2014/05/30 luncheon seminar

MODELING THE SPEED OF PINE WILT DISEASE CAUSED BY NEMATODES WITH PINE SAWYERS AS VECTOR

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THE PROCESS OF PINE WILT DISEASE

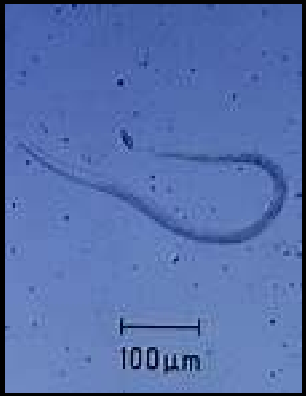
FEED！

産卵
(egg-laying)

Vector

マツノマダラカミキリ
(the pine sawyer beetle)

マツノザイセンチュウ
(nematode)



侵入→通水阻害
(invade → disturb trees to draw up water)

Nematodes and larvae of beetle grow up in Pine from September to July.
When larvae go out the Pine, nematodes get into them through their stoma.

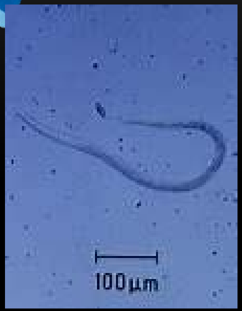
THE LIFE STYLE OF VECTOR AND NEMATODE

	季節	生活環
夏	6月初旬 – 7月下旬	●線虫をのせた成虫がマツから脱出 ●成熟のために健全マツの若枝を後食 →○線虫が傷から樹体に侵入→マツの樹脂滲出が止まる等衰退
	成虫脱出から数週間後	●カミキリ成虫が成熟 →●近い時期の枯死木や衰退木に移動し、産卵
	産卵から一週間以内	●幼虫が孵化し、内樹皮や師部、形成層を摂食
秋	～11月	●ほとんどの幼虫が木部に到達、蛹を作り始める
冬	冬～春先	○線虫が蛹の周りに集まり始める
春	春後半	○線虫が蛹内のカミキリ成虫の気管に侵入し始める
	春後半～初夏	●幼虫が蛹内で成長し、成虫になる

	season	life style
summer	early June – late July	●adult emerge carrying nematodes ●feed on the twigs of the healty pine trees for maturation →○nematode is transmitted to wood tissues through wounds
	after a few weeks of the emergence	●adult female and male beetles get matured →●move to recently killed or weakened pine trees and deposit their egg
	after ～1 week	●larvae hatch and begin feeding on the inner bark, phloem, and cambium
autumn	by November	●most larvae bore into the xylem and construct pupal chambers
winter	during winter and into early spring	○nematode gather around the pupal chambers
spring	late spring	○nematode enter the tracheal system of adults sawyer in the pupal chamber
	late spring–early summer	●the larvae pupate and become adults in the pupal chamber

HISTORY

- Native to Japan



- Aboriginal inhabitant of the United States

- Its first incidents was recorded in 1905 in Nagasaki.
- Now the disease has wide spread in Japan except for Hokkaido.
- The amount of killed trees are decreasing but it is still most serious disease in Japan.

AIM

- 伝染病の生態について焦点をあてて・・・
- With Focusing our attention on the ecology of the epidemic・・・

