

PLANT COMMUNITY DISTRIBUTION AND DYNAMICS IN

BRYCE CANYON NATIONAL PARK

Yearend Report for Year One

May 1986 - April 1987

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See also NRBIB: BRCA-0035 for the final report. A research proposal for this report is located in the Chief Resource Management Specialists Office, five drawer file cabinet, first drawer. File folder is labeled, "Fire Research". A file folder including correspondence, another two copies of this report, and notes pertaining to this study are available in BRCA Chief Resource Management Specialists Office, second five drawer file cabinet, third drawer, file folder is marked, "Dave Roberts, Research-Vegetation/Fuels". There are two more copies in the same office, second wooden shelving unit, fourth shelf.

Citation Abstract:

The overall objective of this research is to develop a comprehensive vegetation classification to characterize the distribution and dynamics of vegetation in Bryce Canyon National Park. The project was initiated in May 1986, and scheduled for completion in April 1988. This report documents our progress to date, and refined objectives for the second year of research. It should be noted that the original proposal outlined two years of research, with separate objectives for each of the two years.

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Bryce Canyon NP**Park Specific Notes Regarding this Citation:**

This report details the progress of one year of this project and lists objectives for the second year. The overall objective of this project is to develop a comprehensive vegetation classification of the plants in Bryce Canyon National Park.

Park Specific Citation Abstract:

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INTRODUCTION

The overall objective of this research is to develop a comprehensive vegetation classification to characterize the distribution and dynamics of vegetation in Bryce Canyon National Park. The project was initiated in May 1986, and scheduled for completion in April 1988. This report documents our progress to date, and refined objectives for the second year of research. It should be noted that the original proposal outlined two years of research, with separate objectives for each of the two years.

OBJECTIVES

The general objectives of the research are:

- 1) To develop a comprehensive vegetation classification for all stages of vegetation development for all lands in Bryce Canyon National Park
- 2) To classify and map the land area as to current vegetation type (community type) and potential vegetation type (habitat type)
- 3) To construct a vital attributes successional model which relates the successional pathways and disturbance pathways from each community type to other community types and the climax type
- 4) To determine the habitats and plant communities in which rare or endangered plants occur, and using the community pathway models, to determine the influence of succession, disturbance, or Agency management on the possible distribution of these species
- 5) To identify and map undisturbed plant communities to serve as baseline reference areas.

RESEARCH STATUS

The research status is listed here by objective as numbered above.

- 1) To develop a comprehensive vegetation classification for all stages of vegetation development for all lands in Bryce Canyon National Park

We have developed a comprehensive vegetation classification for all forested vegetation in the Park. All forested vegetation types have been identified to habitat type, and for each habitat type a successional community classification has been developed following the guidelines of Steele (1984). Experience has shown that the forest habitat types as defined by Youngblood and Mauk (1985) are in reasonable agreement with the vegetation of Bryce Canyon National Park, and the creation of any new forest habitat types will not be required. Table 1 lists the habitat types, the number of plots in each type, and the relative distribution of community types within the habitat type where the number of plots equals 4 or more.

For the forested portion of the Park, the distribution of habitat types is relatively well known. The Park contains five series: Pinus ponderosa, Pseudotsuga menziesii, Picea pungens, Pinus flexilis - Pinus longaeva, and Abies concolor.

Our general understanding at this point is that the habitat types are distributed according to available soil moisture, soil drainage, exposure, and precipitation inputs. Low elevation sites fall into the PIPO/ARNO, PIPO/PUTR, and PIPO/ARPA habitat types. PIPO/ARNO reflects lower timberline and toe slopes within the plateau area, where the soils are generally alluvial, and partly saturated for part of the season, while being well-drained to excessively well-drained at other points in the year (A. Winward, personal communication, Youngblood and Mauk 1985). PIPO/PUTR occupies benches and toe slopes where soils are well drained, on sites that are relatively cool for

BRYCE CANYON

TABLE 1

Sample Plot Habitat Types and Community Types (where $N \geq 4$)

For each habitat type, the number of sample plots is listed. When the number of sample plots is four or greater, the community types within that habitat type are listed, and the relative abundance of each community type is listed.

PIPO/ARNO	N = 2	ABCO/JUCO	N = 4
PIPO/PUTR	N = 3	PIFL/PIFL	0.22
PIPO/ARPA	N = 17	PIFL/ABCO	0.78
JUSC/PIPO	0.62	PIPO/PIPO	0.63
PIPO/PIPO	16.38	PIPO/PSME	0.42
		PIPO/PIPU	0.37
		PIPO/ABCO	1.58
PSME/ARPA	N = 19	ABCO/BERE-BERE	N = 11
PIFL/PIFL	0.59	POTR/POTR	0.13
PIFL/PIPO	1.33	POTR/PIPO	0.25
PIFL/PSME	1.09	POTR/ABCO	0.63
PIPO/PIPO	11.10	PIFL/PIFL	0.05
PIPO/JUSC	0.47	PIFL/PSME	0.62
PIPO/PSME	4.47	PIFL/ABCO	0.32
PSME/BERE-PIPO	N = 2	PIPO/PIPO	1.50
PIPU/JUCO	N = 2	PIPO/PSME	2.97
		PIPO/ABCO	4.53
ABCO/ARPA	N = 19	ABCO/BERE-JUCO	N = 2
PIFL/PIFL	0.33		
PIFL/PIPO	0.90		
PIFL/PSME	0.98		
PIFL/ABCO	0.71		
PIPO/PIPO	7.01		
PIPO/PSME	3.22		
PIPO/JUSC	0.09		
PIPO/ABCO	5.11		
PSME/PSME	0.25		
PSME/ABCO	0.75		

this elevational zone. PIPO/ARPA generally occupies lower and mid-slopes which are well-drained and warm, or subject to high evaporative demand.

