THE EFFECT OF DISTURBANCE FREQUENCY ON FOREST SUCCESSION IN THE PACIFIC NORTHWEST

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ABSTRACT

A computer model of forest succession has been adapted for the Pacific Northwest to include fire, windstorms, and clearcut logging. The simulation experiment consists of having each of these disturbances occur at different frequencies to a 500 year old stand on the western Olympic Peninsula. The model is run for 480 years, and leaf area, basal area, diameter distributions and Douglas-fir biomass are compared. Each disturbance results in unique patterns of stand development. The model is a useful tool for examining long-term stand dynamics.

INTRODUCTION

Forest structure is partially dependent upon the disturbance history of a site and the species which invade following a disturbance. The disturbance type, severity and frequency as well as the existing forest structure can affect species diversity and dominance and stand physiognomy changes over time (Oliver 1981, White 1979, Henry and Swan 1974). In the Pacific Northwest predominant natural disturbances are fire and windstorms. Clearcut logging is a common human disturbance.

Studies of disturbance effects have largely concentrated on particular types of disturbances (e.g. Heinselman 1970, Stephens 1956, Hemstrom and Franklin 1982) or on patterns of recovery subsequent to a single event (Connell and Slatyer 1977, Drury and Nisbet 1973, Egler 1954). Nevertheless it is recognized that vegetation patchiness is in part related to frequency and severity of disturbances (Whittaker and Levin 1977, Levin and Paine 1974).

This paper investigates the influence of disturbance frequency using a model of forest succession in the western Oylmpic Peninsula of Washington state. The simulation projects stand development in a 500 year old upper slope forest that is subjected to clearcut logging, fire and windstorm at different frequencies. The effects of a single event clearcut, fire, windstorm and biological disturbance to a 500 year old stand on the Olympic Peninsula have been examined.[1] When Douglas-fir (Pseudotsuga menziesii) occurs in a projected stand, it dominates stand dynamics. After all Douglas-fir have died, western hemlock (Tsuga heterophylla) and silver fir (Abies amabilis) form the long term stable forest. An increase in leaf area accompanies the transition from Douglas-fir to hemlock dominance. The number of Douglas-fir surviving a disturbance seems to be a good indicator of the long term effect of that disturbance.

The frequency of natural disturbance events depends upon different factors for each disturbance. Fire frequency in a stand is related to climatic conditions, fuels and ignition source availability (Martin 1982). The occurrence of windthrown trees is influenced by weather, substrate, topography and state of the vegetation (Webb 1958).

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[1]/ Dale, V.H., M.A. Hemstrom and J.F. Franklin. Modeling the long term effects of disturbances of forest succession on the Olympic Peninsula, Washington. Manuscript.

MODEL FRAMEWORK

A computer model called CLIMACS simulates forest succession in the Pacific Northwest on a one-fifth hectare plot. CLIMACS was constructed by modifying the FORET forest succession model developed by Shugart and West (1977) for eastern Tennessee. The environmental driving variables of the model are the temperature growth index (Cleary and Waring 1969) and plant moisture stress (Waring and Cleary 1967). The salient features of the CLIMACS model (Hemstrom and Adams 1982) are:

1. Twenty-one Pacific Northwest tree species are included.

2. Forest succession can be examined for an unlimited time period; so that long term stand dynamics can be explored.

3. The model can be initiated with a bare plot or with the characteristics of a measured stand.

4. Regeneration, growth and death of each tree depend on existing stand structure, environmental conditions and species characteristics.

5. Fires, windstorms, outbreaks of pathogenic organisms and clearcut logging can occur at user-specified frequency and severity.

6. Nutrient status information for the site are not included in the model.

7. The stochastic nature of the model allows for variation in climatic conditions and its effect upon tree growth.

A simulation experiment was designed to examine the effects of natural and human disturbances at differing frequencies and severities. The model stand was initiated with the characteristics of a measured 500 year old stand which has a leaf area of 11.2 m^2/m^2 and basal area of 81.5 m^2/ha.[2] Stand characteristics were projected for 480 years (980 years total stand age). Modal simulation runs are presented; so that the variations which would be observed in a natural stand are apparent. Moderately intense windstorms were simulated at 60 and 120 year frequencies (fig. 1, table 1). Understory western hemlock and silver fir are released by canopy opening and quickly fill the regeneration layer following a windstorm. Moderately intense fires were simulated at 120, 240 and 480 year return intervals. In the simulation trees die following a fire in inverse proportion to their diameter (fig. 1). Probability of death is species specific (table 1). Clearcut logging occurs at a rotation interval of 60 years, and the stand is planted with Douglas-fir saplings (1250/ha).

RESULTS AND DISCUSSION

Without disturbance, Douglas-fir remain in the projected stand until 810 years (figure 2). With the death of the last Douglas-firs, the suppressed hemlocks and silver fir are released. The ensuing western hemlock - silver fir stand stabilizes by stand age 900. Both basal area and leaf area in the climax forest are substantially higher than in the Douglas-fir forest (table 2).