防除によってどのように伝染を抑えられるかを予測する！

Predict how the spread of disease could be controlled by removal of pine sawyers

↑

数理的モデルの構築！

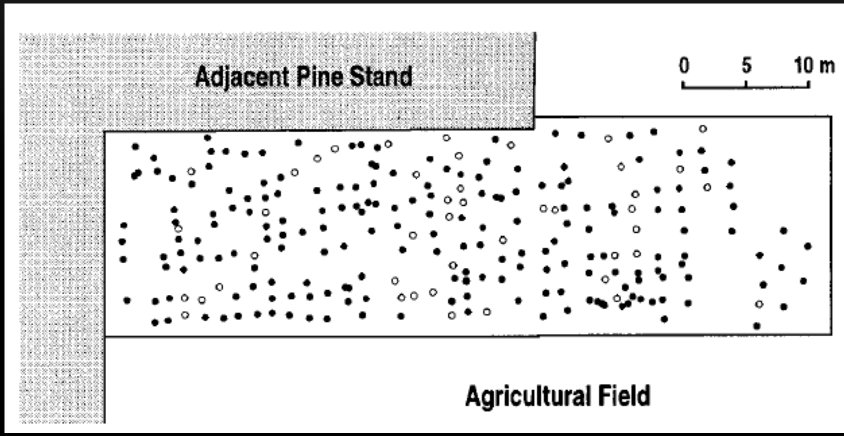
Develop the mathematical model

↑

1980-1983年に石川県でとられたデータ（カミキリ個体数とマツの感染数）

Detailed data on the population dynamics of pine sawyer beetles and the incidence of pine wilt disease taken during 1980-1983 at a pine stand in Ishikawa Prefecture

DATA IN 1980-1983 BY TOGASHI

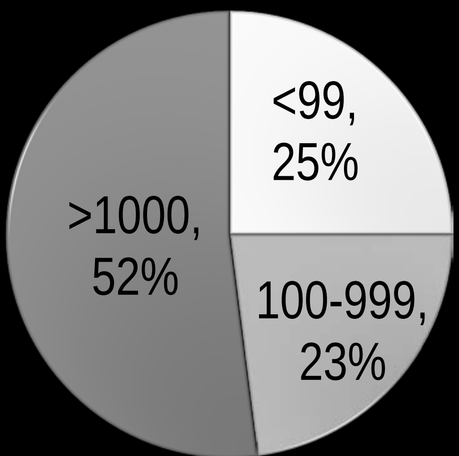


- 石川県押水町のクロマツ林外縁部
  - Japanese black pine forest located at the landward fringe of a littoral pine forest at Oshimizu town, Ishikawa Prefecture
- 1974年に初めて感染が確認された
  - A incidence of pine wilt disease in the forest was first reported in 1974
- 調査地における全ての被害木は、翌年の成虫脱出前に除去
  - All dead trees were removed from the study stand before the start of adult emergence to completely prevent the recruitment of pine sawyers
- 隣接したクロマツ林では被害木の除去と殺虫剤散布が行われた
  - The neighboring pine stand was subjected to the governmental effort to eradicate

DATA IN 1980-1983 BY TOGASHI

- カミキリ成虫の調査は mark-recapture によって調査地全てのマツについて行われた(1980-1983年の6-9月に毎週)
  - A census of adult beetles was carried out by using a mark-recapture method each week during June-September from 1980 to 1983 for all trees in the stand
- カミキリ一個体が有する線虫数は大きく異なりその出現頻度は右の通り(年ごとの有意差なし)
  - There was a large variation in the number of nematodes carried by beetles. The frequency distribution of nematode abundance within beetles did not significantly change from change from year to year

As constant



The number of nematodes per beetle

DATA IN 1980-1983 BY TOGASHI

- 幼虫の生存率は丸太ごとの産卵数と脱出成虫数によって推定された
  - Survival rate was estimated by the number of emerging adults divided by the number of eggs deposited in each log

- 密度に依存した死亡率の増加がみられたが、これは種内競争の結果と思われた
- There was a significant density-dependent mortality, possibly as a result of interspecific competition
- $$A(E) = \frac{0.98E}{(1+0.065E)}$$

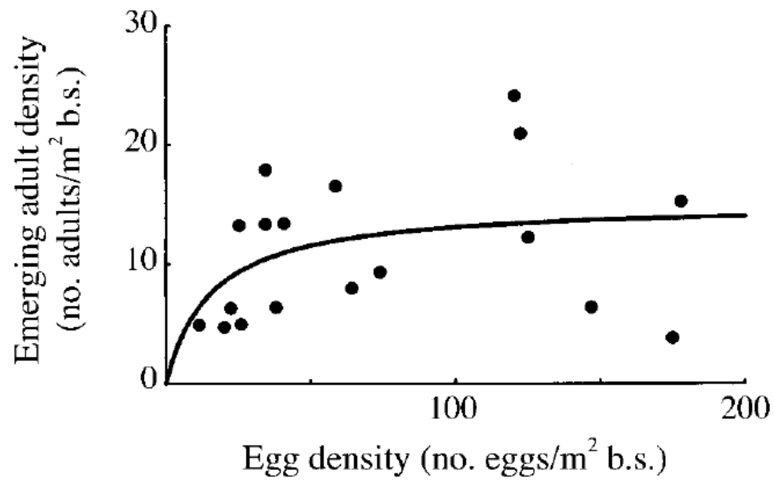


FIG. 2. Relationship between egg density, E (no. eggs/m^2 of bark surface [b.s.]), and the density of emerging adults of the pine sawyer, A (no. adults/m^2 of b.s.). Experimental data (solid circles) were fitted with a hyperbolic curve by using a least-square method (———).

