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FOREST PEST MANAGEMENT STRATEGIES BASED ON COMMUNITY MODELS[1]

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Abstract. In this paper, several models of the dynamics and the interactions between community components of the pine forest are described: the pest population dynamics model (including development - temperature model and population size model), the tree leaf biomass and seasonal dynamics model, the wood volume growth model of pine trees, and models for the interactions between pest and tree, and between pest and pesticide spray. These models are used in management decision analysis. The main damage stages of pine caterpillars to trees are the 4 to 6 instars of larva. The degree of leaf damage has a strong influence on the survival rate of the pest. The wood volume growth rate is slowed after leaf damage. However, because trees of different ages have different resistance, the wood volume losses may differ. Management decisions depend on pest development stage, population level, tree age, leaf biomass and the economics of pesticide spray and wood harvest..

Introduction

Pinus massoniana Lamb is the most common tree in southern China, covering nearly one quarter of the total forest area. A serious problem in these pine forests is the damage by a species of pine caterpillar *(Dendrolimus punctatus* Walker). About 6 million acres are damaged every year. This problem has plagued the forestry industry for many years. Pest control strategies are not successful because good predictions of pest population dynamics are laking, and the degree of harvest losses caused by pest damage remains unknown. So, the forest and farm managements do not know what control method will be 'optimal'.

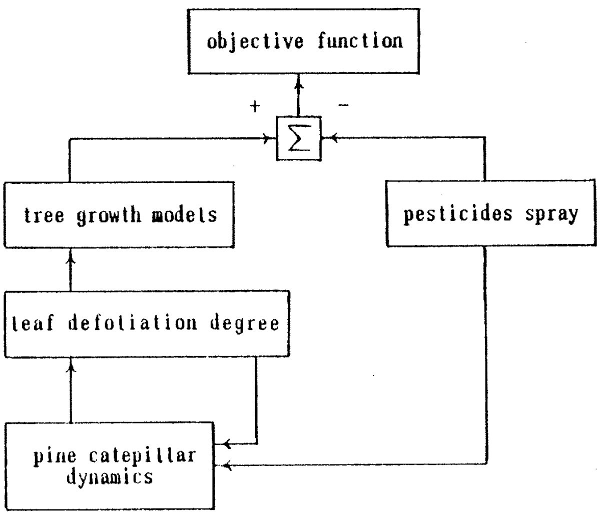

Fig. 1. Outline of the research approach. The model system consists of major components of decision making.

As shown in Fig. 1, our study is mainly on pest population dynamics and pest-tree interaction which aims at giving a good prediction of pest population dynamics and pest damage losses, and suggesting some ways of optimal decision making. We developed the simulation models of pest, tree, and their interactions to be useful in theoretical research as well as in practice.

The population dynamics of *D. punctatus*

Dendrolimus punctatus Walker like many other holometabolous insects has four developmental stages: egg, larva (commonly 6 instars), pupa and adult. When enough food is available, the rate of development depends essentialy on the ambient temperature. Experiments with different temperature conditions have enabled us to develop a linear accumulated degree-day model for simulation. This model is based on threshold temperatures of development and the sum of effective temperatures for instars.

Field populations of *Dendrolinus punctatus* in different stages have different survival rates. They are influenced by environmental factors, such as food availability, weather conditions, natural enemies and control measures. We found that food supply acted as the most important factor affecting the pest population level. Similar result had been suggested by Tsai *et al.* (1961).

Based on field survey data, we developed the following mathematical model for survival rate:

$$R=1-\frac{1-k}{a}\int_{0}^{L} \exp\left(-(L-u)^2/q^2\right) d L$$

where L is defoliation degree, u is a certain value (defo-

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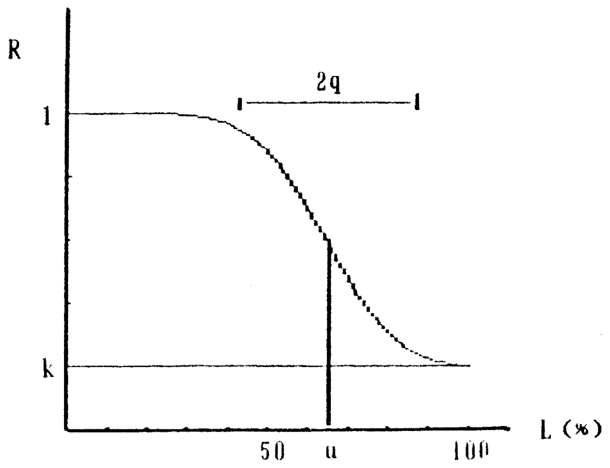