With increasing available moisture, Pseudotsuga menziesii becomes the climax dominant. The majority of the Pseudotsuga menziesii series is in the PSME/ARPA habitat type. These sites are similar to the PIPO/ARPA habitat type, but apparently have greater moisture availability at lower points of the rooting zone.

With additional moisture, Abies concolor becomes climax, with a total of four habitat types and phases represented. The minimum moisture requirement of Abies concolor appears to be very similar to Pseudotsuga menziesii in Bryce Canyon National Park, so that climax Pseudotsuga forests often occupy a relatively narrow band between the Pinus ponderosa series and the Abies concolor series. Relatively warm dry sites within the Abies concolor series are in the ABCO/ARPA habitat type, with understories similar to the PSME/ARPA habitat type, although supporting somewhat greater cover. Intermediate sites are occupied by ABCO/JUCO, with more mesic sites occupied by ABCO/BERE.

The Picea pungens series, with the PIPU/JUCO habitat type, appears to occupy a unique topo-edaphic site characterized by coarse colluvial soils and accumulation of cold air drainage. These sites typically occur on toe slopes of mountains or ridges facing into narrow canyons. The Pinus flexilis - Pinus longaeva series also occupies unique topo-edaphic sites. These sites are generally extremely exposed, and occur on coarse colluvial soils with excessive drainage.

While the defined habitat types appear to fit relatively well, some modification of the distribution of seral tree species may be indicated.

Youngblood and Mauk (1985) apparently never observed Pinus edulis in the PIPO/ARPA habitat type (Appendix B, pg. 68), whereas we observe this species in the dry end of the type. Youngblood and Mauk employed an arbitrary cutoff point of 25% crown cover for sampling, where some of our samples may support lower cover. Essentially, the PIPO/ARPA type in Bryce Canyon National Park appears to grade into the Pinus ponderosa - Pinus edulis - Juniperus scopulorum woodlands at lower elevations, and accordingly some of the drier plots contain scattered Pinus edulis.

Youngblood and Mauk (1985) also list Juniperus scopulorum as a minor co-climax species in the PSME/ARPA and ABCO/ARPA habitat types. While Juniperus scopulorum does occur in these types in Bryce Canyon National Park, we have never observed this species in the absence of other seral conifers. It seems likely that crown closure sufficient to exclude Pinus ponderosa and Pinus flexilis from these stands would also exclude Juniperus scopulorum, but we have been unable to determine whether or not this is true. Consequently, in the preliminary community type classifications, Juniperus scopulorum is treated as a potential co-climax as indicated by Youngblood and Mauk.

We have developed community type classifications for all forested habitat types, and all sample plots have been classified to community type. We have modified the guidelines of Steele (1984) to better implement a successional pathway model which is superimposed on the classification. The general approach is to identify the least shade tolerant species with significant basal area in the stand as the indicator species. The community types are then derived by assigning plots a membership value in seral classes which reflect the indicator species and the relative abundance of the other species in the stand. The method employs fuzzy set theory as the underlying

mathematics of the model to classify seral stands by membership in fuzzy sets representing successional stages. This approach allows efficient use of field data, and provides a natural interface to a modeling approach. The details of this approach were presented by Roberts (1986).

The community type classifications indicate that the majority of the forest vegetation in Bryce Canyon National Park should be considered as mid-seral. In the majority of stands, the climax tree species is established and occasionally dominant, but generally seral species are still well represented. Table 1 lists the relative abundance of each successional type within the appropriate habitat type where the number of plots equals four or more.

In general, the great majority of Bryce Canyon National Park is wooded or forested, and is included in the forest habitat type classification. Areas not included are:

- 1) Artemisia nova - grasslands in alluvial valleys within the Park
- 2) Pinus ponderosa - Pinus edulis - Juniperus scopulorum communities on the north and east boundaries of the Park
- 3) Badlands and Breaks within the Park

We have identified eight ecological site types within these areas as the types are currently defined by the SCS draft ecological site type classification. Many of these types differ only in characteristics of the soil, however, and support very similar plant communities. Unfortunately, the SCS has made very little progress in refining the draft types. Additionally, the types are difficult to use in combination with the forest habitat types due to a different methodology of classification.

Accordingly, we have chosen to develop non-forest habitat types for these vegetation types from data collected during the second field season. We are currently intensively sampling these areas for the development of a classification system which is in better agreement with the methodology and procedures used in the forest habitat type classification. These non-forest habitat types will then be cross-referenced to the draft SCS types, rather than derived from them. This approach offers the advantage of greater uniformity of classification, allows us to complete the work independent of the pace of the SCS, and still allows us to incorporate data included in the draft types where possible.

