WORKING PAPER SERIES

FISHERIES STOCK ASSESSMENT

TITLE XII
Collaborative Research Support Program

Fisheries Stock Assessment CRSP Management Office
International Programs, College of Agriculture
The University of Maryland, College Park, Maryland 20742

In cooperation with the United States Agency for International Development (Grant No. DAN-4146-G-SS-5071-00) the Fisheries Stock Assessment CRSP involves the following participating institutions:

The University of Maryland—Center for Environmental and Estuarine Studies
The University of Rhode Island—International Center for Marine Resource Development
The University of Washington—Center for Quantitative Sciences
The University of Costa Rica—Centro de Investigación en Ciencias del Mar y Limnología
The University of the Philippines—Marine Science Institute (Diliman)—College of Fisheries (Visayas)

In collaboration with The University of Delaware; The University of Maryland—College of Business and Management; The University of Miami; and The International Center for Living Aquatic Resources Management (ICLARM).

WORKING PAPER SERIES

Working Paper No. 36

"User's Guide to
MCON
(Multiple COhort N-dimensional model)"
Modern Fisheries Economics"
by

Jerald S. Ault and William W. Fox, Jr.
University of Miami

March, 1988

Fisheries Stock Assessment
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The Fisheries Stock Assessment CRSP (sponsored in part by USAID Grant No. DAN-4146-G-SS-5071-00) is intended to support collaborative research between the U.S. and developing countries' universities and research institutions on fisheries stock assessment and management strategies.

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Fisheries Stock Assessment CRSP

USER'S GUIDE To
MCON (Multiple COhort N-dimensional model)

by

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February 1988

MCON - Multiple COhort N-dimensional

I. Identification

Program Name: **MCON** Version 1.0

Language: FORTRAN

Reference: Ault, J.S. 1988. *Nonlinear Numerical Simulation Models for Assessing Tropical Fisheries with Continuously Breeding Multicohort Populations*. Ph.D. Dissertation. University of Miami, Florida. 242p.

MCON is a generalized dynamic differenced second-order numerical model designed to compute the coupled nonlinear abundance/density second-order differential equations to simulate continuous N-cohort age-structured multicohort population behavior. The present version is coded in VAX FORTRAN V4.5-219 for the Digital mainframe, and FORTRAN 77 for the COMPAQ 286 and IBM-PC/AT compatible microcomputers.

II. Introduction

MCON is a widely applicable second-order nonlinear differential equation multicohort population simulation model. The model incorporates salient population features through continuous nonlinear age-structured effects. The model uses coupled abundance-density equations for tropical multicohort populations. The system of equations is n-dimensional. The numerical running scheme employed is a second order finite differenced system. The time-step is resolved in terms of the highest changing rate parameter. The model was developed to understand the time evolution of tropical multicohort fishery systems. Component mechanisms programmed into the present model which affect each cohort life stage are: (i) resource assimilation rate, (ii) environmental carrying capacities for each age strata, (iii) basal metabolic rate, (iv) optimal weights at age strata, (v) density-dependent instantaneous natural mortality rate, (vi) density -dependent intraspecific competition coefficients, (vii) density-dependent net fecundity and birth rates.

III. Input File → MCON.DAT

FORMAT 2(8F10.0): Variable type: *REAL* ≡ two rows per cohort.

R(J)	≡	resource assimilation or intrinsic growth rate.
A(J)	≡	environmental carrying capacity for ensemble cohort.
B(I,J)	≡	competition coefficient between ensemble cohort i and the specific j cohort abundances (n-1 values required per cohort where n equals the total number of cohorts simulated).
F(J)	≡	fishing and/or predatory pressure for the ith aged individual of the jth cohort.
AL(J)	≡	intrinsic basal metabolic costs rate for the ensemble cohort.
XMU(J)	≡	instantaneous natural mortality rate for the ensemble individual of the jth cohort.
XN(J,DT)	≡	system starting population abundance for cohort j during time-step Δt (four time-stepped values are required as initial guesses).
FJ(J)	≡	ensemble fecundity for the jth age class.
RIJ(J)	≡	instantaneous rate of recruitment from the jth to the ith population region.

FORMAT (4F10.0) Variable type: *REAL*

DT	≡	time-step.
WINF(J)	≡	optimal weight for the ith ensemble individual of the jth aged cohort (one value per cohort).

