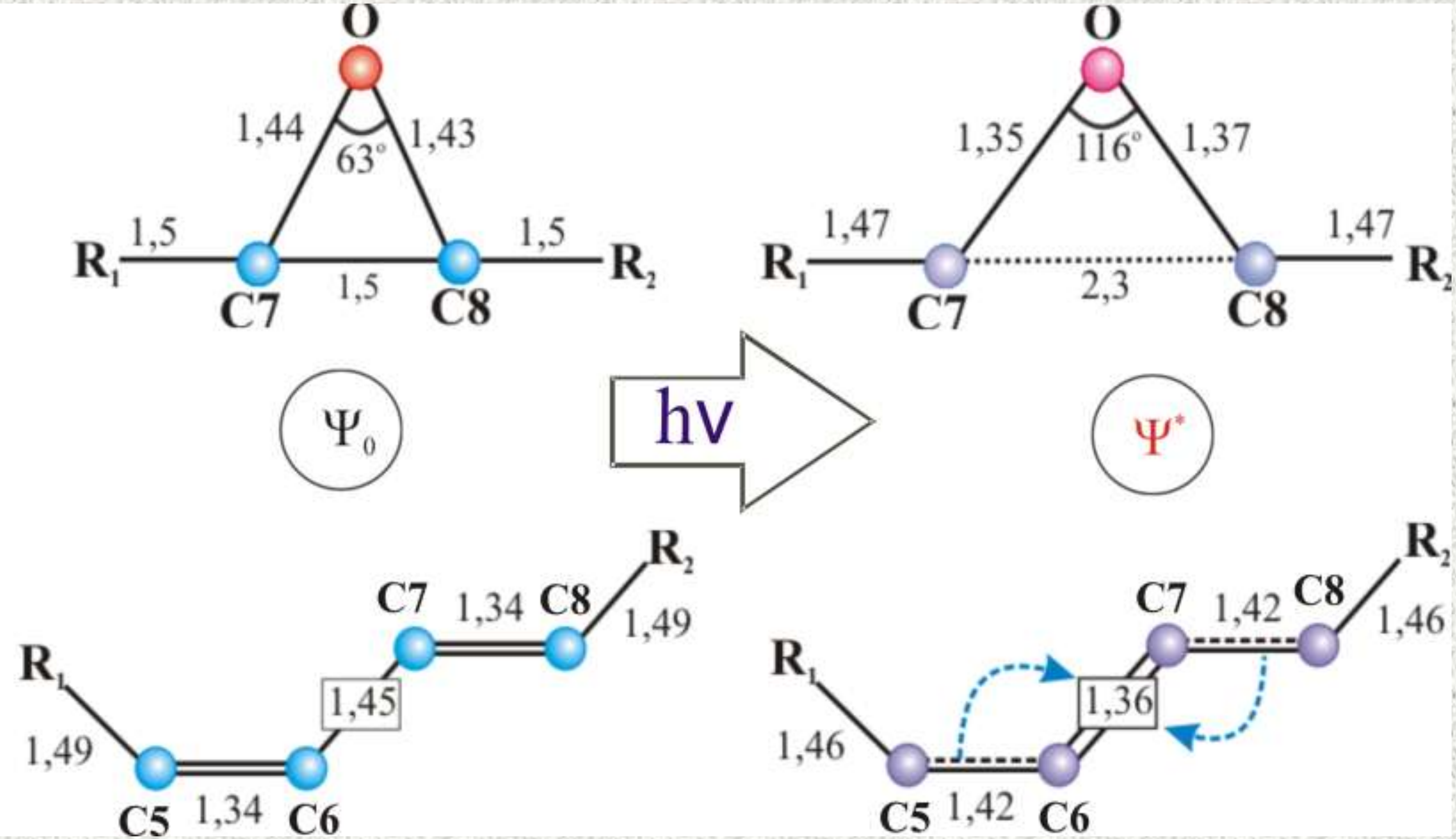