2) To classify and map the land area as to current vegetation type (community type) and potential vegetation type (habitat type)

During the first field season, approximately 15000 acres of the Park, representing numerous individual stands, were ground-truth mapped. These stands were combined with sample plot data and overlaid on soils maps to create a data base suitable for statistical analysis of habitat type distribution, and to develop a predictive model of habitat type distribution. The predictive models were developed only for habitat types which are sufficiently abundant to have numerous samples. Relatively uncommon habitat types will have to be managed as special cases. Analysis has consisted of linear discriminant analysis and classification and regression tree (CART) analysis (Breiman et al. 1984).

The procedure is first to predict which of three series (PIPO, PSME, or ABCO) a specified stand belongs to. This is accomplished with a probabilistic linear discriminant function based on elevation and radiation budgets (Figure 1). N-fold cross-validation attempts demonstrate that the

FIGURE 1

EXTRAPOLATIVE MAPPING GUIDES

- 1) determine appropriate series by calculating maximum probability function:

$$\text{Probability} = \text{elevation} * c1 + \text{solar radiation} * c2 + \text{constant}$$

Series	c1 elevation	c2 solar radiation	constant
PIPO	0.080	0.125	-369.0
PSME	0.085	0.103	-393.0
ABCO	0.090	0.096	-429.0

Cross-validation data:

	predicted		
actual	PIPO	PSME	ABCO
PIPO	29	4	1
PSME	5	11	7
ABCO	1	3	46

- 2) PIPO series habitat type key

	HT	correct
A) slope less than 3%		
B) permeability greater than moderate	PIPO/ARNO	(2/2)
B) permeability moderate or less	PIPO/PUTR	(4/4)
B) permeability moderate or less	PIPO/PUTR	(4/4)
A) slope greater than 3%		
C) soil organic matter less than 4.75%		
D) solar radiation greater than 960 langleys	PIPO/ARPA	(2/2)
D) solar radiation less than 960 langleys	PIPO/PUTR	(2/2)
C) soil organic matter greater than 4.75%	PIPO/ARPA	(20/23)

- 3) ABCO series habitat type key

	HT	correct
A) slope position lower slope or bottom	ABCO/BERE	(5/5)
A) slope position not lower slope or bottom		
B) c-horizon pH greater than 7.6		
C) slope greater than 19%		
D) soil depth greater than 30 inches	ABCO/BERE	(9/15)
D) soil depth less than 30 inches	ABCO/ARPA	(17/17)
C) slope less than 19%	ABCO/BERE	(3/3)
B) c-horizon pH less than 7.6	ABCO/ARPA	(8/8)

discriminant function has an apparent accuracy of 80%. The PSME series is problematic, in that more plots than expected are predicted to be in the PSME series, and the error is almost equally weighted between PIPO and ABCO. As noted under objective one, the distribution of climax Pseudotsuga menziesii appears to be a very narrow band in Bryce Canyon National Park, and the differentiation between adjacent series is environmentally very subtle. We are currently attempting to employ soil moisture availability modeling to improve prediction at the series level.

Within series, habitat types are predicted using a CART model (Breiman et al. 1984). CART models produce cross-validated optimal dichotomous keys as predictors. The CART models for the PIPO and ABCO series are shown in Figure 1. The PSME series has only one common habitat type, and so has no CART model.

The PIPO series CART model has an apparent accuracy of 88%, with the errors occurring in differentiation of PIPO/ARPA and PIPO/PUTR when PIPO/PUTR occurs on slopes greater than 3%. Consequently, we have targeted lower gentle slopes in the PIPO series for increased sampling to better resolve the two types.

The ABCO series CART model also has an apparent accuracy of 88%, with problems in resolving ABCO/BERE and ABCO/ARPA on relatively steep slopes. To date, the model cannot differentiate between ABCO/JUCO and ABCO/BERE, and so these two types have been lumped. This problem may be resolved when additional information from aerial photography is supplied to the predictive models.

Using the predictive models developed we are predicting the habitat type for 100 additional stands in Bryce Canyon. These stands will be identified on the topo maps and field verified this field season.

- 3) To construct a vital attributes successional model which relates the successional pathways and disturbance pathways from each community type to other community types and the climax type

Using the community type classification described above, we developed a succession simulation model based on the concepts of vital attributes (Nobel and Slatyer 1980). The model requires inputs for each species of

- 3.1) method of reproduction (wind-dispersed seed, vegetative)
- 3.2) minimum age of sexual maturity
- 3.3) longevity
- 3.4) relative shade tolerance

For the stand, the model requires

- 3.5) current stand table (minimum and maximum age of existing trees)
- 3.6) annual probability of disturbance (fire)

From the information supplied, using a Monte Carlo stochastic simulation technique, the model predicts the relative abundance of each species in the stand for periods up to 1000 years. The basis of the model is an age-structured population model. The minimum age class and the maximum age-class for each species are retained in memory, and updated for each iteration of the model. The keys to species presence and abundance are the reproductive requirements and shade tolerance. The model calculates for each iteration which species are capable of reproducing under current conditions, and which also have reproductive propagules present. Such species continue to reproduce, while other species become present only in the older age classes. Reproduction can be limited by excessive shade or by lack of propagules. The maximum age of each species is specified, so when species maximum age class reaches the maximum age, one age-class is lost from the model.

