Extinction Risk of DDT to Herring Gull in Long Island

DDTの生態リスク評価 ーセグロカモメの生物濃縮を例にー

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Ecological Risk of DDT (DDT の生態リスク)

No Acute Toxicity (急性毒性なし)

Biological Concentration (生物濃縮) .... Half life: 100 years (半減期約100年)

DDE

- Bird eggshell thinning (鳥の卵殻薄化)
- Decline of the bird populations (鳥の個体群減少)
- Increase of the brood mortality (鳥のヒナ死亡率上昇)

Endocrine-Disrupting chemicals cause abnormal parental behaviors (内分泌攪乱物質による異常行動)

eg) Herring Gull(セグロカモメ)

Biological Concentration of DDT
(ΣDDT の生物濃縮)

Long Island, NY		Biomagnification Factor
birds, 1.07 - 75.5 ppm	鳥	10^5 - 10^6
fishes , 0.17-2.07 ppm	魚	10^4 - 10^5
shrimps, insects	エビ･昆虫	10^4
plankton, 0.04 ppm	プランクトン	10^3
water, 0.00005ppm	水	1

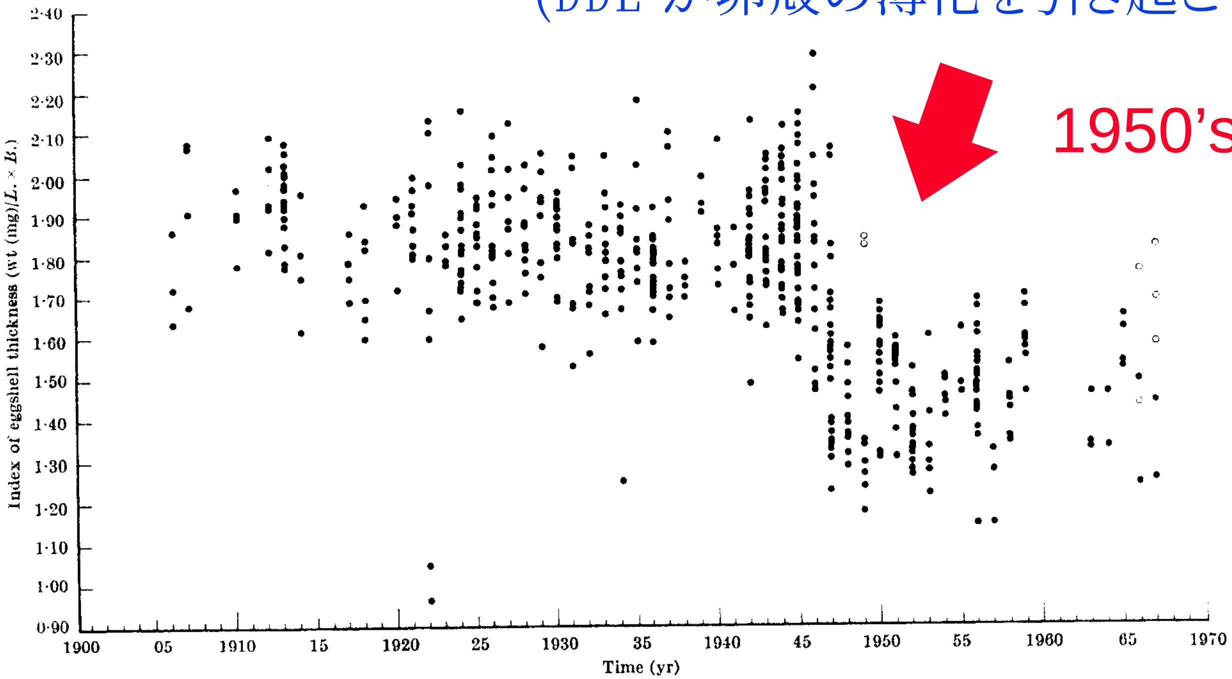
Eggshell thinning of *peregrine falcon* inBritain
(ハヤブサの卵殻薄化)

DDE caused the thinning of eggshell
(DDE が卵殻の薄化を引き起こした)

1950's

卵殻の厚さ

thickness of eggshell



year

Fig. 1. Change in the ratio of weight to size (index of thickness) in eggshells of the peregrine falcon in Britain. Circles represent eggshells from the central and eastern Scottish Highlands, and dots represent eggshells from other districts (see Table 1).

Average numbers of raptors per observation day
(一日当たりに観測された猛禽類の平均数)