RESULTS IN 1980-1983 BY TOGASHI

TABLE 1. The density of *Monochamus alternatus*, the density of pine trees, and environmental conditions in 1980–1983 (modified from Togashi, 1988, 1989*b*).

Experimental property	1980	1981	1982	1983
Mean density of wild pine sawyers for June and July (m^{-2})†	0.030	0.051	0.033	0.025
Density of added nematode-free pine sawyers (m^{-2})	0.090	0.053	0.037	0.012
Density of healthy trees in early June (no. pine trees/m^2)	0.263	0.211	0.149	0.103
Density of trees killed by late May of following year (no. pine trees/m^2)	0.052	0.062	0.046	0.013
Egg density (no. eggs/newly killed pine trees)	43.9	60.7	36.6	79.9
Average air temperature for June–July (°C)	21.3	22.2	21.0	21.1
Average precipitation for June–July (mm/d)	10.1	6.9	3.3	9.9

† Mean of estimated beetle densities from the first day of their detection through the last census day in July.

- Let's make the models!!

MODELING

- (1) $\boldsymbol{H_{t+1} = e^{(-\propto P_t)} H_t}$

マツが感染を逃れる確率
The probability that a pine tree escapes infection

- H_t ：t 年における健全マツの本数密度[/m^2]
  the population density of healthy pine trees in year t [/m^2])
- P_t ：t 年初夏におけるカミキリ成虫の平均個体密度[/m^2]
  the average density of adult beetles during early summer in year t [/m^2]
- ∝：単位個体密度及び単位時間あたりのマツ平均感染率×成熟期間
  i.e.伝染効率を表し、定数とみなせる
  the product of the average rate at which a pine tree gets infected by a unit density of beetle per unit time and the period of maturation feeding
  (i.e. the transmission efficiency that is assumed a constant)

MODELING

- (2) $\widetilde{H_t} = H_t - H_{t+1} = \left\{1 - e^{(-\propto P_t)}\right\} H_t$

- $\widetilde{H_t}$：t 年の一年で感染するマツの個体数密度

  the density of pine trees infected by nematodes in year t

- H_t：t 年における健全マツの本数密度[/m^2]

  the population density of healthy pine trees in year t [/m^2]

MODELING

- (3) $P_{t+1} = F(P_t, \widetilde{H_t})\widetilde{H_t}$

- $F(P_t, \widetilde{H_t})$：枯死木一本から翌年脱出するカミキリ成虫数

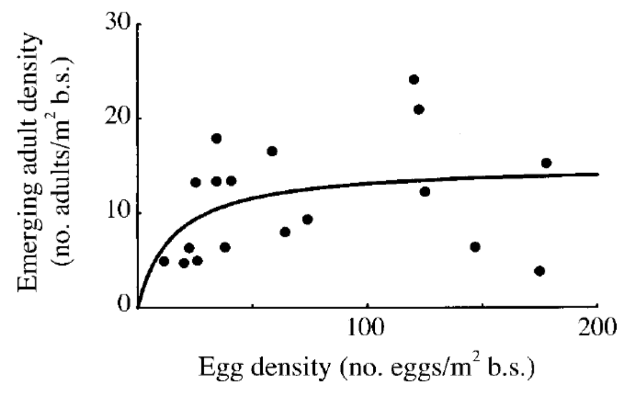
  the number of adult beetles that will emerge from a dead pine trees next year (that depend on both P_t and $\widetilde{H_t}$)

- (4) $P_{t+1} = (1 - \theta)F(P_t, \widetilde{H_t})\widetilde{H_t}$

- θ：年末におけるカミキリ駆除率（殺虫剤や枯死木除去による）

  excluded rate against pine sawyers by eradication efforts by insecticide or removal of infected trees at the end of the year ($0 < \theta < 1$)

MODELING



- (5) $F\left(P_t, \widetilde{H_t}\right) = A(E_t)S$

- A：樹皮単位面積当たりから脱出するカミキリ成虫密度

  the emerging adult density per bark surface [no adults/m^2 b.s.]