The model also simulates disturbance regimes (principally fire). The model simulates fire randomly on specified average fire-return intervals. Fire intensity is determined by the interval since the last fire. Each species has a specified resistance to fire determined primarily by bark characteristics. If a fire occurs with an intensity greater than that tolerated by a species, that species will be removed from the stand.

Because the fires are simulated randomly (Monte Carlo approach), it is necessary to replicate all simulations and average the outputs to produce realistic outcomes. Presently, the model simulates specified stands for periods up to 1000 years (on a ten-year time step), with up to 100 replicates. The model is relatively small and fast. A simulation of 1000 years with 100 replicates takes approximately one minute on a microcomputer. FORTRAN code for the model as included in Appendix A. Sample output from the model for the ABCO/BERE habitat type is included as Appendix B.

This model will be presented at the International Society of Ecological Modelling Meetings in 8/87.

- 4) To determine the habitats and plant communities in which rare or endangered plants occur, and using the community pathway models, to determine the influence of succession, disturbance, or Agency management on the possible distribution of these species

No Federally protected species are known to exist in Bryce Canyon National Park. Of the rare or endemic species listed by Buchanan and Graybosch (1981) or Graybosch and Buchanan (1983), only six remain under study for protection. Of the six, we have observed two: Psoralea pariensis and Castilleja revealii. Castilleja revealii was observed only once, as a single specimen, and it is not known whether or not this observation represents a new

sighting. Psoralea pariensis was observed in several patches on one site, and the observation apparently represents a new sighting for this species. Accordingly, we have established a transect through similar habitat for sampling next field season to determine whether the species is relatively more wide spread than previously thought. Similar sites to the area of observation of Castilleja revealii will also be examined for possible additional populations.

At this time it is not possible to specify community types in which endangered species occur because we have too few samples. Following this field season we will have numerous additional samples of areas similar to those in which these species have been found, and will have a better basis for analysis. It appears at this time, however, that these species have specific substrate requirements, and will be more sensitive to geology than to successional trends. However, the preferred substrates are loose, stony soils, and either recreation or management in these sites is likely to reduce the habitat available for these species.

- 5) To identify and map undisturbed plant communities to serve as baseline reference areas.

We are currently reviewing field notes from the first field season, as well as reference material on the disturbance history of the Park, to help identify relatively undisturbed areas within the Park. During the field mapping portion of the second field season, candidate stands will be visited for determination of inclusion in the list of reference areas.

SUMMARY

This project was designed for completion within two years, with two field seasons. During the first field season we:

- 1) collected sufficient plot samples to characterize the distribution and characteristics of forest habitat types
- 2) mapped sufficient area of the Park to develop the extrapolative mapping guide
- 3) determined that the SCS ecological site types will be insufficient and incompatible with the other habitat types
- 4) updated the known distribution of rare plants within the Park

To date we have:

- 1) classified all sample plots to habitat type and developed habitat type distribution statistics
- 2) developed a preliminary community type classification and classified all sample plots to community type
- 3) developed the predictive model of habitat type distribution for extrapolative mapping
- 4) developed and tested a simple vital attributes succession simulation model for Bryce Canyon National Park

Activities for current field season:

- 1) collection of additional sample plot data in non-forest communities for non-forest habitat type classification
- 2) field testing of extrapolative mapping guides and increasing the area of ground truth mapped
- 3) updating the distribution of rare plant species by transect sampling

Data analyses and projects scheduled for next year:

- 1) improve extrapolative mapping guide to reflect information gained from field testing
- 2) update habitat type and community type classifications to reflect second years data
- 3) map habitat types and community types throughout the Park using new mapping guides

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- 4) calibrate the successional and disturbance pathways using first and second year's data on transition rates

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```

C*****
C
C      VITAL2
C
C      A model to simulate plant community dynamics based on the
C      vital attributes model of Noble and Slatyer.
C
C*****
C
C      PARAMETER (MAXSPC = 20)
C
C* STRUCTURE STAND
C
C      INTEGER*2 COMPOS(MAXSPC,100)      ! stand composition table
C
C* STRUCTURE TREE
C
C      INTEGER*2 MINAGE(MAXSPC)           ! youngest age class by species
C      INTEGER*2 MAXAGE(MAXSPC)           ! oldest age class by species
C      INTEGER*2 MATURE(MAXSPC)           ! age of maturity
C      INTEGER*2 LONGEV(MAXSPC)           ! longevity of species
C      INTEGER*2 RESIST(MAXSPC)           ! resistance to disturbance
C      INTEGER*2 PROPAG(MAXSPC)           ! presence or absence of propagules
C      INTEGER*2 REPRO(MAXSPC)            ! method of reproduction by species
C      INTEGER*2 TOLRNT(MAXSPC)           ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
C      INTEGER*2 NUMSPC                    ! number of species in model
C      INTEGER*2 YEAR                      ! current year
C      INTEGER*2 NUMYRS                    ! number of years to simulate
C      INTEGER*2 SHADE                     ! current shadyness of stand
C
C* STRUCTURE LABEL
C
C      CHARACTER*8 LABEL(MAXSPC)           ! species names for output
C
C* LOCAL
C
C      INTEGER*2 NUMSIM                    ! number of replicates to simulate
C      INTEGER*2 DISTRB                    ! disturbance return interval
C      INTEGER*2 COMOUT(MAXSPC,100)        ! output for COMPOS
C      INTEGER*2 LSTDST                    ! year of last disturbance
C      INTEGER*2 DFACTR                    ! disturbance index
C
C      INTEGER*4 SEED                      ! random number seed
C
C      REAL*4 PROB                         ! yearly probability of disturbance
C
C      CHARACTER*8 NAME                    ! name read from input file
C      CHARACTER*32 INFILE,OUTFIL          ! input and output file names
C      CHARACTER*1 CHAR(20),LINE(100)     ! graphics characters on output

```