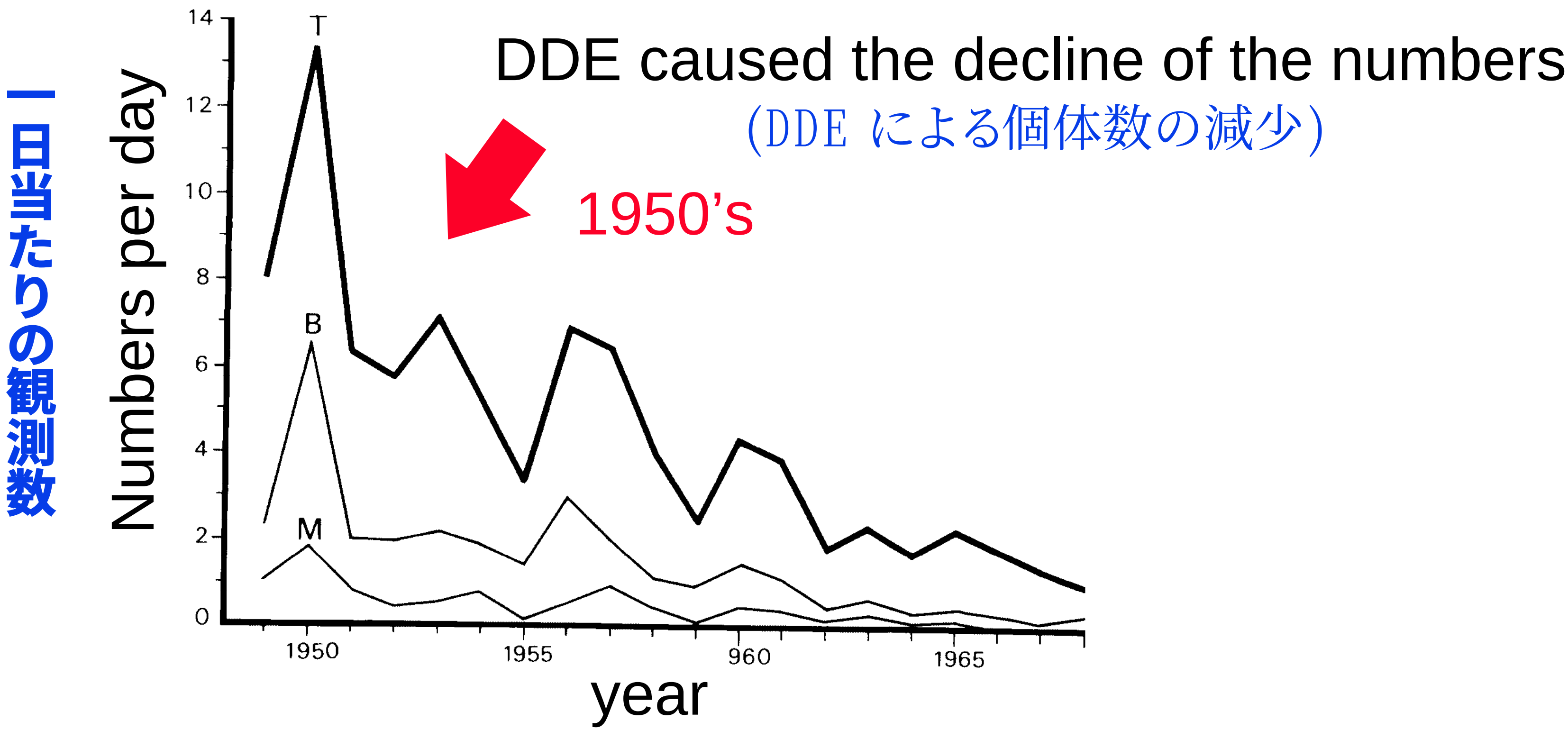
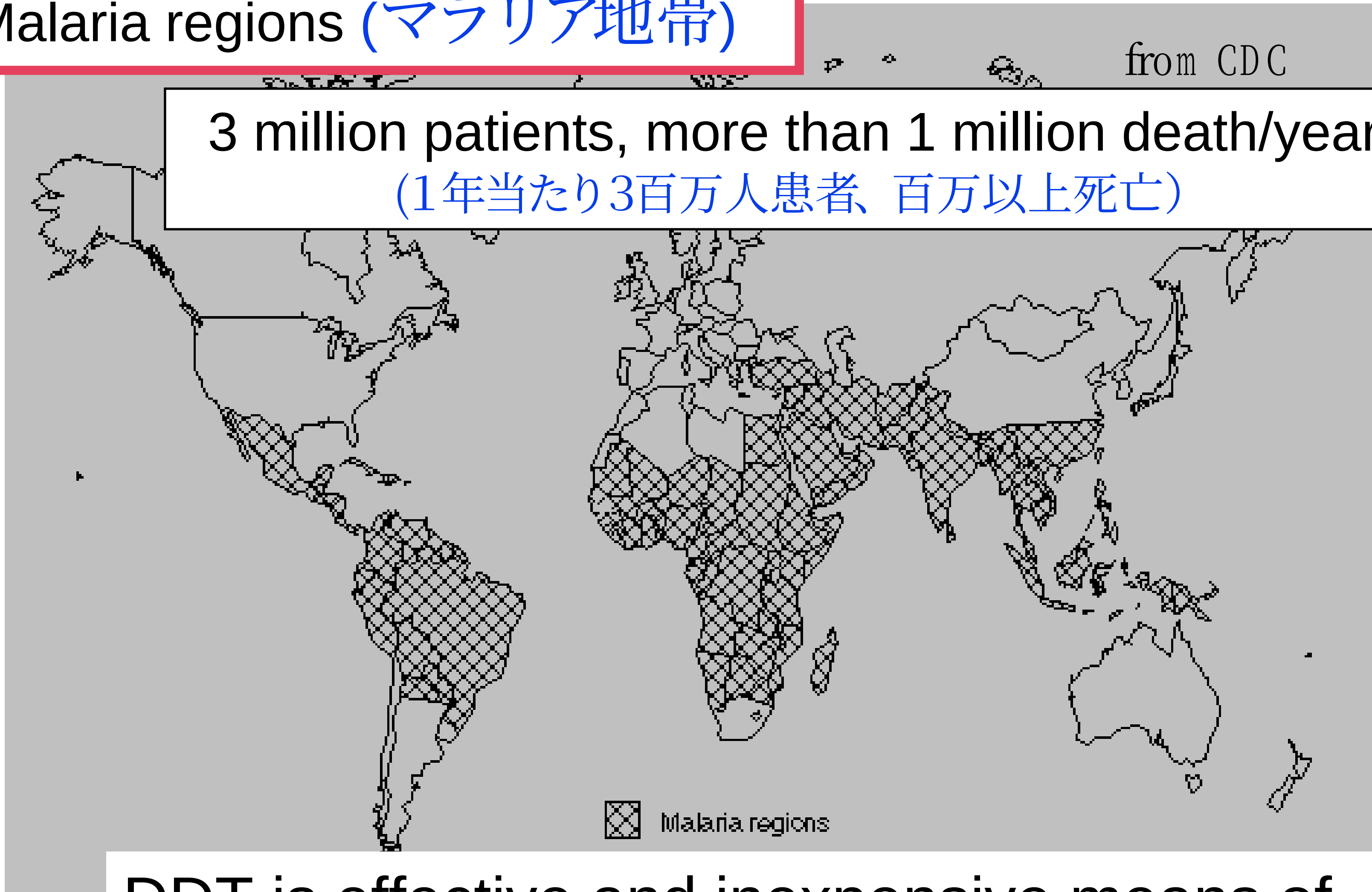


Figure 47. Average numbers of raptors seen per observation day in part of Bavaria, 1949–68. T – Total, B – Buzzard, M – Marsh Harrier. Re-drawn from Bezzel 1969.