- E：t 年における樹皮単位面積当たり卵密度

  the egg density of pine sawyers in year t (no.eggs / m^2 of bark surface)

- S：マツ一本当たりの樹皮総面積

  the total area of bark surface per pine tree [no eggs/ /m^2 b.s.]

MODELING

- (6) $E_t S\widetilde{H_t} = \frac{K\sigma P_t \widetilde{H_t}}{a+\widetilde{H_t}}$

- σ：カミキリの性比（雌）

  Sex ratio (female)

- K：カミキリ雌成虫の平均最大産卵数(枯死木が十分あった場合)

  the average number of eggs that a female beetle can maximally deposit when dead trees are extremely abundant

- (7) $F\left(P_t, \widetilde{H_t}\right) = \frac{0.98\sigma S K P_t}{S(a+\widetilde{H_t})+0.065\sigma K P_t}$

CO-RELATIONSHIPS OF EQUATIONS

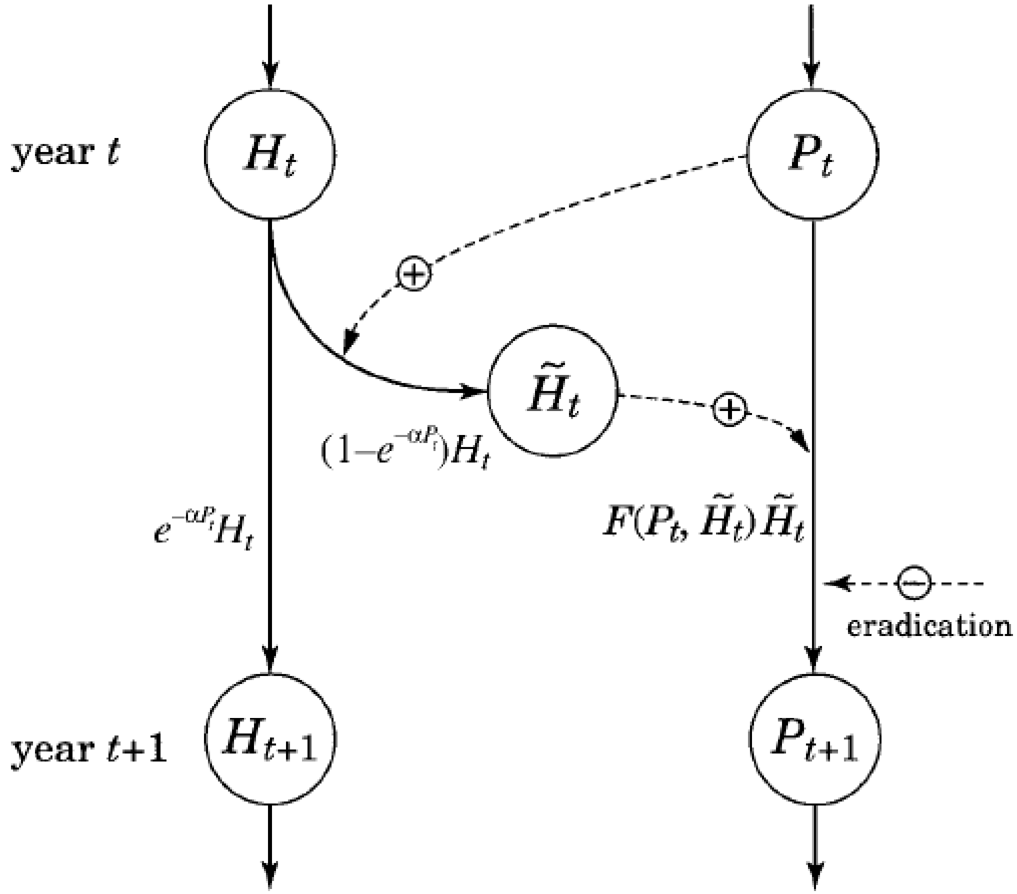


FIG. 3. Diagrammatic flow chart for the population dynamics of host–vector association in pine wilt disease. See *Population dynamics of host–vector association* for the definition of variables and functions. The dashed lines with plus and minus signs indicate, respectively, positive and negative effects on the processes represented by the solid lines.