The clearcut simulation is dominated by Douglas-fir throughout the run. Frequent cutting and replanting of Douglas-fir does not allow any other species to enter the canopy. Both leaf area and basal area remain

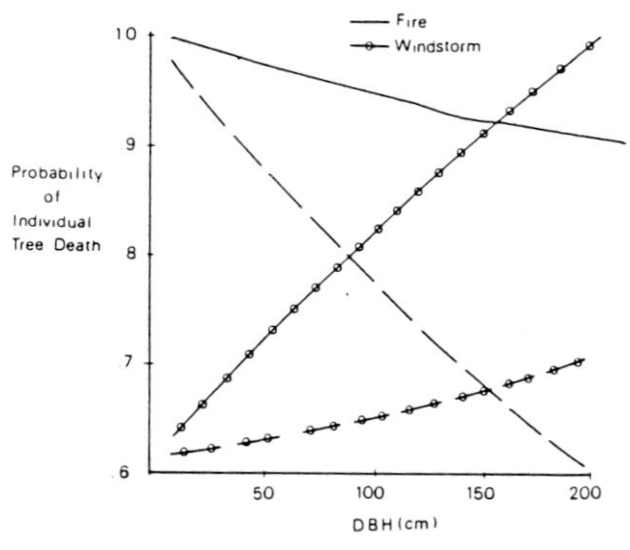

Figure 1.--The curves used in CLIMACS for the probability of a tree dying following a moderate fire and windstorm as a function of tree diameter for disturbance-tolerant species (dashed line) and for disturbance-intolerant species (solid line). *Abies amabilis*, *Tsuga heterophylla* and *T. mertensiana* do not survive the fire in the model.

2/ Unpublished data provided by J. Agee and M. Huff, College of Forest Resources, University of Washington, Seattle, Washington.

Table 1.--Disturbance tolerance categories for the species in the CLIMACS model based upon Minore (1979).

Species	Fire[1]	Wind[2]
Abies amabilis	0	2
Abies grandis	2	2
Abies lasiocarpa	2	2
Abies procera	2	2
Acer macrophyllum	1	2
Alnus rubra	1	2
Arbutus menziesii	1	2
Calocedrus decurrens	1	2
Castanopsis chrysophylla	1	2
Chamaecyparis nootkatensis	1	2
Picea engelmannii	1	1
Picea sitchensis	1	1
Pinus contorta	1	2
Pinus lambertiana	2	2
Pinus monticola	1	2
Pinus ponderosa	2	2
Pseudotsuga menzeisii	2	2
Quercus garryana	2	2
Thuja plicata	1	2
Tsuga heterophylla	0	1
Tsuga mertensiana	0	1

[1] Tolerance to moderate fire level is a function of DBH and species (larger trees and thick-barked species are more likely to survive a fire): 0 - no individuals survive, 1 - some individuals survive, and 2 - most individuals survive.

[2] Shallow rooted species prone to windthrow are ranked 1. Deep rooted species less susceptibly to windthrow are ranked 2.

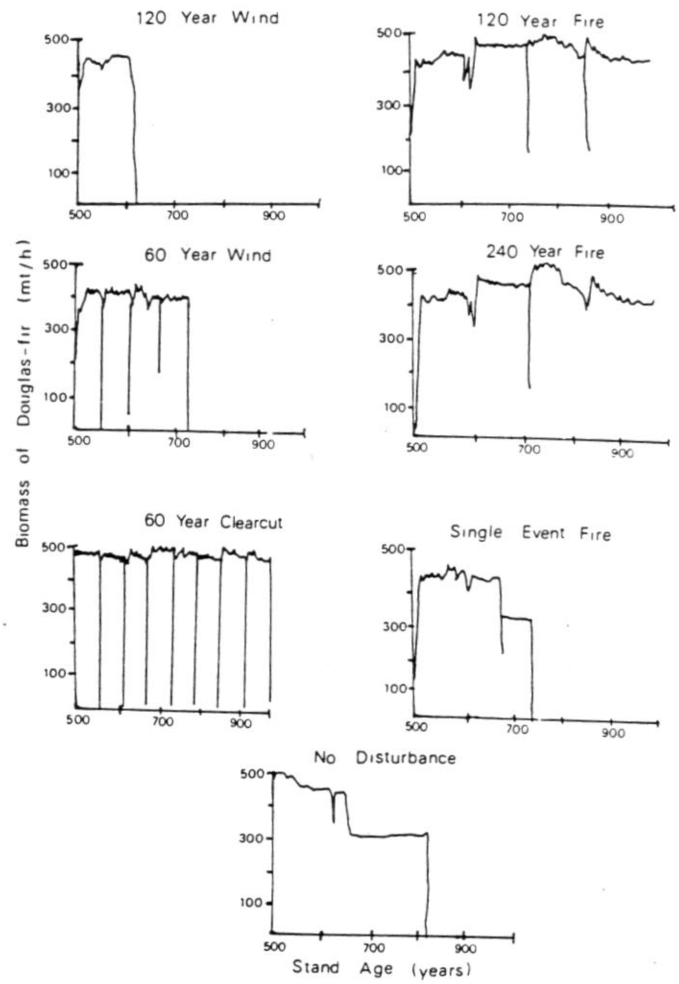

Figure 2.--Douglas-fir biomass for an undisturbed forest, clearcut logging at 60 year rotations and moderately intense windstorms and fire. The disturbance occurs at stand age 500 and thereafter at different frequencies thereafter. Due to the compressed time scale, the lag in biomass development following a disturbance is not apparent.