Fig. 2. Relationship between relative survival rate (R) and leaf defoliation degree (L). The survival rate of the pest decreases sharply when the defoliation degree is around a certain value u. k is a minimum survival rate and q the interval on L over which R is reduced from 1 to k.

liation degree), and

$$a=\int_0^{100} \exp\left(-(L-u)^2/q^2\right) dL$$

q is a deviation associated with u. The value of R is from k to 1. The absolute survival rate (Sa) is

$$Sa(g, i)=Sc(g, i)*R$$

where g is the generation and i the instar. The relationship between pest survival rate and the tree damage degree described by this model is shown in Fig. 2. The influence of weather and natural enemies is included in Sc (g, i).

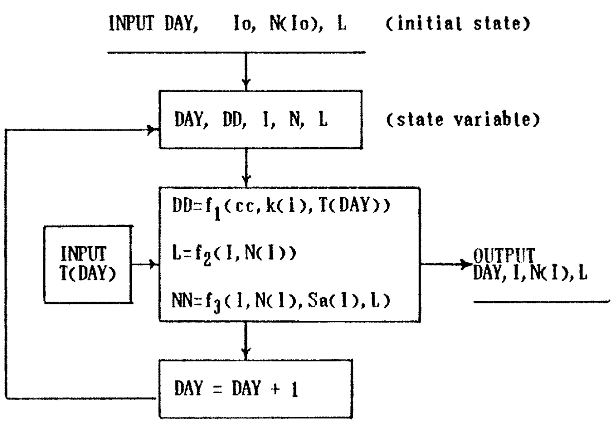

Fig. 3. Outline of the population simulation network. The pest development progress based on environment temperature and the population dynamics based on leaf damage degree are simulated on a daily basis.

The above model is used in the prediction of population dynamics. The computer simulation chart is shown in Fig. 3.

Pine tree growth models

Considering ages less than 20 years, which are the sensitive ages to pest damage, the pine tree growth curve has characteristic exponential shape. The model which fits well the field data is

$$W=2.0897*t^{2.8868}*10^{-5} \qquad r=.9913$$

Where w is wood volume of the individual tree (m^3) and t is tree age (year). W is graphed in Fig. 4.

Under different conditions (soil, geographical location etc.), the parameters may differ, but the shape of the curve is similar.

Leaves are important in the interaction between pest dynamics and tree growth, the relation between tree age t and leaf biomass F is

$$F=862.4*t^{1.7234} \qquad r=.9908$$

which is the average leaf biomass expressed in leaf numbers per tree. The leaf biomass displays seasonal fluc-