LET'S USE THE MODELS!!

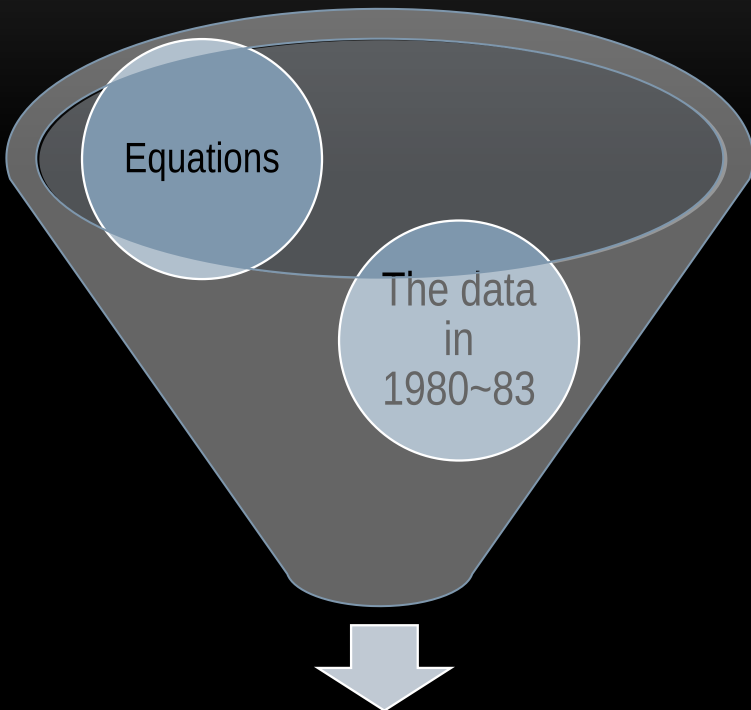


Table 2. Estimated values of the parameters in the model.

Symbol	Definition	Value
K	Maximum number of eggs deposited by a female	80†
σ	Sex ratio	0.48†
S	Area of bark surface per pine tree	2.4 m^2
α	Transmission efficiency	7.7 m^{-2}
a	$1/a$ is the oviposition efficiency	0.022 m^{-2}
θ	Eradication rate	Various

† Source: Togashi, 1989[b].

- Evaluate the effect of eradication
- Find the relationships among the parameters with changing various constants

BOUNDARY CURVES FOR SUCCESSFUL INVASION (UNDER THE VARIOUS θ)