Malaria regions (マラリア地帯)

3 million patients, more than 1 million death/year
(1年当たり3百万人患者、百万以上死亡)



DDT is effective and inexpensive means of controlling malaria (DDTは効果的、経済的)

Alternatives are expensive (代替品は高価)

Risk VS. Risk （リスク VS. リスク）

Human Health Risk Assessment (健康リスク評価)

↕ Trade-off （トレードオフ）

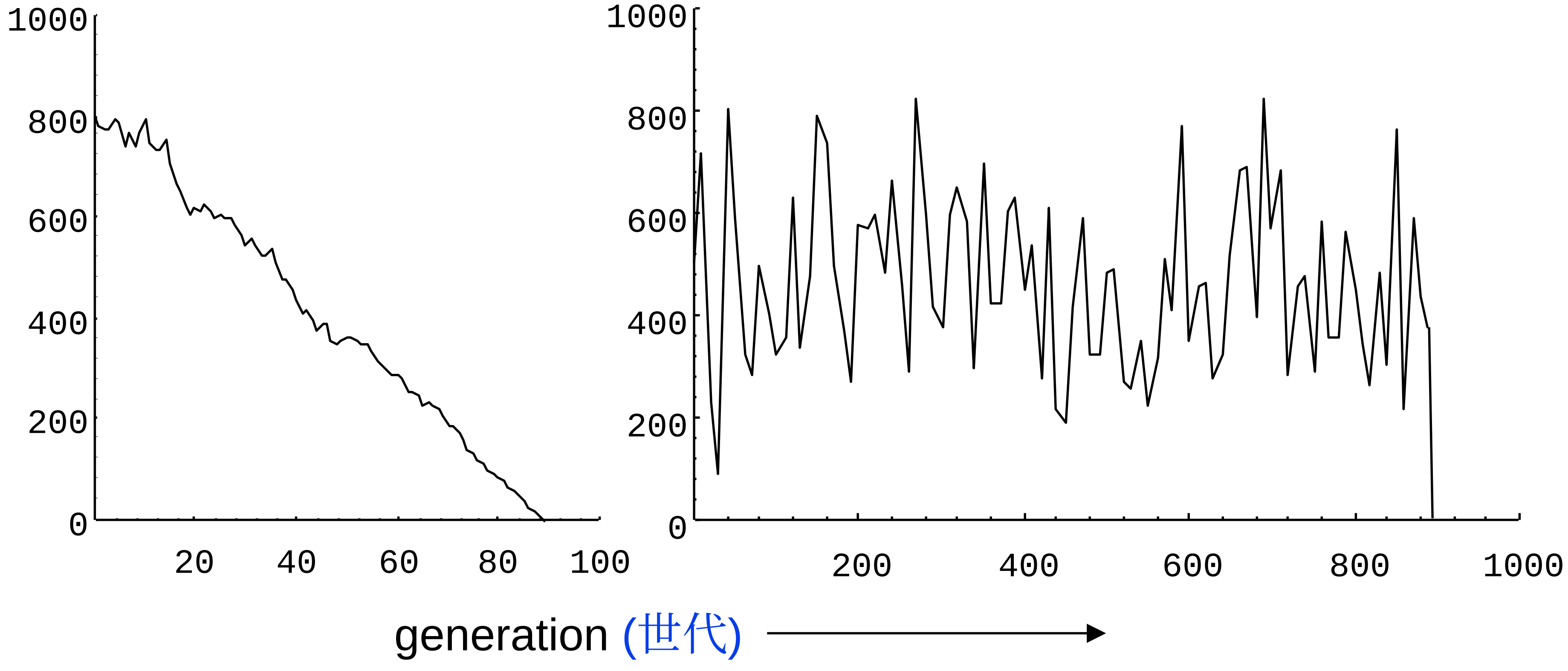
Ecological Risk Assesment (生態リスク評価)

ΔR = the decrease of average extinction time
(期待存続時間の減少分)

Risk/Benefit Analysis（リスク/ベネフィット解析）

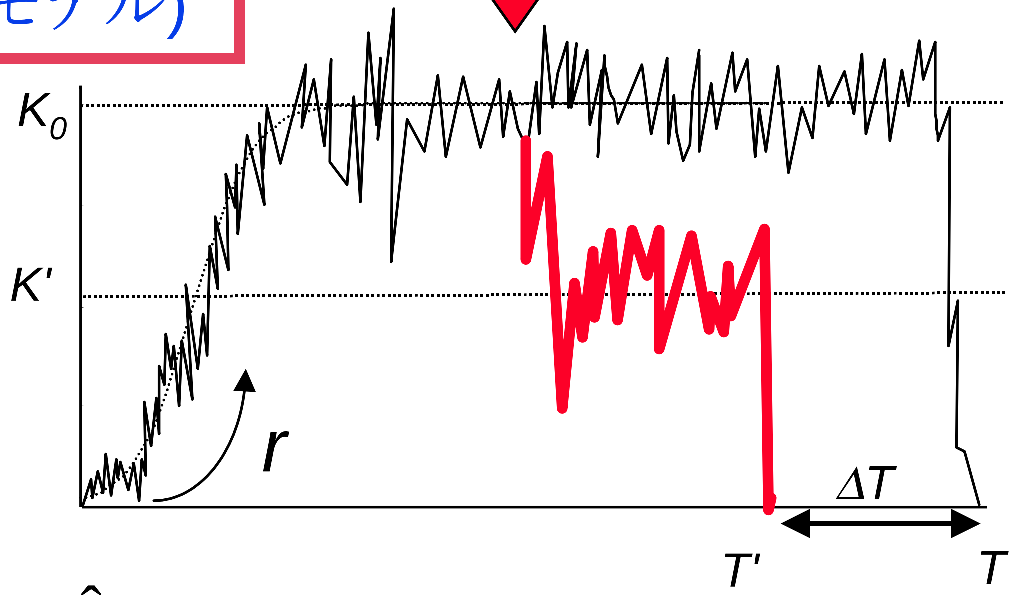
$$\frac{\Delta B}{\Delta R} = \frac{\text{Cost to reduce Risk （リスク減少のコスト）}}{\text{Magnitude of Risk reduced （リスク減少量）}}$$