```

C      COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+      REPRO,TOLRNT
C      COMMON / STAND / COMPOS
C      COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
C      COMMON / LBLS / LABEL
C
C*****
C
C      Block one determines the parameters of the species to be
C      included in runs of the model.  By preparing different versions
C      of the VITAL2.DAT file, it is possible to simulate different
C      plant communities or areas of the world.
C
C*****
C
C      OPEN (UNIT=1,FILE='VITAL2.DAT',STATUS='OLD')
C
C      KOUNT = 1
C      10 READ(1,100,END=11) LABEL(KOUNT),REPRO(KOUNT),TOLRNT(KOUNT),
+      RESIST(KOUNT),MATURE(KOUNT),LONGEV(KOUNT)
C      KOUNT = KOUNT + 1
C      IF (KOUNT .GE. 21) GOTO 11
C      GOTO 10
C
C      11 CLOSE (1)
C      NUMSPC = KOUNT -1
C
C      100 FORMAT (A8,2X,A1,2I1,2(I4))
C

```

```

C* VITAL2 ***** TWO *****
C
C   Block two asks the user for information about the particular
C   simulation to be run, including number of years to simulate,
C   and disturbance return interval.
C
C*****
C
  WRITE(5,220)
  READ(5,210) NUMYRS
  IF (NUMYRS .GT. 1000) NUMYRS = 1000
  NUMITR = NUMYRS / 10
  WRITE(5,230)
  READ(5,210) NUMSIM
  IF (NUMSIM .GT. 100) NUMSIM = 100
  WRITE(5,240)
  READ(5,210) DISTRB
  WRITE(5,245)
  READ(5,210) DFACTR
  IF (DFACTR .GT. 5) DFACTR = 5
  IF (DFACTR .LT. 0) DFACTR = 0
  PROB = (1.0 - (FLOAT(DFACTR) / FLOAT(DISTRB))) ** 10
  WRITE(5,250)
  READ(5,260) INFILE
  WRITE(5,255)
  READ(5,260) OUTFIL
  WRITE(5,270)
  READ(5,280) SEED
  IF (SEED .EQ. 0) THEN
    SEED = NINT(SECNDS(0))
  ENDIF
C
  OPEN (UNIT=1,FILE=INFILE,STATUS='OLD',ERR=20)
  GOTO 21
20 WRITE(5,290) INFILE
  STOP
21 CONTINUE
C
210 FORMAT (I4)
220 FORMAT ('$',' ENTER THE NUMBER OF YEARS TO SIMULATE ',T50,' : ')
230 FORMAT ('$',' ENTER THE NUMBER OF REPLICATES ',T50,' : ')
240 FORMAT ('$',' ENTER THE DISTURBANCE INTERVAL ',T50,' : ')
245 FORMAT ('$',' ENTER THE DISTURBANCE INDEX ',T50,' : ')
250 FORMAT ('$',' ENTER THE FILE NAME FOR THE INPUT DATA',T50,' : ')
255 FORMAT ('$',' ENTER THE FILE NAME FOR THE OUTPUT',T50,' : ')
260 FORMAT (A32)
270 FORMAT ('$',' ENTER THE RANDOM NUMBER SEED ',T50,' : ')
280 FORMAT (I8)
290 FORMAT (' ERROR OPENING FILE ',A32)
C

```

C* VITAL2 ***** THREE *****

C

OPEN (UNIT=2,FILE=OUTFIL,STATUS='NEW')

C

WRITE(2,300) NUMYRS
WRITE(2,310) NUMSIM
WRITE(2,320) DISTRB
WRITE(2,330) DFACTR
WRITE(2,340) SEED

C

DO 30 I=1,NUMSIM
CALL INIT (I)
YEAR = 0
LSTDST = 0
DO 31 J=1,NUMITR
YEAR = YEAR + 10
CALL GROW (J,SEED)
CALL DIST (PROB,SEED,LSTDST)
CALL REPROD (SEED)

31 CONTINUE

30 CONTINUE

C

300 FORMAT (' ',' NUMBER OF YEARS SIMULATED ',T40,I4)
310 FORMAT (' ',' NUMBER OF REPLICATES ',T40,I4)
320 FORMAT (' ',' DISTURBANCE INTERVAL ',T40,I4)
330 FORMAT (' ',' DISTURBANCE INDEX ',T40,I4)
340 FORMAT (' ',' SEED ',T40,I8)

C

C* VITAL2 ***** FOUR *****

C

WRITE(2,400)

C

DO 40 I=1,NUMSPC
DO 41 J=1,NUMITR
COMOUT(I,J) = (COMPOS(I,J) * 9) / NUMSIM
COMPOS(I,J) = (COMPOS(I,J) * 100) / NUMSIM

41 CONTINUE

WRITE(2,410) I,LABEL(I),(COMOUT(I,J),J=1,NUMITR)

40 CONTINUE

C

DO 42 I=1,NUMSPC
COMPOS(I,1) = (2 * COMPOS(I,1) + COMPOS(I,2)) / 3
COMPOS(I,2) = (COMPOS(I,1) + 3*COMPOS(I,2) + COMPOS(I,3)) / 5
DO 43 J=3,NUMITR-2
COMPOS(I,J) = (COMPOS(I,J-2) + 2*COMPOS(I,J-1) + 3*COMPOS(I,J) +
+ 2*COMPOS(I,J+1) + COMPOS(I,J+2)) / 9

43 CONTINUE

COMPOS(I,NUMITR-1) = (2*COMPOS(I,NUMITR-1) + COMPOS(I,NUMITR)) / 3

COMPOS(I,NUMITR) = (COMPOS(I,NUMITR-1) + 2*COMPOS(I,NUMITR)) / 3

42 CONTINUE

400 FORMAT ('0',' CONDENSED COMPOSITION VECTORS',/)

410 FORMAT (1X,I3,2X,A8,2X,100I1)

