FIR SAWYER BEETLE-SIBERIAN FIR INTERACTION MODELING: RESISTANCE OF FIR STANDS TO INSECT OUTBREAKS

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INTRODUCTION

Entomological monitoring is part of a total ecological monitoring system. Its purpose is the identification, prognosis, and estimation of forest ecosystem impacts induced by insects. The entomological monitoring of a forest is based on a clear understanding of the role played by insects in forest ecosystems. The patterns of insect population dynamics in space and time have to be discovered. Mathematical models can be used to make a prognosis and determine the components and parameters of a given system.

SAWYER BEETLE BIOLOGY

After monitoring fir forests in the northeastern part of the U.S.S.R., we present here a mathematical model describing an outbreak of *Monochamus urussovi* Fisch. (Cerambycidae: Coleoptera). It is known that food availability is the major factor determining population density of this sawyer beetle and other xylophages. Sawyer beetles generally colonize only weak and dying trees, where the larvae of this species develop. The adult insects feed in the crowns on the thin bark of branches, and in so doing causes branches to dry out. When the feeding damage is considerable, the tree weakens and becomes suitable for oviposition and larval feeding. In a resistant forest ecosystem, the variations in sawyer beetle populations are determined by the variations in availability of weakened trees for infestation. Population density is regulated by the negative feedback principle. The population was in a stable state at the time of our study. During a sawyer beetle outbreak the high beetle numbers decrease the resistance of normally vigorous trees, and this positive feedback results in expansion of the outbreak area. If the process of forest destruction is stabilizing, the sawyer beetle population achieves a hyperstable state.

MODELING BEETLE-STAND INTERACTIONS

Our simulation model of the "stand-beetle" system takes into account patterns of interaction between sawyer beetles and separate fir trees at different stages of damage. The system variables are: number of imagos (N), food supply (F) for imago, and food supply for larvae (D). A system of three discrete equations describes the interaction of insects with separate trees. The beetles colonize the most attractive trees surrounding the one from which they have emerged. The attractiveness of a tree is a function of the extent of damage to the tree by the beetles and is determined from the

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experimental data. The parameters of the system are 1) the dimensions and condition of the tree, 2) the time when the tree is suitable as a food resource, 3) survival during ontogenesis, 4) fecundity, 5) sex ratio, 6) time of pre-imago development, and 7) migration characteristics.

The model is solved through a set of computer programs. Simulation experiments allow us to study the dynamics of a system in space and time. The system may be in one of two states: stable or hyperstable. Transition from one state to another is related to the transition of the parameter values from below to over threshold values. We have shown that the stable state of a system is achieved as a result of natural random dying of trees. The hyperstable state takes on the form of running waves of sawyer beetle densities and food resources. Threshold values exist for the initial imago density, annual rate of food consumption per one beetle (Ro), initial food resources, and some others. Crossing of a threshold transforms a system from a stable state into a hyperstable one.

We have found that a metastable state can occur only in stands with a certain defined structure. A tree is suitable for colonizing when the ratio of damage by beetles to the crown during adult feeding is greater than a critical ratio. This critical ratio depends on the values of N, F, and Ro. The greater the ratio between imago density and food supply in the crown, the greater the probability of positive feedback in the system, and, consequently, of an outbreak.

In the hyperstable state, the number of emerged imago at some selected part of the forest is determined by the total identifiable food supply for larvae. This number was obtained from the experimental data on the relationship between the number of emerging imagos and tree diameter (d) and is equal to $\sum_{i=1}^{n} k_i(d)$, where $k_i(d)$ is the number of imago emerging from the tree with diameter, d, and n is the number of trees in the given part of the forest. The food supply for imago in the same part of the forest is equal to $\sum_{i=1}^{n} F_i(d,P)$, where F(d,P) is the food supply in the crown of a tree with diameter, d, and P is the stand density. We have introduced the parameter, $\eta = \Sigma k_i / \Sigma F_i$, to characterize fir stand resistance to sawyer beetle damage. Classifications of stable and unstable stands are made using this parameter. Increase in the mean diameter and density of a stand indicates an increase in the probability of an outbreak.