2 tyies of Extinction (絶滅2種類)



Canonical Model
(カノニカルモデル)

Exposed to ΣDDT (ΣDDT の暴露)



$$\frac{dX}{dt} = rX\left(1 - \frac{X}{K_0}\right) + \sigma_e \xi_e \circ X + \sigma_d \xi_d \sqrt{X} - aX$$

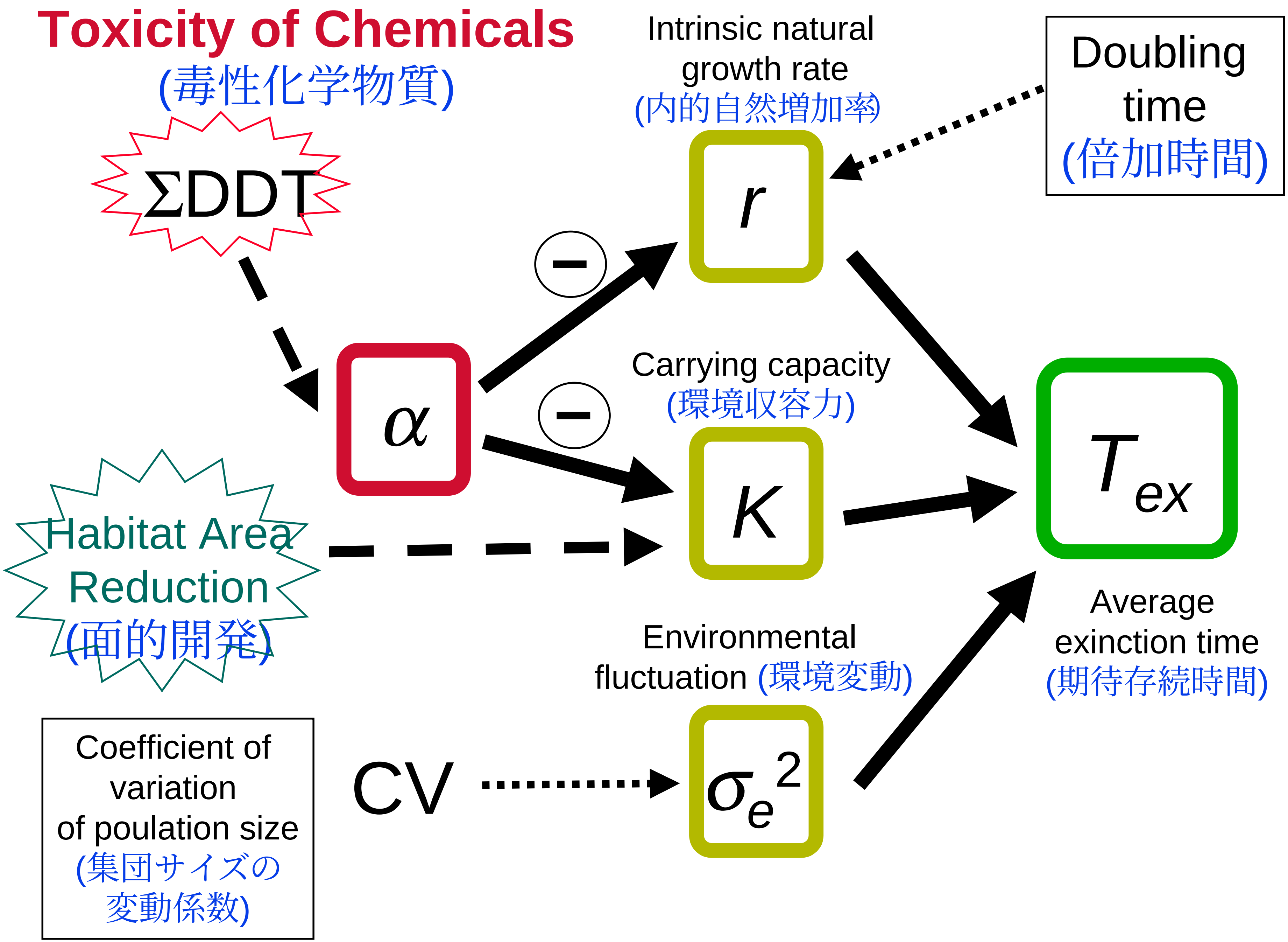
logistic eq. (ロジスティック式)

environmental stochasticity (環境確率性)

demographic stochasticity (人口学的確率性)

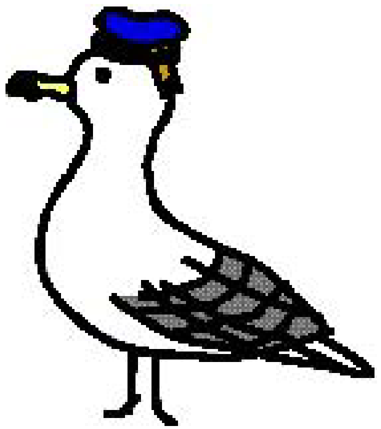
effect of ΣDDT (ΣDDT の影響)

$$r' = (r - a) \qquad K' = K_0 \frac{(r - a)}{r}$$


Toxicity of Chemicals
(毒性化学物質)
ΣDDT
Intrinsic natural growth rate
(内的自然増加率)
Doubling time
(倍加時間)
r
α
Carrying capacity
(環境収容力)
K
Habitat Area Reduction
(面的開発)
T_{ex}
Average exinction time
(期待存続時間)
Environmental fluctuation (環境変動)
Coefficient of variation
of poulation size
(集団サイズの
変動係数)
CV
σ_e^2

Herring Gull (セグロカモメ)