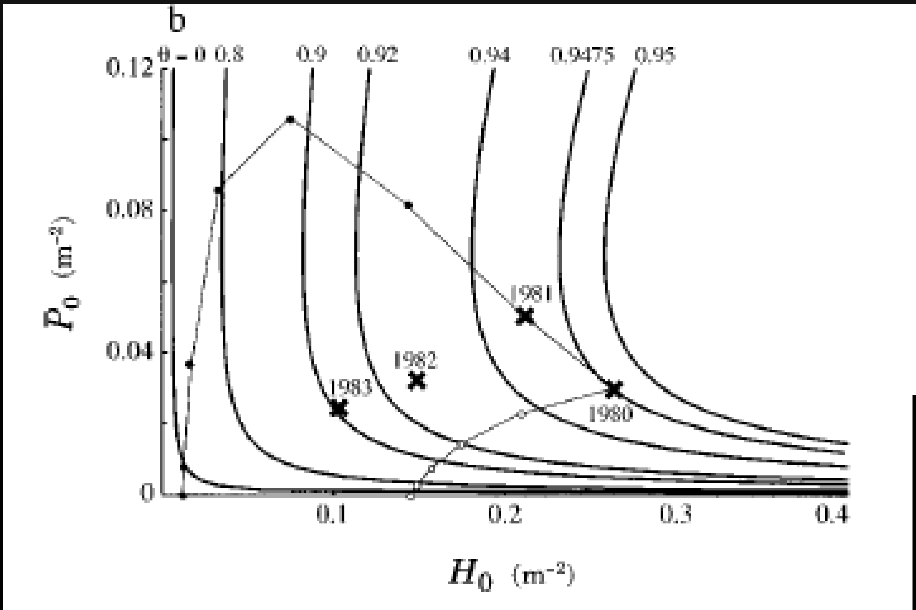


FIG. 6. (a) Boundary curves for the successful invasion of the pine sawyer in the (H_0, P_0) plane for various values of θ. H_0 and P_0 are the initial densities of healthy pine trees and beetles, respectively. On the right side of each curve, the beetle density increases the next year, while on the left side, it decreases. For $\theta = 0.95$, the threshold pine density is indicated by H^*, below which invasion of disease fails at any value of P_0. (b) The rectangular region enclosed by the dashed line in (a) is enlarged. Observed data during 1980–1983 (×); predicted course of disease in the subsequent years where the eradication rate θ is assumed to be 0.96 (open circles) and 0.91 (solid circles).

○ : θ =0.96 ● : θ =0.91

- On the left side of the boundary → the beetle density declines in the next year
- As θ approaches 1, the region of unsuccessful invasion increases in an accelerated manner
- Larger P_0 is, larger H_0 is required both for maturation and oviposition

INITIAL AND FINAL PINE DENSITY

- Various θ (upper) and P_0 (lower)

- High H_0 helps oviposition
  - $\rightarrow$causes low H_f
  - $\rightarrow$necessity for higher θ

- At a relatively large value of H_0, a slight decrease in P_0 results in a dramatic increase of eventually surviving rates