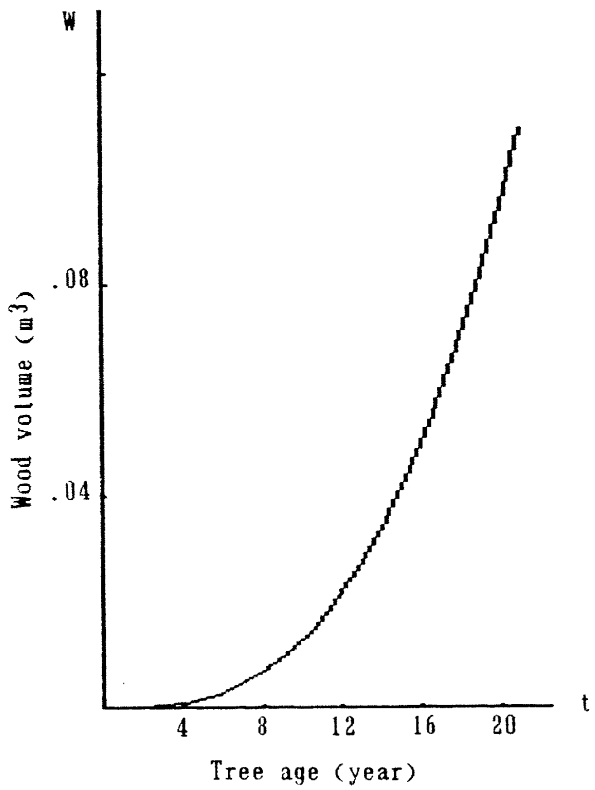

Fig. 4. The simulated growth curve of wood volume (w) in pine on an individual tree basis at given age (t).

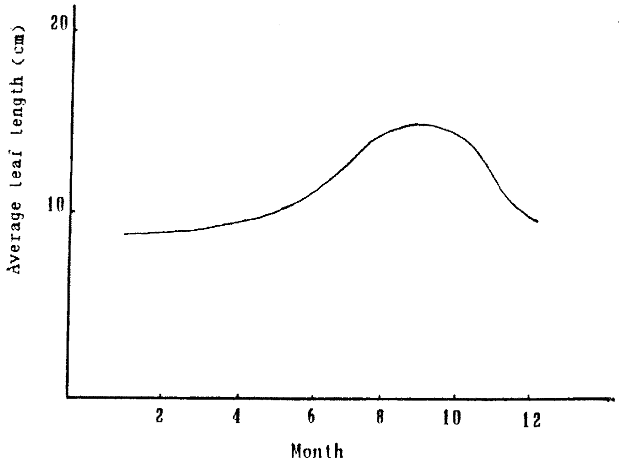

Fig. 5. The seasonal dynamics of leaf length, showing the average length of leaves of the current year and the former year.

tuation, and generally the life span of a leaf is two years. The average leaf length is shown in Fig. 5.

Li qianshen *et al.* (1987) concluded based on field survey that the effect of pest damage on the growth rate of wood volume for trees less than 10 year old is

$$D=(0.4617-0.03696*t)*L^2$$

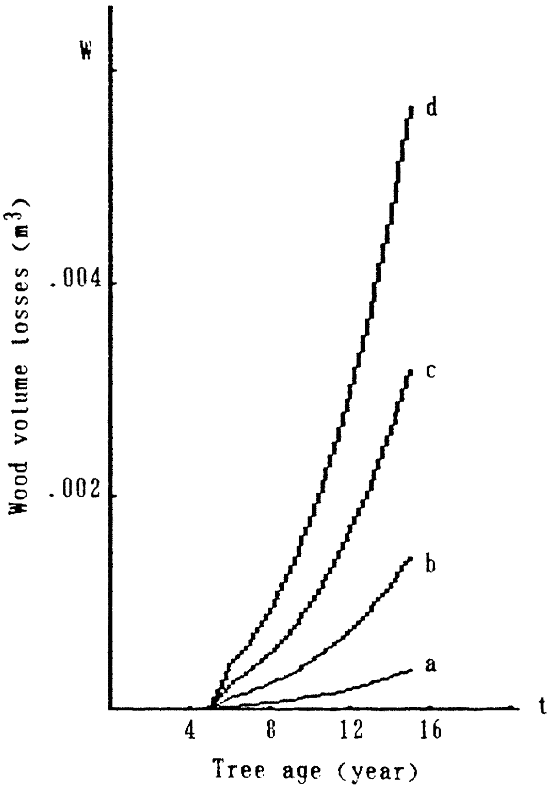

Fig. 6. Wood volume losses caused by pest damage of different degrees at damage age t = 5. Damage degrees are respectively, a: 25%, b: 50%, c: 75%, d: 100%.