ΣDDT 11.9 ppm



Biomagnification Factor

$$\mathrm{BMF} = \frac{\text{conc. in the body, } C_b \text{ (体内中濃度)}}{\text{conc. in the environment, } C_e \text{ (環境中濃度)}}$$

$$\mathrm{BMF} = 11.9 / 0.00005 = 2.38 \times 10^5$$

The procedure for calculating the extinction time of Herring Gull
(セグロカモメの期待存続時間の計算の流れ)

(1) intrinsic growth rate per year r
(年当たりの内的自然増加率)

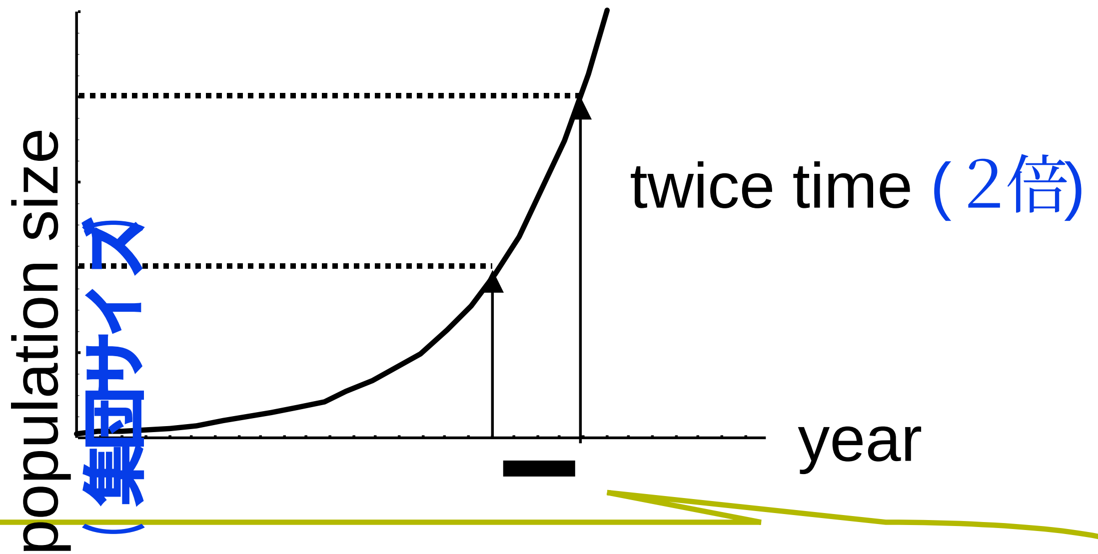
(2) environmental flucuation σ_e^2 (環境変動)

(3) initial carrying capacity K_0 (環境収容力)

(4) the effect of DDT α (ΣDDT の効果)

→ average extinction time from the canonical eq.
(カノニカルモデルから導出した期待存続時間に代入)

(1) the intrinsic growth rate per year (r^*)
(年当たりの内的自然増加率)



the doubling time 15 years (倍加時間15年)

$$exp(r^* \times \text{doubling time}) = 2$$

$$r^*_{/\,year} = 0.0462$$

(2) environmental flucuation σ_e^2 (環境変動)

The coefficient of variation of poulation size (CV)
(集団サイズの変動係数)

$$CV^2 = Var[X] / E[X]^2$$

$$\sigma_e^2 = 2r \cdot CV^2$$

from Pimm *et al*. CV = 0.2 - 0.8

in New England CV = 0.02 - 0.15

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(3) carrying capacity *K* (環境収容力)

the number of females
(メスの数)

$$10 \le K_0 \le 250$$

(4) the effect of DDT, α (ΣDDT の効果)

1. fertility $f(a)$ of females not exposed to ΣDDT
(ΣDDT に暴露されてない時の繁殖率)

from age-structured matrix model (齢構成モデルより)

2. C; the decrease in fertility caused by ΣDDT
(ΣDDT によって引き起こされる繁殖率の減少)

using the Black Duck data (アメリカガモのデータを使用)

3. the intrinsic growth rate exposed to ΣDDT
(ΣDDT に暴露されたときの内的自然増加率)

4. converting into the intrinsic growth rate per generation (r)
(年当たりの増加率を世代当たりに変換)

5. the relationship between ΣDDT conc.(C_e) in water and r, using BMF
(ＢＭＦ から、環境中ΣDDT濃度と内的自然増加率との関係を出す)

Age-structured matrix model (齢構成行列モデル)

$f(a)$; female fertility at age '*a*'
(a才での繁殖率)

$$\begin{pmatrix} n_0(t+1) \\ n_1(t+1) \\ \vdots \\ \\ \vdots \\ n_w(t+1) \end{pmatrix} = \begin{pmatrix} f(0) & f(1) & \cdots & f(a) & \cdots & f(w) \\ p_1 & 0 & 0 & \cdots & \cdots & 0 \\ 0 & p_2 & \ddots & \vdots & & \vdots \\ \vdots & 0 & \ddots & 0 & & \vdots \\ \vdots & \vdots & \vdots & p_a & 0 & \vdots \\ 0 & \cdots & \cdots & 0 & p_w & 0 \end{pmatrix} \begin{pmatrix} n_0(t) \\ n_1(t) \\ \vdots \\ \\ \vdots \\ n_w(t) \end{pmatrix}$$

affected by ΣDDT
(ΣDDTの影響あり)

p_a; the survivership from '*a*-1'years old to '*a*'
(a-1才からa才までの生存率)

not affected by ΣDDT (ΣDDTの影響なし)

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population growth rate *r** satisfies (増殖率*r**は以下の式を満たす)

Euler-Lotka eq.
(オイラーロトカ方程式)

$$1 = \sum_{a=0}^{w} e^{-(a+1)r^*} \cdot f(a) \cdot p_1 \cdots p_a$$

$f(a)$; female fertility at age 'a' (no effect of ΣDDT)
(a才の繁殖率（ΣDDT の影響なし））

female age 'a' (a才のメス)	the number of fledged (巣立ちヒナの数)	$f(a)$
less than 4	0	0
5	0.51	$0.52M$
6	0.71	$0.72M$
more than 7	0.99	M