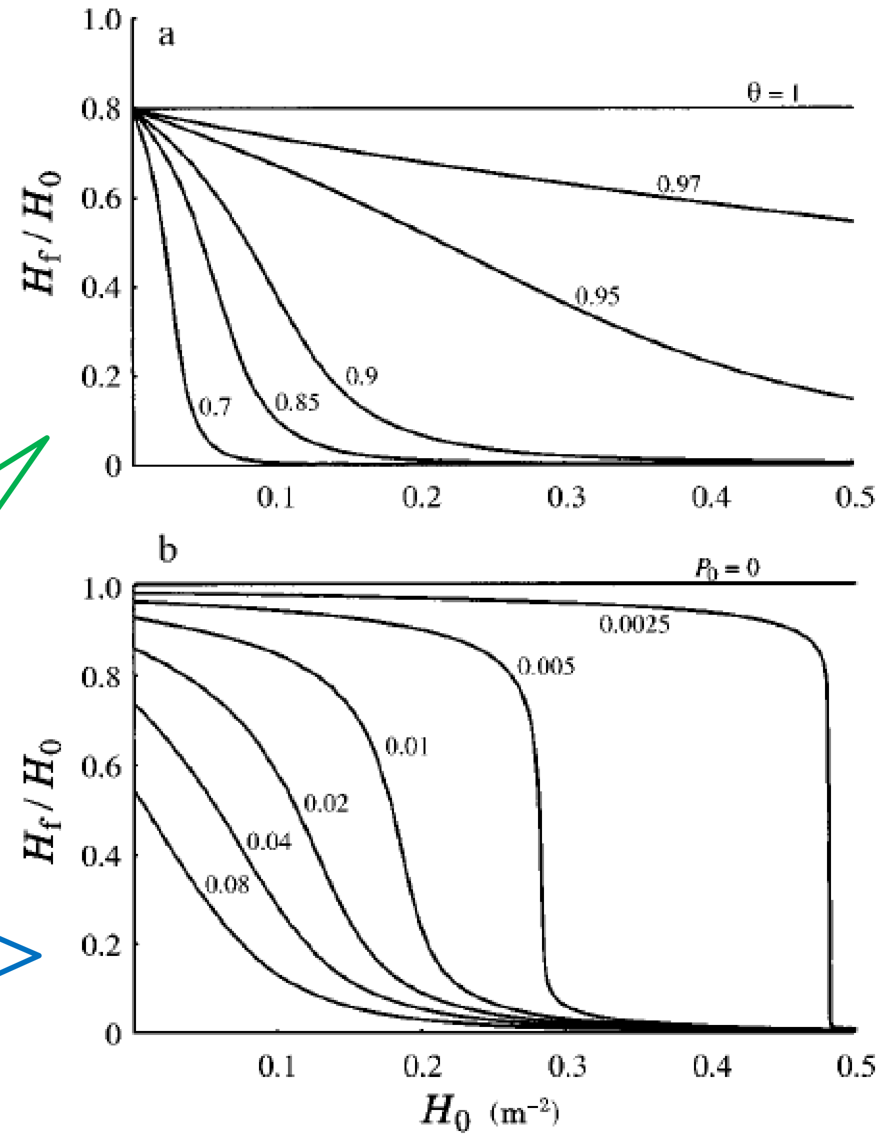


FIG. 7. The relationship between the initial pine density H_0 and the ratio of the final density of healthy pines to the initial pine density, H_f/H_0, for varying values of θ and P_0. (a) P_0 is fixed as 0.03; (b) θ is fixed as 0.9.

POPULATION DYNAMICS OF PINE TREE AND BEETLES

- (a) means population pine trees and (b) means pine sawyers in various θ

- H_t when θ=0.9 is very close to the actual density

- θ=0

  $\rightarrow P_t$ increase explosively in 2 years

  $\rightarrow H_t$ decreases rapidly to 0 in 3 years

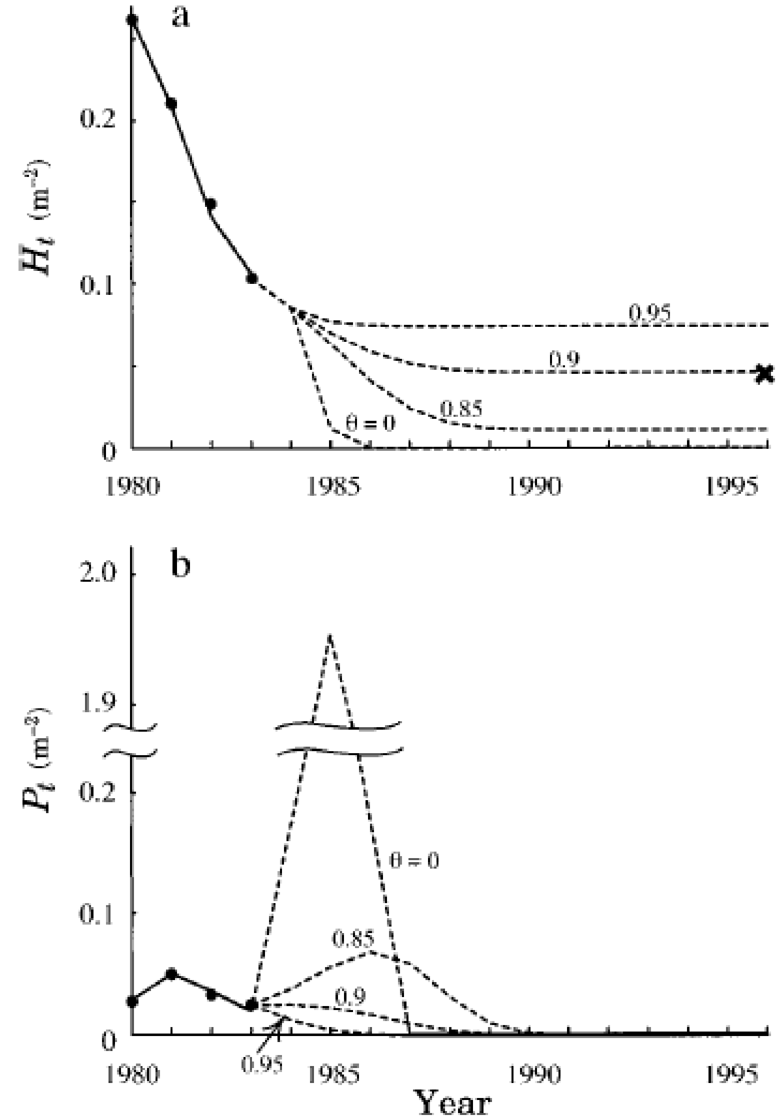


FIG. 5. Population dynamics of (a) pine trees and (b) pine sawyers from 1980 to 1996. Observed data from 1980 to 1983 (●); simulated curves with θ = 0.91 for 1980 and θ = 0.96 for 1981 and 1982 (———); numerical results from the model for θ = 0, 0.85, 0.9, and 0.95 (– – –); healthy pine density observed in 1996 (×).