```

C* VITAL2 ***** FIVE *****
C
      DATA CHAR / '1','2','3','4','5','6','7','8','9',')',
+           '!', '@', '#', '$', '%', '^', '&', '*', '(', '+', /
C
      WRITE(2,500)
C
      DO 50 I=1,100
      LINE(I) = ' '
50 CONTINUE
C
      DO 51 I=10,100,10
      LINE(I) = '+'
51 CONTINUE
      WRITE(2,510) (LINE(I),I=1,100)
C
      DO 52 I=10,100,10
      LINE(I) = ' '
52 CONTINUE
C
      YEAR = 0
      DO 53 I=1,NUMITR
      YEAR = YEAR + 10
      DO 54 J=1,NUMSPC
      LINE(COMPOS(J,I)) = CHAR(J)
54 CONTINUE
      WRITE(2,520) YEAR,LINE
      DO 55 J=1,NUMSPC
      LINE(COMPOS(J,I)) = ' '
55 CONTINUE
53 CONTINUE
C
500 FORMAT ('0','PLOT OF SPECIES PRESENCE',/)
510 FORMAT (7X,100A1)
520 FORMAT (1X,I4,2X,100A1)

      END
C
C

```

```

C* VITAL2 ***** SUBROUTINE INIT *****
C
  SUBROUTINE INIT (SIMNUM)
C
  PARAMETER (MAXSPC = 20)
C
C* STRUCTURE TREE
C
  INTEGER*2 MINAGE(MAXSPC)      ! youngest age class by species
  INTEGER*2 MAXAGE(MAXSPC)      ! oldest age class by species
  INTEGER*2 MATURE(MAXSPC)      ! age of maturity
  INTEGER*2 LONGEV(MAXSPC)      ! longevity of species
  INTEGER*2 RESIST(MAXSPC)      ! resistance to disturbance
  INTEGER*2 PROPAG(MAXSPC)      ! presence or absence of propagules
  INTEGER*2 REPRO(MAXSPC)       ! method of reproduction by species
  INTEGER*2 TOLRNT(MAXSPC)      ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
  INTEGER*2 NUMSPC              ! number of species in model
  INTEGER*2 YEAR                ! current year
  INTEGER*2 NUMYRS              ! number of years to simulate
  INTEGER*2 SHADE               ! current shadyness of stand
C
C* STRUCTURE LABEL
C
  CHARACTER*8 LABEL(MAXSPC)     ! species names for output
C
C* LOCAL
C
  INTEGER*2 AGEMIN              ! minimum age read from file
  INTEGER*2 AGEMAX              ! maximum age read from file
  INTEGER*2 SIMNUM              ! simulation replicate number
C
  CHARACTER*8 NAME              ! species name read from file
C
  COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+    REPRO,TOLRNT
  COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
  COMMON / LBLS / LABEL

```