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put r, p_a and $f(a)$ into

$$1 = \sum_{a=0}^{w} e^{-(a+1)r^*} \cdot f(a) \cdot p_1 \cdots p_a$$

fertility of adult
(成鳥の繁殖率)

$M = 2.27$

C; the decrease in fertility *f*(*a*) caused by ΣDDT
(ΣDDT による繁殖率の減少率)

ΣDDT residues in egg (卵中のΣDDT残量)	survivorship from egg to 3-wk brood (3週間目のヒナの生存率)	*C*
0 ppm	38 %	1
46 ppm	23 %	0.61
144 ppm	9 %	0.24

fertility (繁殖率) = *Cf*(*a*)

$$1 = \sum_{a=0}^{w} e^{-(a+1)(r^{*}-a)} \times Cf(a) \times p_1 \times \cdots p_a$$

the intrinsic growth rate per year (年当たりの内的自然増加率)

$$r_{/\,generation} = r_{/\,year} \cdot T_g$$

$T_g = 8.05$

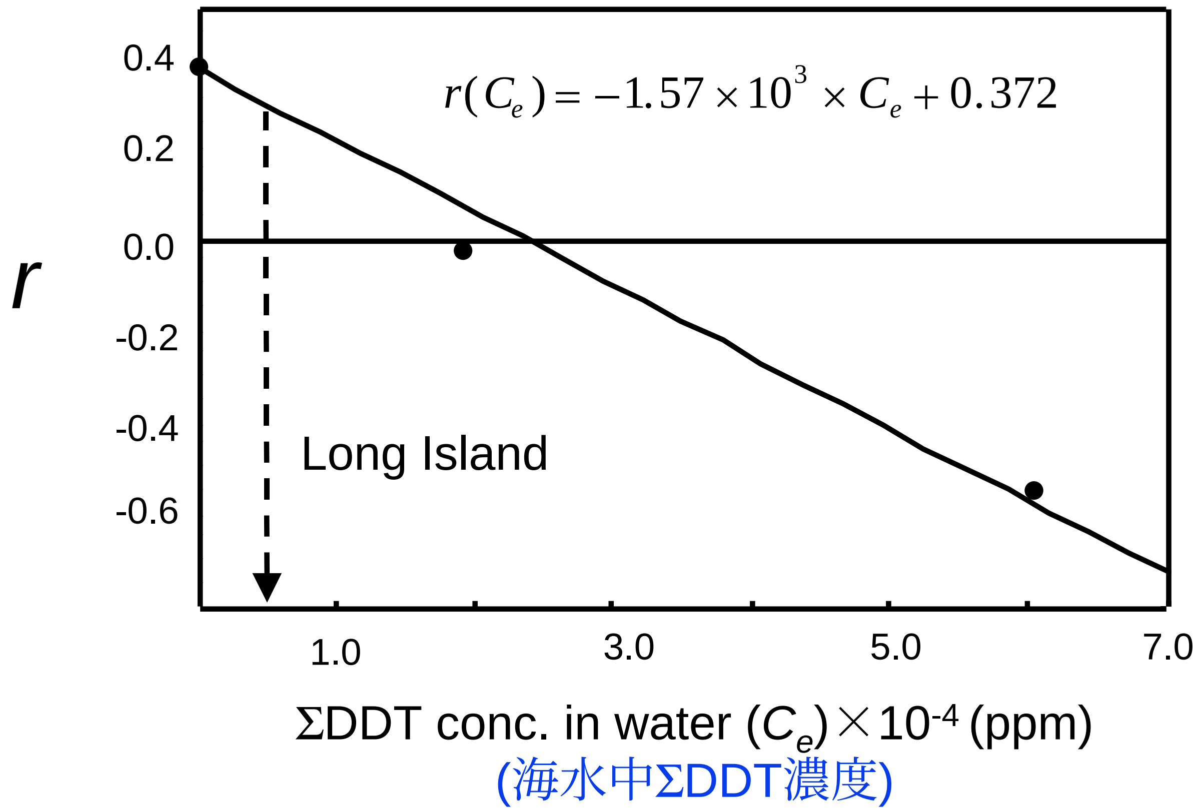
the intrinsic growth rate per generation
(世代当たりの内的自然増加率に変換)

ΣDDT conc. in body = ΣDDT conc. in egg
(体内中の濃度＝卵中濃度、と仮定)

ΣDDT conc. in body = ＢＭＦ×ΣDDT conc. in water (C_e)
(体内中濃度＝ＢＭＦ×環境中濃度)

cf. BCF of Herring Gull ; 2.38×10^5

the intrinsic growth rate per generation (*r*)
(世代当たりの内的自然増加率)



Mean extinction time (Hakoyama & Iwasa)
(期待存続時間)

$$T = \frac{2}{\sigma_e^2}\int_0^{x_0}\int_x^{\infty} e^{-R(y-x)}\left(\frac{y+D}{x+D}\right)^{R(K+D)+1}\frac{dy}{(y+D)y}\,dx$$