FORMAT (5I10) Variable type: *INTEGER*

NOC	≡	number of cohorts used in simulation.
MIN	≡	maximum number of time steps used in the forward differencing calculations.
MAX	≡	maximum number of time steps used in the centered differencing calculations.
INC	≡	
NPINC	≡	number of time steps incremented for each print step in the output data files.

IV. Output Data Files for MCON

Unit files 3-9 are written as ASCII data files so that they may be plotted by the graphics routine PLT on the Digital VAX. Each record is dimensioned (F15.0, F15.0, I5).≡ (X-field, Y-field, Plot Number).

Unit	File Name	Contents
1	MCOHN	Parameter file as specified (MCON.DAT)
3	POPN	XX,XN(K,I),K
4	PHASEMC	BIOM(1,III), BIOM(2,III),1
5	BIOPHA	BIOM(K,I), BDT(K,I),K
6	→Monitor Screen	
7	NLWT	XX,WT(K,I),K
8	SUMBIO	SUMBIO(I), SUMBDT(I),K
9	RECRUITS	XX, RIJ(1),1

$$\text{BIOM(K,III)} = \text{XN(K,I)} \bullet \text{WT(K,I)} \qquad \forall\ \text{K}$$

$$\text{BDT(K)} = \frac{\text{BIOM}(\text{K},t+\Delta t) - \text{BIOM}(\text{K},t-\Delta t)}{2\Delta t} \qquad \forall\ \text{K}$$

$$\text{SUMBIO(K)} = \Sigma\ \text{BIOM(K,I)} \qquad \text{K} = 1,\ldots,n$$

$$\text{SUMBDT(K)} = \frac{\text{SUMBIO}(\text{K},t+\Delta t) - \text{SUMBIO}(\text{K},t-\Delta t)}{2\Delta t} \qquad \text{K} = 1,\ldots,n$$

V. Acknowledgements

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VI. Literature Cited

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Caddy, J.F. and G.D. Sharp. 1986. An ecological framework for marine fishery investigations. FAO Fish. Tech. Pap., (283):152p.

Hunter, J.R. and S.R. Goldberg. 1980. Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax*. Fish. Bull. 77(3):641-652.

Hunter, J. R. and R. Leong. 1981. The spawning energetics of female northern anchovy, *Engraulis mordax*. Fish. Full. 79(2):215-230.

Parrish, R.H., D.L. Mallicoate and R.A. Klingbeil. 1986. Age independent fecundity, number of spawnings per year, sex ratio, and maturation stages in northern anchovy, Engraulis mordax. Fishery Bull. 84(3):503-517.

Tillman, M.F. and D. Stadelman. 1976. Development and example application of a simulation model of the northern anchovy fishery. Fish. Bull. 74(1):118-130.

Table 1: Engrauloid annual rate parameters used in the continuous simulations of the second order nonlinear multicohort population model. Data from Tillman & Stadelman (1976), Hunter & Goldberg (1980), Hunter & Leong (1981), Parrish et al. (1986), Caddy & Sharp (1986).

Cohort	r(i)	a(i)	μ(i)	$W^{\infty}(i)$	f(j)	α(i)
I	1.023	.0003500	1.1	11.81	1.00	0.077
II	1.012	.0007500	1.1	18.41	1.93	0.088
III	1.001	.0003913	1.1	24.50	2.93	0.099
IV	0.990	.0004444	1.1	29.68	3.88	0.110
V	0.985	.0004667	1.1	33.86	4.72	0.116
VI	0.979	.0005455	1.1	37.14	5.42	0.121
VII	0.974	.0006250	1.1	39.46	5.98	0.127

Table 2: Matrix of interaction b(i,j) coefficients. Rows are the cohorts affected while the columns are the cohorts who are causing the interaction.