```

C* VITAL2 ***** SUBROUTINE INIT *****
C
  SUBROUTINE INIT (SIMNUM)
C
  PARAMETER (MAXSPC = 20)
C
C* STRUCTURE TREE
C
  INTEGER*2 MINAGE(MAXSPC)      ! youngest age class by species
  INTEGER*2 MAXAGE(MAXSPC)      ! oldest age class by species
  INTEGER*2 MATURE(MAXSPC)      ! age of maturity
  INTEGER*2 LONGEV(MAXSPC)      ! longevity of species
  INTEGER*2 RESIST(MAXSPC)      ! resistance to disturbance
  INTEGER*2 PROPAG(MAXSPC)      ! presence or absence of propagules
  INTEGER*2 REPRO(MAXSPC)       ! method of reproduction by species
  INTEGER*2 TOLRNT(MAXSPC)      ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
  INTEGER*2 NUMSPC              ! number of species in model
  INTEGER*2 YEAR                ! current year
  INTEGER*2 NUMYRS              ! number of years to simulate
  INTEGER*2 SHADE               ! current shadyness of stand
C
C* STRUCTURE LABEL
C
  CHARACTER*8 LABEL(MAXSPC)     ! species names for output
C
C* LOCAL
C
  INTEGER*2 AGEMIN              ! minimum age read from file
  INTEGER*2 AGEMAX              ! maximum age read from file
  INTEGER*2 SIMNUM              ! simulation replicate number
C
  CHARACTER*8 NAME              ! species name read from file
C
  COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+    REPRO,TOLRNT
  COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
  COMMON / LBL / LABEL

```

```
C
DO 10 I=1,NUMSPC
  MINAGE(I) = 0
  MAXAGE(I) = 0
  PROPAG(I) = 0
10 CONTINUE

C
  REWIND (1)

C
11 READ(1,100,END=12) NAME,AGEMIN,AGEMAX
  DO 13 I=1,NUMSPC
    IF (NAME .EQ. LABEL(I)) THEN
      MINAGE(I) = AGEMIN
      MAXAGE(I) = AGEMAX
      PROPAG(I) = 1
      GOTO 11
    ENDIF
13 CONTINUE
  GOTO 11

C
12 IF (SIMNUM .EQ. 1) THEN
  WRITE(2,110)
  DO 14 I=1,NUMSPC
    WRITE(2,120) LABEL(I),MINAGE(I),MAXAGE(I),REPRO(I),
+      TOLRNT(I),RESIST(I),MATURE(I),LONGEV(I)
14 CONTINUE
  ENDIF

C
  RETURN

C
100 FORMAT (A8,2(2X,I4))
110 FORMAT ('0',' ORIGINAL SPECIES COMPOSITION',/)
120 FORMAT (' ',A8,2(2X,I3),2X,A1,2(2X,I1),2(2X,I4))

C
  END

C
```

```

C* VITAL2 ***** SUBROUTINE GROW *****
C
      SUBROUTINE GROW (ITRNUM,SEED)
C
      PARAMETER (MAXSPC = 20)
C
C* STRUCTURE TREE
C
      INTEGER*2 MINAGE(MAXSPC)      ! youngest age class by species
      INTEGER*2 MAXAGE(MAXSPC)      ! oldest age class by species
      INTEGER*2 MATURE(MAXSPC)      ! age of maturity
      INTEGER*2 LONGEV(MAXSPC)      ! longevity of species
      INTEGER*2 RESIST(MAXSPC)      ! resistance to disturbance
      INTEGER*2 PROPAG(MAXSPC)      ! presence or absence of propagules
      INTEGER*2 REPRO(MAXSPC)       ! method of reproduction by species
      INTEGER*2 TOLRNT(MAXSPC)      ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
      INTEGER*2 NUMSPC              ! number of species in model
      INTEGER*2 YEAR                ! current year
      INTEGER*2 NUMYRS              ! number of years to simulate
      INTEGER*2 SHADE               ! current shadyness of stand
C
C* STRUCTURE STAND
C
      INTEGER*2 COMPOS(MAXSPC,100) ! stand composition table
C
C* LOCAL
C
      INTEGER*2 ITRNUM              ! iteration number
      INTEGER*4 SEED                ! random number seed
C
      COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+      REPRO,TOLRNT
      COMMON / STAND / COMPOS
      COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
C

```

```
DO 10 I=1,NUMSPC
IF (MINAGE(I) .EQ. LONGEV(I)) THEN
    MINAGE(I) = 0
    MAXAGE(I) = 0
    GOTO 10
ENDIF
IF (MINAGE(I) .GT. 0) MINAGE(I) = MINAGE(I) + 10
IF (MAXAGE(I) .GT. 0) MAXAGE(I) = MAXAGE(I) + 10
IF (MAXAGE(I) .GT. LONGEV(I)) MAXAGE(I) = LONGEV(I)
IF (MINAGE(I) .GT. 0 .OR. MAXAGE(I) .GT. 0) THEN
    COMPOS(I,ITRNUM) = COMPOS(I,ITRNUM) + 1
ENDIF
10 CONTINUE
C
RETURN
C
END
C
```