$$R \equiv \frac{2r}{\sigma_e^2 K_0} \qquad D \equiv \frac{1}{\sigma_e^2}$$

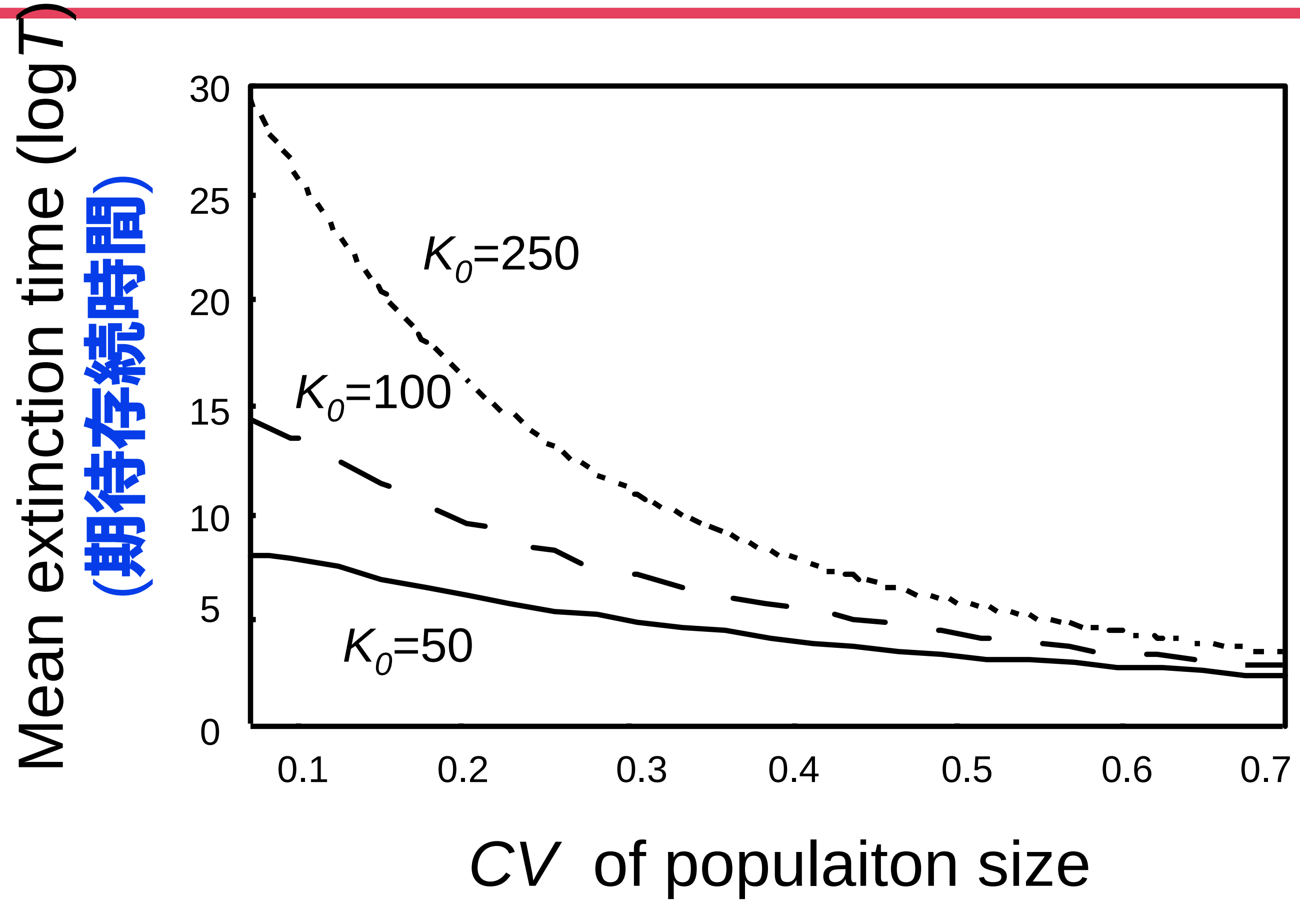
regression
(回帰)

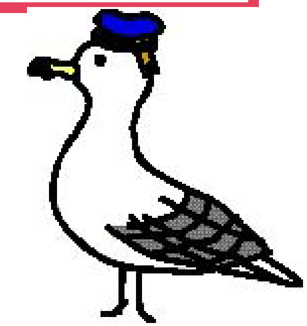
$$\log T = -\log\left(\frac{r}{0.1}\right)$$
$$+\left(1.12073\left(\frac{0.1\sigma_e^2}{r}\right)^{0.318121} - 0.0267559\right)\log\left(\frac{rK_0}{0.1}\right)^{\left(-9.70471\left(\frac{0.1\sigma_e^2}{r}\right)^{0.176337}+8.07769\right)}$$
$$+\left(-1.93776\left(\frac{0.1\sigma_e^2}{r}\right)^{0.113793} + 2.56977\right)$$

$$10^{-4} r \le \sigma_e^2 \le r \qquad 1/r \le K_0 \le 100/r$$

Mean extinction time of Herring Gull not exposed to ΣDDT

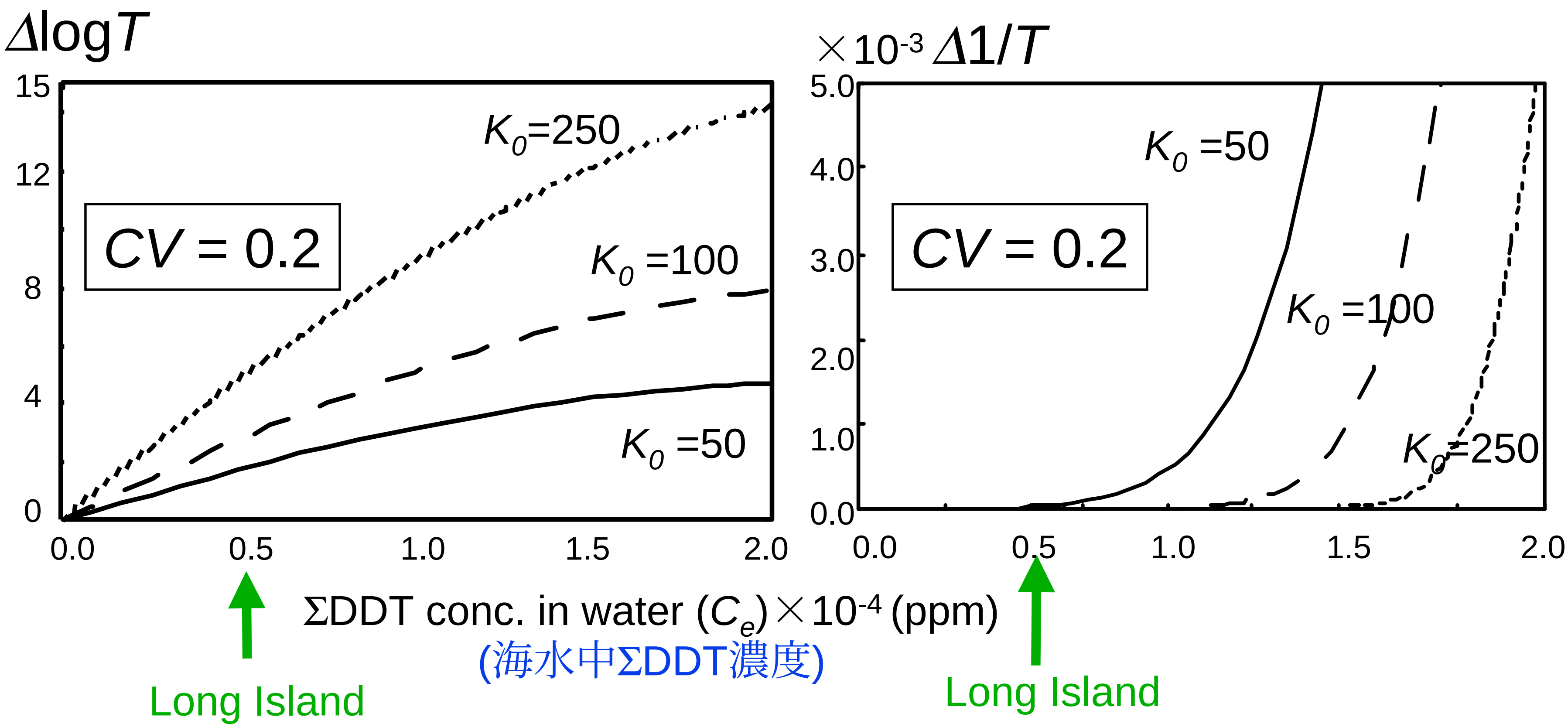
(ΣDDT に暴露されてないセグロカモメの期待存続時間)