APPLICATION OF THE MODEL TO INDEPENDENT DATA

- Let's see the utility of this model!

  →It was applied to data in Ibaragi Prefecture

- Almost same!!

- Due to the difference in forest conditions or the method used to count beetles

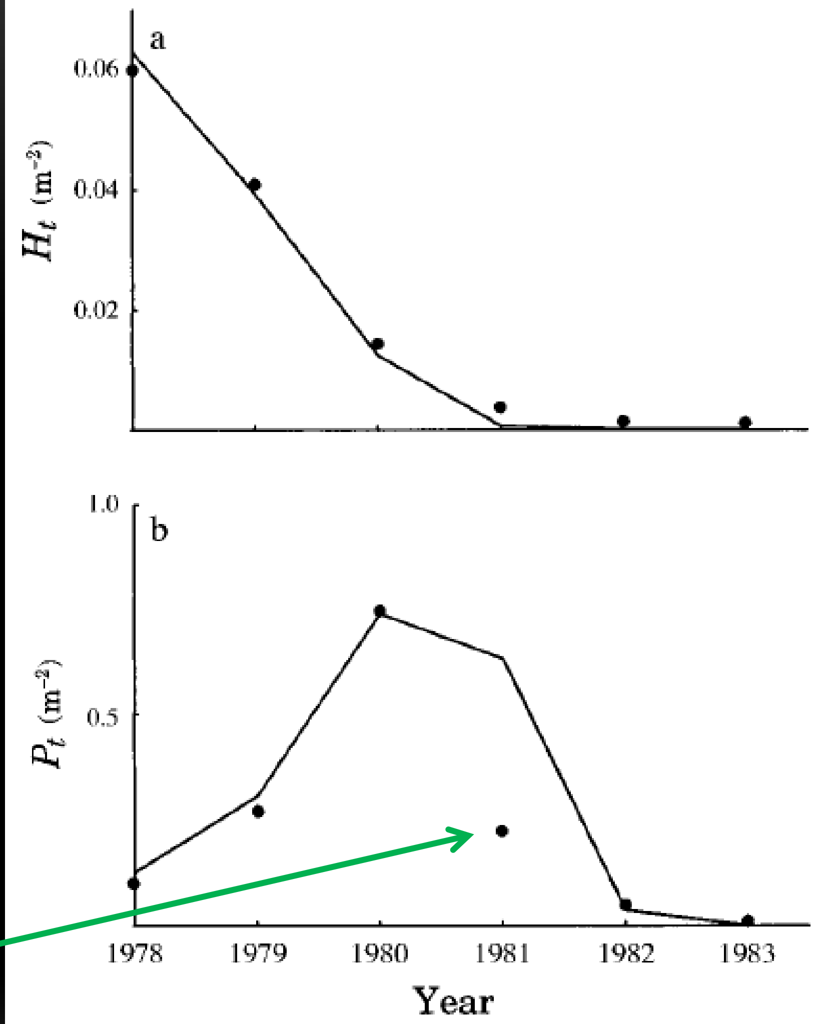


FIG. 8. The incidence of pine wilt disease in a Japanese red pine forest at Naka, Ibaragi Prefecture. (a) Change in the density of healthy pine trees during 1978–1983. (b) Change in the density of adult pine sawyers. Solid circles depict observed data (Kishi 1995); solid lines show simulated curves derived from the present model. Parameters are chosen as $K = 80$, $\sigma = 0.48$, $S = 9.4$, $\alpha = 3.7$, $a = 0.31$.

DISCUSSION

- We cannot use the ∝ as a constant
  - The beetles activity
  - number of nematodes per beetle
  - the susceptibility of the pine tree

  } make ∝ cange

  ↑ make them change

  - Temperature, precipitation, soil condition, air pollution, and so on

- “The studies are under way towards these goal!!”