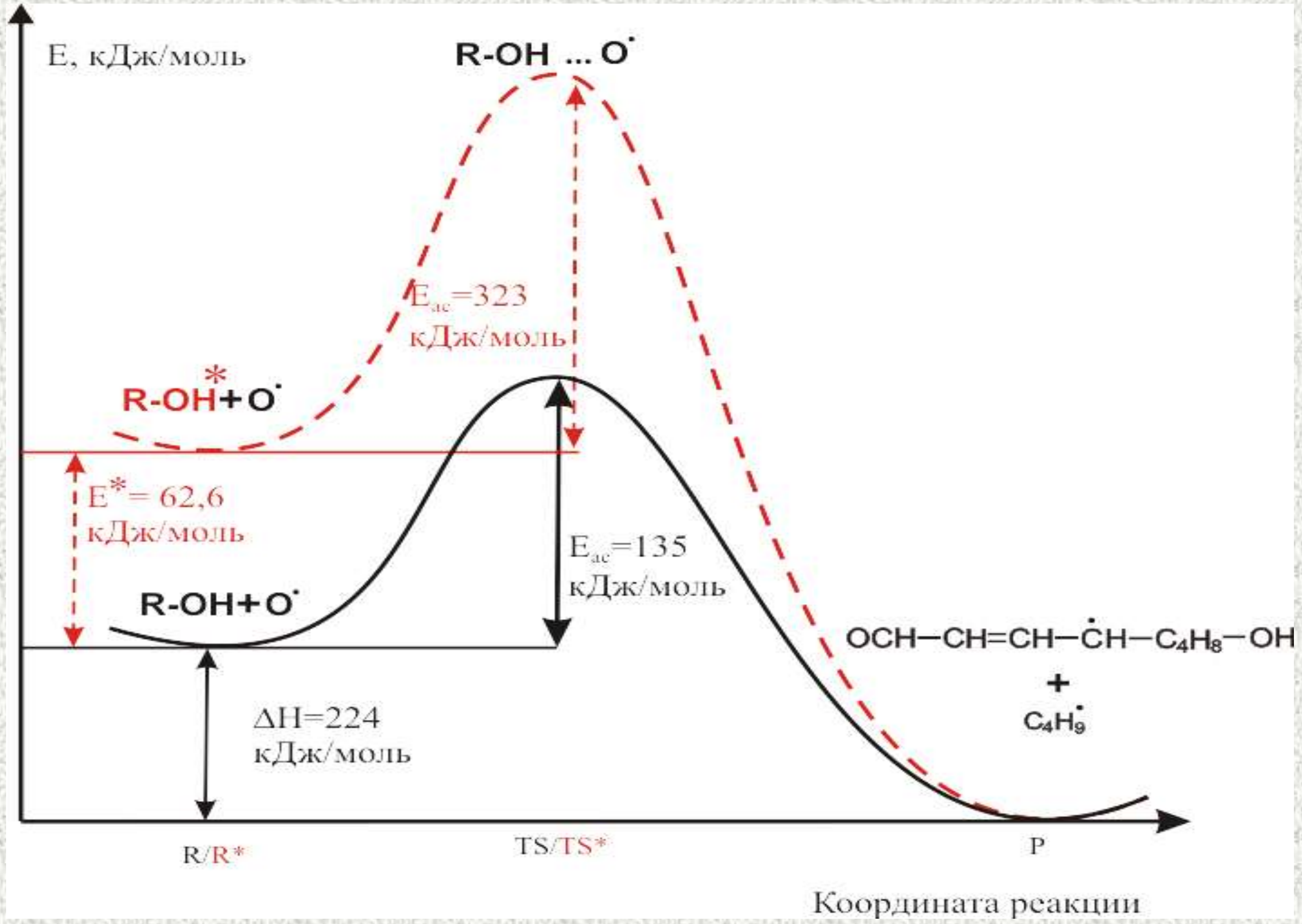