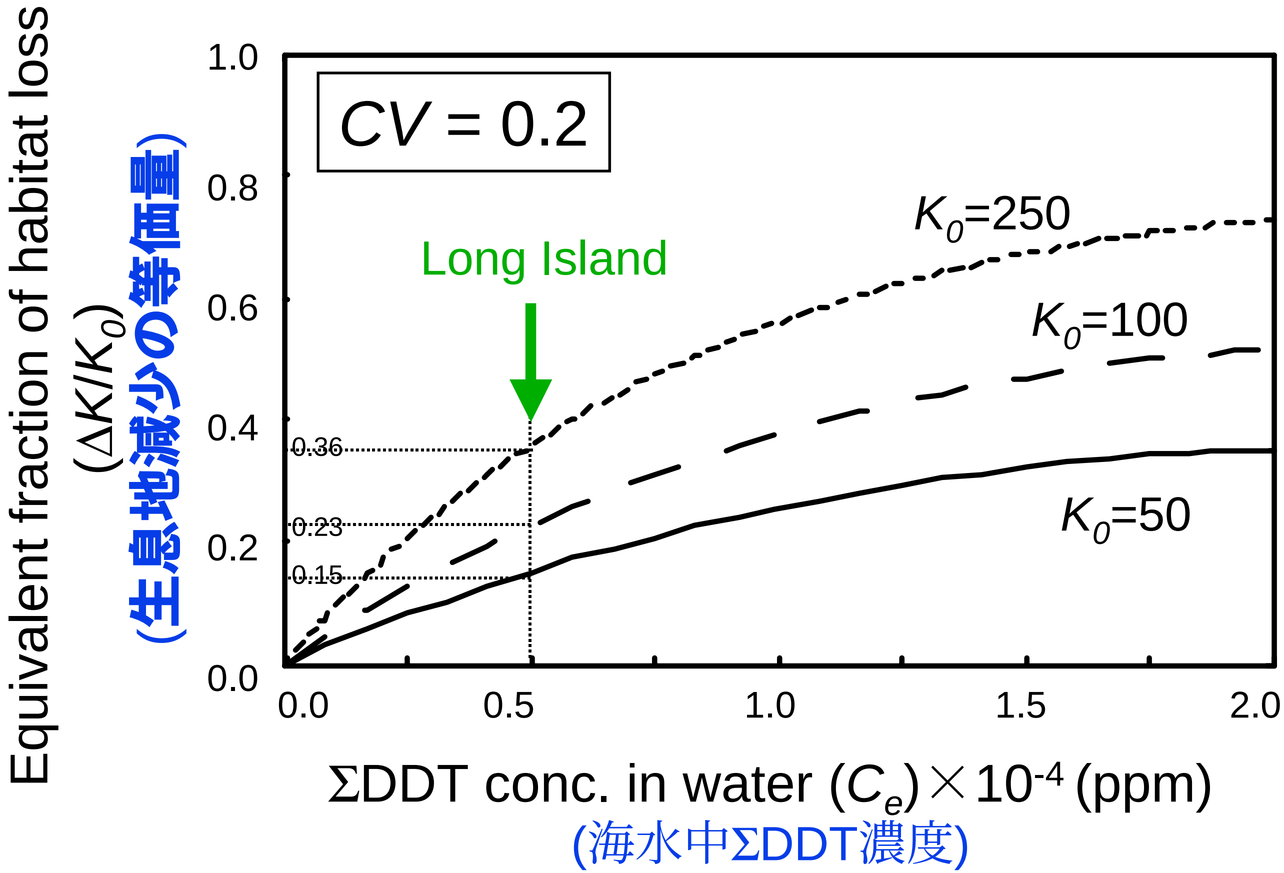
(1) Change in log$T$
(log$T$の変化量)

(2) Change in 1/T
(1/Tの変化量)



The equivalent loss of habitat area causing the same decrease in *T*
(期待存続時間の減少と等リスクになる生息地減少)

$$\Delta \log T \approx \frac{1}{\mathrm{CV}^2} \Delta \log K$$ (Hakoyama, Iwasa & Nakanishi)



Conclusion

ΔR ＝the habitat loss ($\Delta K/K_0$)
(リスク変化量＝等価生息地減少量)

In Long Island, NY,
ΣDDT conc. in water (0.00005ppm) caused
the 10-30 % habitat loss of Herring Gull
(1960年代のニューヨークのロングアイランドでのΣDDT濃度での絶滅リスクは、セグロカモメの生息地を10-30 % 減少させるのに相当する。)

Risk Equivalent
(リスク当量)