AFFECTS

	1	2	3	4	5	6	7
1	XXX	.00025	.000005	.000001	.000001	.0000001	1.0E-8
2	.000125	XXX	.000125	.000125	.000125	1.0E-6	1.0E-7
3	.000225	.00035	XXX	.000125	.000025	1.0E-5	1.0E-6
4	.000	.00001	.001	XXX	.0001	.00005	1.0E-7
5.	.000	.001	.001	.001	XXX	.00001	1.0E-5
6	.000	.000001	.00001	.0001	.0005	XXX	1.0E-4
7	.000	.000001	.00001	.0001	.0002	.00001	XXX

```
      PROGRAM MCOHN
C**********************************************************************
C                                                                     *
C     PROGRAM TO COMPUTE THE COUPLED SECOND-ORDER                     *
C     NONLINEAR WEIGHT/DENSITY DIFFERENTIAL                           *
C     EQUATIONS FOR AN N-COHORT POPULATION.                           *
C                                                                     *
C**********************************************************************
      DIMENSION XN(3,600),DAMP(3),BINJ(3),A2(3),A3(3),A4(3),A5(3),
     $A6(3),A7(3),FOR(3),RIJ(3),DRIJ(3),XNDT(3,600),BIOM(3,600),
     $WT(3,600),R(3),A(3),B(3,5),F(3),XK(3),DF(3),FJ(3),AL(3),
     $D(3),XMU(3),BDT(3,600)
      OPEN(UNIT=1,FILE='MCOHN.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='MCOHPLOT.DAT',STATUS='NEW')
      OPEN(UNIT=4,FILE='PHASEMC.DAT',STATUS='NEW')
      OPEN(UNIT=5,FILE='BIOPHA.DAT',STATUS='NEW')
      WRITE(*,1)
    1 FORMAT(7X,'EXECUTING READ ON DATA FILE MCOHN.DAT....'/)
      READ(1,10)
     $R(1),A(1),B(1,2),B(1,3),B(1,4),B(1,5),F(1),AL(1),
     $XMU(1),XN(1,1),XN(1,2),XN(1,3),XN(1,4),FJ(1),RIJ(1),RIJ(1),
     $R(2),A(2),B(2,1),B(2,3),B(2,4),B(2,5),F(2),AL(2),
     $XMU(2),XN(2,1),XN(2,2),XN(2,3),XN(2,4),FJ(2),RIJ(2),RIJ(2),
     $R(3),A(3),B(3,1),B(3,2),B(3,4),B(3,5),F(3),AL(3),
     $XMU(3),XN(3,1),XN(3,2),XN(3,3),XN(3,4),FJ(3),RIJ(3),RIJ(3)
      READ(1,13)DT,WINF
      READ(1,11)NOC,MIN,MAX,INC
   10 FORMAT(8F10.0)
   13 FORMAT(2F10.0)
   11 FORMAT(4I10)
      DO 5 I=1,NOC
      XK(I)=R(I)/A(I)
      WRITE(*,6)XK(I),R(I),A(I),XMU(I),AL(I),I
      WRITE(*,6)B(1,2),B(1,3),B(1,4),B(1,5),F(I),I
    5 CONTINUE
    6 FORMAT(7X,F13.5,2X,F8.5,2X,F8.5,2X,F8.5,2X,F8.5,2X,I3)
      MMIN=MIN+1
      WRITE(*,2)NOC
    2 FORMAT(7X,'CALCULATING ',I3,'-COHORT WEIGHT DENSITY PHASE PLANE
     $ RELATIONSHIP'/)
C*****ESTABLISH CONSTANT TERMS FOR FIRST TIME STEP
      DO 12 J=1,NOC
      DAMP(J)=0.
      BINJ(J)=0.
      FOR(J)=0.
      A2(J)=0.
      A3(J)=0.
      A4(J)=0.
      A5(J)=0.
      A6(J)=0.
      A7(J)=0.
   12 CONTINUE
      DO 20 I=1,NOC
      DO 18 J=1,NOC
      IF(I.EQ.J) GOTO 18
```

```
      DAMP(I)=DAMP(I)+(B(I,J)*XN(J,4))
   18 CONTINUE
      BINJ(I)=DAMP(I)/A(I)
   20 CONTINUE
C*****DEVELOPING POPULATION EQUATION TERMS FOR THE J-COHORTS
      DO 30 J=1,NOC
      FOR(J)=((1/XMU(J))*((F(J)*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))+
     $       ((R(J)*RIJ(J))/XK(J))-DF(J)))+
     $       (WINF*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))