```

C* VITAL2 ***** SUBROUTINE DIST *****
C
      SUBROUTINE DIST (PROB,SEED,LSTDST)
C
      PARAMETER (MAXSPC = 20)
C
C* STRUCTURE TREE
C
      INTEGER*2 MINAGE(MAXSPC)           ! youngest age class by species
      INTEGER*2 MAXAGE(MAXSPC)           ! oldest age class by species
      INTEGER*2 MATURE(MAXSPC)           ! age of maturity
      INTEGER*2 LONGEV(MAXSPC)           ! longevity of species
      INTEGER*2 RESIST(MAXSPC)           ! resistance to disturbance
      INTEGER*2 PROPAG(MAXSPC)           ! presence or absence of propagules
      INTEGER*2 REPRO(MAXSPC)           ! method of reproduction by species
      INTEGER*2 TOLRNT(MAXSPC)           ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
      INTEGER*2 NUMSPC                   ! number of species in model
      INTEGER*2 YEAR                     ! current year
      INTEGER*2 NUMYRS                   ! number of years to simulate
      INTEGER*2 SHADE                    ! current shadyness of stand
C
C* LOCAL
C
      INTEGER*2 SEVERE                   ! fire severity rating (0-5)
      INTEGER*2 LSTDST                   ! year of last fire
      INTEGER*4 SEED                     ! random number seed
C
      REAL*4 TEST                        ! random number
      REAL*4 PROB                        ! probability of fire
C
      COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+      REPRO,TOLRNT
      COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
C
      TEST = RAN(SEED)
C
      IF (TEST .LT. PROB) RETURN
C

```

```

TIME = YEAR - LSTDST
IF (TIME .LT. 10) THEN
    SEVERE = 1
ELSE IF (TIME .GE. 10 .AND. TIME .LT. 30) THEN
    SEVERE = 2
ELSE IF (TIME .GE. 30 .AND. TIME .LT. 50) THEN
    SEVERE = 3
ELSE IF (TIME .GE. 50 .AND. TIME .LT. 80) THEN
    SEVERE = 4
ELSE
    SEVERE = 5
ENDIF

```

C

```

DO 10 I=1,NUMSPC
IF (SEVERE .GT. RESIST(I)) THEN
    IF (REPRO(I) .EQ. 'D') THEN
        PROPAG(I) = 1
    ELSE IF (REPRO(I) .EQ. 'V' .OR. REPRO(I) .EQ. 'C') THEN
        IF (MAXAGE(I) .GT. MATURE(I)) THEN
            PROPAG(I) = 1
        ELSE
            PROPAG(I) = 0
        ENDIF
    ENDIF
    MINAGE(I) = 0
    MAXAGE(I) = 0
ENDIF

```

10 CONTINUE

C

LSTDST = YEAR

C

RETURN

C

END

C

```

C* VITAL2 ***** SUBROUTINE REPROD *****
C
      SUBROUTINE REPROD (SEED)
C
      PARAMETER (MAXSPC = 20)
C
C* STRUCTURE TREE
C
      INTEGER*2 MINAGE(MAXSPC)      ! youngest age class by species
      INTEGER*2 MAXAGE(MAXSPC)      ! oldest age class by species
      INTEGER*2 MATURE(MAXSPC)      ! age of maturity
      INTEGER*2 LONGEV(MAXSPC)      ! longevity of species
      INTEGER*2 RESIST(MAXSPC)      ! resistance to disturbance
      INTEGER*2 PROPAG(MAXSPC)      ! presence or absence of propagules
      INTEGER*2 REPRO(MAXSPC)       ! method of reproduction by species
      INTEGER*2 TOLRNT(MAXSPC)      ! relative tolerance by species
C
C* STRUCTURE PARAMS
C
      INTEGER*2 NUMSPC              ! number of species in model
      INTEGER*2 YEAR                ! current year
      INTEGER*2 NUMYRS              ! number of years to simulate
      INTEGER*2 SHADE               ! current shadyness of stand
C
      INTEGER*2 TEMTOL              ! tolerance place holder
      INTEGER*4 SEED                ! random number seed
      REAL*4 TEST                   ! random number
C
      COMMON / TREE / MINAGE,MAXAGE,MATURE,LONGEV,RESIST,PROPAG,
+      REPRO,TOLRNT
      COMMON / PARAMS / NUMSPC,YEAR,NUMYRS,SHADE
C
      SHADE = 0
      DO 10 I=1,NUMSPC
      TEMTOL = TOLRNT(I)
      IF (MAXAGE(I) .GE. 40) SHADE = MAX(SHADE,TEMTOL)
10 CONTINUE
C
      DO 11 I=1,NUMSPC
      IF (PROPAG(I) .EQ. 0) GOTO 11
      IF (TOLRNT(I) .GE. SHADE .AND. TOLRNT(I)-SHADE .LE. 3) THEN
      MINAGE(I) = 10
      IF (MAXAGE(I) .EQ. 0) MAXAGE(I) = 10
      ENDIF
11 CONTINUE
C
      RETURN
C
      END
C

```

APPENDIX B

The following printout shows a typical stand dynamics for the ABCO/BERE habitat type.
The mean fire return interval is 100 years, with a cumulative probability of fire within 100 years of 95%. Under this fire regime, Ponderosa pine (PINCON) remains dominant, with Douglas-fir (PSEMEN) the secondary dominant in the stand.

NUMBER OF YEARS SIMULATED	500
NUMBER OF REPLICATES	100
DISTURBANCE INTERVAL	100
DISTURBANCE INDEX	3
SEED	483671

ORIGINAL SPECIES COMPOSITION

POPTRE	10	20	V	1	0	10	130
PINPON	0	0	D	2	2	40	400
PSEMEN	0	0	D	3	1	30	300
PICPUN	0	0	D	4	0	30	400
ABICON	0	0	D	5	0	30	300

PLOT OF SPECIES RELATIVE ABUNDANCE

			+			+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+				+		
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