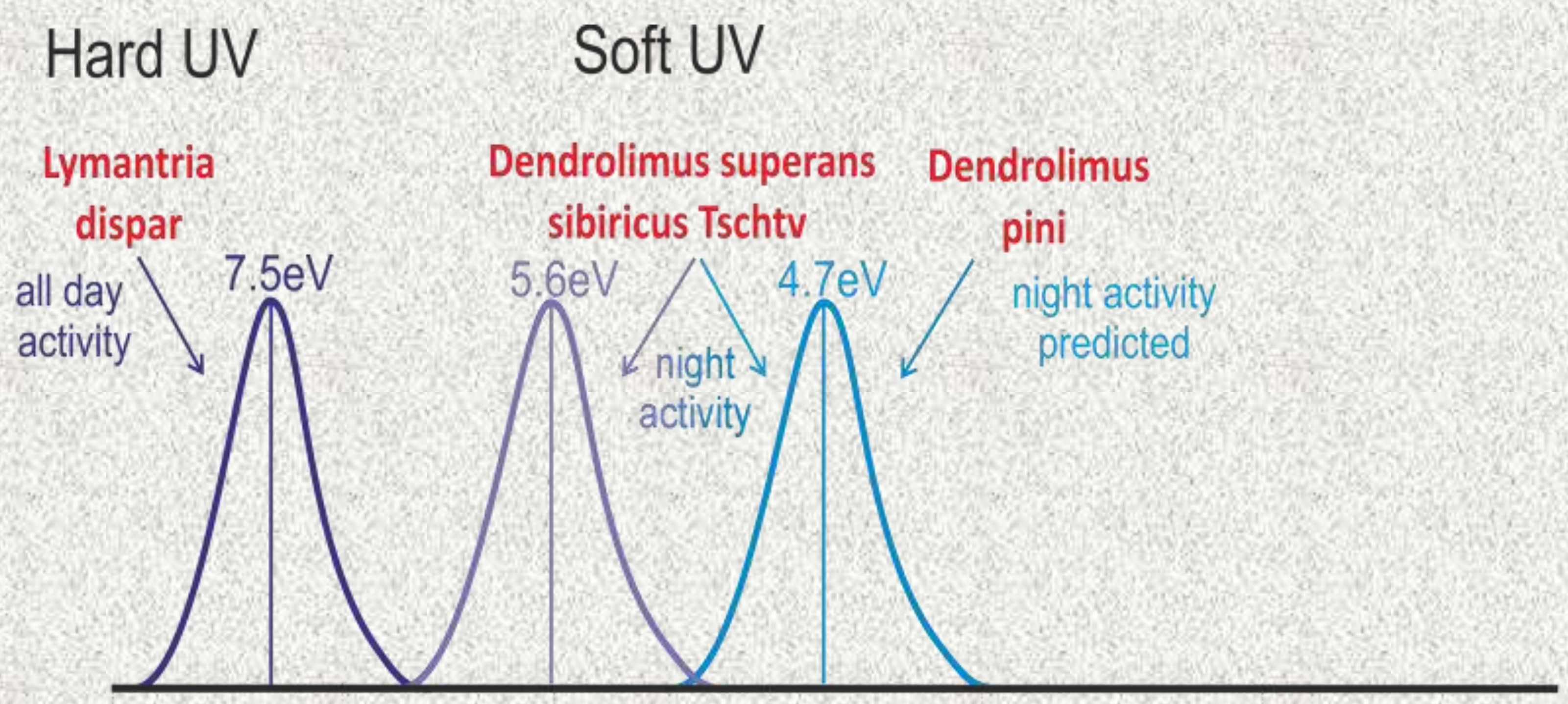
Photo-physical processes



Trajectory of reaction of pheromone with H_2O activated by UV



Excitation bands



Name	Ultraviolet C	Middle	Ultraviolet B	Near	Ultraviolet A	Visible
Abbreviation	UVC	MUV	UVB	NUV	UVA	-
Wavelength, nm	280–100nm	300–200nm	315–280nm	400–300nm	400–315nm	380–700nm
Energy, eV	4.43–12.4eV	4.13–6.20eV	3.94–4.43eV	3.10–4.13eV	3.10–3.94eV	3.26–1.68eV

Ultra violet

Visible spectrum

Pheromone communication for Siberian moth is successful only at night.

Pheromone communication for gypsy moth may be successful 24 hours in day.

Therefore, a system of gypsy moth pheromone communication is more effective in relation to system of Siberian moth pheromone communication. .

Comparison of parameters for two species

Gypsy moth	**Siberian moth**
Small radius of behavior activity and high local population density	Long range zone of behavior activity and small local population density
High reliability and small zone of affectivity for pheromone communication system	Low reliability and wide zone of affectivity for pheromone communication system
Low consumption prices for majority of food species	High consumption prices for nonspecific breeds
Relative low critical population density	High critical population density
Wide range of optimal climate conditions	Limited range of climate conditions

The condition of successful invasion

- low ecological prices of food destruction and biomass synthesis;
- high local population density;
- stability of pheromone molecules to environmental impact;
- small critical population density;
- specific susceptibility to impact of external ecological field.

Thanks for your attention