relatively low due to Douglas-fir dominance (table 2). The diameter distribution (figure 3) supports Ford's (1975) claim that the size frequency distribution for dense even-aged stands are bimodal, presumably a result of self-thinning.

Intense windstorms on 60 and 120 year cycles topple all the Douglas-fir before the end of the 480 year period. Western hemlock up to 120 cm DBH and silver fir as large as 90 cm are dominant. Leaf area and basal area are relatively high, reflecting the dominance of shade tolerant species.

A few Douglas-fir survive the moderately intense fires simulated. As fire becomes more frequent, the stand becomes sufficiently open for Douglas-fir to regenerate. Under these conditions, Douglas-fir dominates stand dynamics throughout the projection period. For the single fire event, however, the surviving Douglas-fir are dead by stand age 850. Leaf area and basal area increase with increasing time since the last fire, reflecting accumulation of shade tolerant trees in the stand. Leaf area changes and species biomass dynamics are similar for the 120 and 240 year fire frequencies, but fewer, larger Douglas-fir dominate the stand under the 240 year fire frequency.

Table 2.--Stand characteristics of a 980 year old forest from CLIMACS simulations initiated with the attributes of a 500 year old stand and which have different disturbance type and frequency.

Disturbance Type	Period (years)	Leaf Area (m^2/m^2)	Basal Area (m^2/h)
Clearcut	60	10.4	77.7
Wind	60	16.7	115.6
Wind	120	15.1	111.7
Fire	120	7.8	72.3
Fire	240	13.4	78.8
Fire	480	15.8	112.3
None	--	16.4	113.9

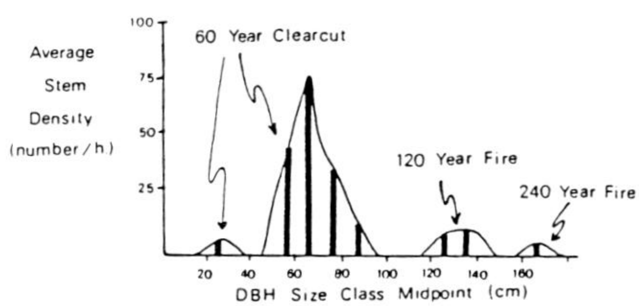

Figure 3. Douglas-fir diameter distributions for a 980 year old stands following clearcutting every 60 years, and fire on 120 and 240 years cycles. No Douglas-fir remained for any other disturbance type and frequency projected.

THE VALUE OF SUCCESSION MODELS

Long-term succession models provide a means of organizing existing information and highlighting missing information. Simulation experiments suggest where the system is most sensitive and provide a first testing ground for hypotheses.

Information from ecological literature and research provides the life-history characteristics for individual species used in the growth, birth and mortality equations and in structuring the model framework of CLIMACS.[3] If the simulation results match stands that have been measured, we have some reason to believe that our hypotheses about the way trees grow and interact arecorrect. If the results are in error, either we do not understand how stands grow or we did not link the information together correctly in the model. In either case, the model provides a testing ground for current stand dynamics hypotheses and shows where we can improve our understanding.

For Pacific Northwest forests, the characteristics of old trees are largely unreported. For example, there is no published relationship between stem diameter and leaf area for very large trees.

This simulation experiment shows that frequent windstorms hasten climax stand development while frequent fires delay it. For frequent fires, Douglas-fir survive and are able to regenerate in the high levels of light penetrating to the forest floor. As fire fequency decreases, the forest comes closer to a climax state between fires. Following windstorms, suppressed hemlocks and silver fir fill the canopy gaps eventually eliminating Douglas-fir from the forest.

The experiment was done to test the hypothesis that long-term stand structure is independent of disturbance frequency. That hypothesis was rejected. For the no disturbance simulation, the death of the last Douglas-firs allows the development of climax western hemlock - silver fir forest with high leaf area and basal area. Similarly, the windstorms and single event fire create conditions under which Douglas-fir eventually drop out of the stand. The 120 and 240 year fire cycles, however, allow Douglas-fir to dominate the stand for the entire simulation period. The 60 year rotation clearcutting regime produces even-aged Douglas-fir stands with a normal diameter distribution. This model does not include dead wood or nitrogen dynamics which would undoubtably influence long-term forest structure.

3/ Dale, V.H. and M.A. Hemstrom. In preparation. Documentation of CLIMACS: Computer Linked Integrative Model for Assesing Community Structure. USDA Forest Service Research Report.

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