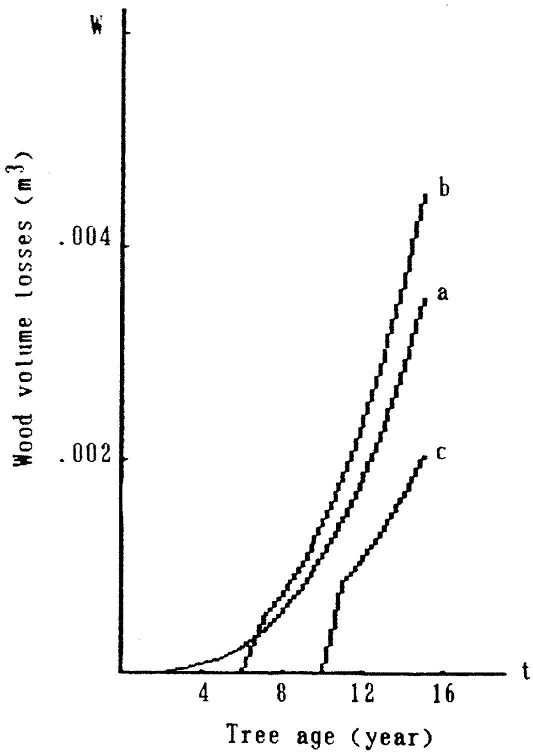

Fig. 7. Wood volume losses caused by pest damage at different ages. Damage degree is 50%. Damage ages (t) are respectively, a: 2, b: 6, c: 10.

D is the decrease of wood growth rate and L the defoliation degree of tree at tree age t.

The growth rate is not affected by defoliation in the former years. Thus the wood growth rate is:

$$G=(1-\frac{1}{t})^{2.8868}-1-D$$

Based on this, we can carry out simulations of tree growth. Fig. 6-7 shows the various growth curves resulted from such simulations.

The harvest losses of wood caused by pest damages can also be simulated. Suppose a tree at age 20 would be harvested. The wood volume losses for this caused by pest damage are shown in Fig. 8 which illustrates that the harvest wood losses differ significantly with different damage ages and the most severe damages occur at the ages from 4 to 6 years. This result is important in managment decision making.

Management decision making

With the above model, we can investigate the economics of pest damage and the optimal decision making by means of computer simulation (Li Dianmo *et al.* 1983). The structure of the decision support system is shown in Fig. 9.

The computerized decision support system in Fig. 9

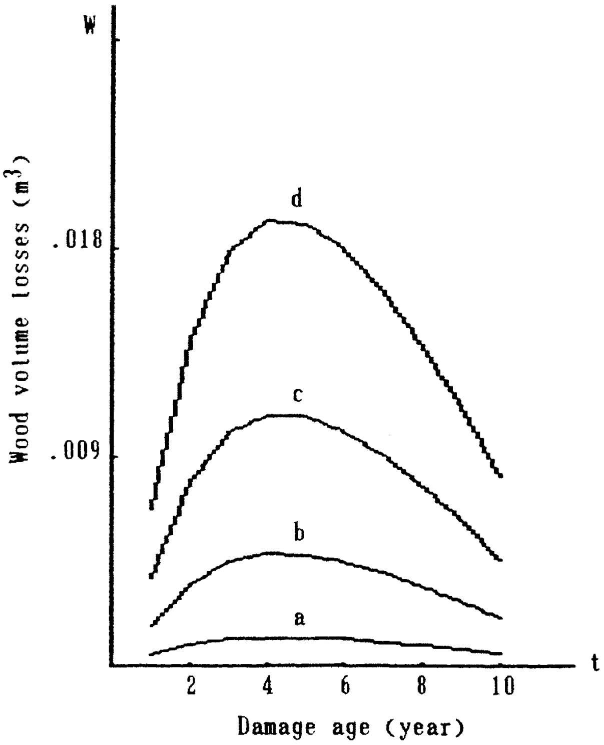

Fig. 8. Harvest wood volume losses of pine caused by pest damage at different ages (t) and by different degrees. Damage degrees are respectively, a: 25%, b: 50%, c: 75%, d: 100%.

is able to output optimal decisions based on economic aims and state of pest and tree. According to models presented above, the losses of wood volume at harvest year will be

$$V\,(T)=0.000020897*T^{2.8868}/((1+\frac{1}{t})^{2.8868})*D$$

$$=f\,(t,\,T)*D$$

where T is the harvest age of tree and t the age at which the pest damage occurs. If control measures are taken, the income will be:

$$I=P*\,(1+e)^{(t-T)}*f\,(t,\,T)*(Dn-Dc)$$

where P is wood price, e the interest rate, and Dc and Dn the value of D under conditions with control and withut control respectively. Suppose the control measure has a cost function as follows:

$$C=B+m*n^{i}$$

where B is the average labour cost, i pest instar, m and n parameters. This model is based on the fact that the later instars of the pest require more pesticides. The objective function is

Max: I—C

Consider the following situation: B=.03, m=.005,

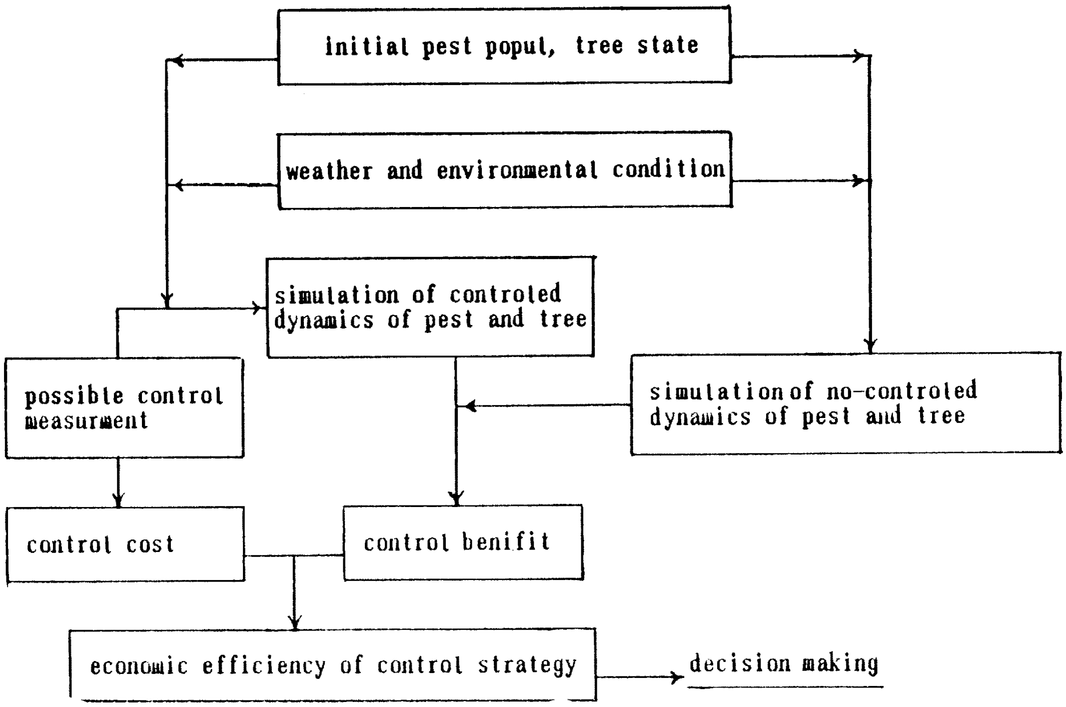

Fig. 9. Decision support system of optimal management.

P=400, T=20, n=2, g=2 and the initial pest population level N(1)=900, initial leaf damage degree is L=50%, damage age of the tree is t=5. Based on the above simulation models we can work out the economic evaluation for a particular control strategy. For example, when pesticide spray is at the 4th instar, the expected benefit will be .619 yuan, but if at the 6th instar the benefit will be . 379 yuan. So the earlier spray would give higher benefit. Similarly, we can investigate the economics of control strategies at different pest population levels, different pesticide spray, and so on.

Conclusions

The main conclusions are as follows:

1) The pest population size is greatly influenced by the degree of tree defoliation, which implies the cause of the periodical pest outbreaks.

2) Pine trees of age 4 to 6 years are most sensitive and require control measures.

3) Since larvae in later instars are more resistent to pesticides, earlier control will be more economic.

4) If the pest population is at a low level, it may be wise not to implement controls.

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