      A2(J)=1/XMU(J)
      A3(J)=(R(J)*(1-(BINJ(J)/XK(J))))-AL(J)
      A4(J)=R(J)/(XK(J)*XMU(J))
      A5(J)=(R(J)/XK(J))*(WINF+(F(J)/XMU(J)))
      A6(J)=(RIJ(J)*A3(J))-DRIJ(J)
      A7(J)=RIJ(J)
   30 CONTINUE
C*********************************************************************
C                                                                    *
C     POPULATION DERIVATIVES - FORWARD IN TIME                       *
C                                                                    *
C*********************************************************************
      DO 1000 II=3,MIN
      RIJ(1)=0.
      IF(II.EQ.3) GOTO 950
      DO 990 JJ=1,NOC
      DAMP(JJ)=0.
      BINJ(JJ)=0.
  990 CONTINUE
C*****ACCUMULATE NEW CONSTANTS
      DO 100 I=1,NOC
      DO 99 J=1,NOC
      IF(I.EQ.J) GOTO 99
      DAMP(I)=DAMP(I)+(B(I,J)*XN(J,II+1))
   99 CONTINUE
      BINJ(I)=DAMP(I)/A(I)
  100 CONTINUE
C*****CALCULATING FORWARD DERIVATIVES
  950 DO 900 J=1,NOC
      RIJ(J)=0.
      FOR(J)=0.
      A3(J)=0.
      A6(J)=0.
      A7(J)=0.
      XN(J,II+2)=0.
      XK(J)=0.
      XK(J)=R(J)/A(J)
      FOR(J)=((1/XMU(J))*((F(J)*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))+
     $       ((R(J)*RIJ(J))/XK(J))-DF(J)))+
     $       (WINF*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))
      A3(J)=(R(J)*(1-(BINJ(J)/XK(J))))-AL(J)
      A6(J)=(RIJ(J)*A3(J))-DRIJ(J)
      A7(J)=RIJ(J)
      XN(J,II+2)=((DT**2)*(XN(J,II)*(FOR(J)/A2(J))))-
     $           ((DT*(XN(J,II+1)-XN(J,II))*A7(J))/XN(J,II))+
     $           (((XN(J,II+1)-XN(J,II))**2)/XN(J,II))+
```

```
     $              (DT*(XN(J,II+1)-XN(J,II))*
     $              (A3(J)-(XN(J,II)*(A4(J)/A2(J)))))-
     $              ((XN(J,II)**2)*(((DT**2)*A5(J))/A2(J)))-
     $              ((DT**2)*A6(J))-
     $              (2*XN(J,II+1))+(XN(J,II))
      IF(XN(J,II+2))200,200,200
C 150 XN(J,II+2)=0.01
C      GOTO 200
  200 XNDT(J,II+1)=0.
      DRIJ(J)=0.
      WT(J,II+2)=0.
      DF(J)=0.
      RIJ(J)=0.
C      RIJ(1)=RIJ(1)+(FJ(J)*XN(J,II+2))
C      RIJ(1)=RIJ(1)+(FJ(J)*(WT(J,II+1)-WINF))
      XNDT(J,II+1)=(XN(J,II+2)-XN(J,II+1))/DT
      WT(J,II+2)=WINF+((1/XMU(J))*(F(I)+((1/XN(J,II+1))*(XNDT(J,II+1)-
     $              RIJ(J)))))
      BIOM(J,II+1)=XN(J,II+1)*WT(J,II+1)
      BDT(J,II)=(BIOM(J,II+1)-BIOM(J,II))/DT
C      WRITE(*,197)
C 197 FORMAT(7X,'DERIVATIVES AND WEIGHTS')
C      WRITE(*,192)XNDT(J,II+1),DRIJ(J,II+2),DF(J),
C     $             WT(J,II+2),RIJ(J,II+2)
  900 CONTINUE
C*****TIME STEP PRINT TO DATA FILE
      III=II+2
      WRITE(4,199)XN(1,III),XN(2,III),XN(3,III),III
      WRITE(5,199)BIOM(1,II),BDT(1,II),WT(1,II),II
  192 FORMAT(7X,E12.4,3X,E12.4,3X,F5.1,3X,E12.4,3X,E10.4)
  190 FORMAT(E15.4,E15.4,I5)
  199 FORMAT(E15.4,E15.4,E15.4,I5)
  191 FORMAT(7X,E12.4,5X,E12.4,3X,E12.4,3X,E12.4,I5)
C      WRITE(*,193)
C 193 FORMAT(7X,'POPULATION VALUES')
C      WRITE(*,191)XN(1,III),XN(2,III),XN(3,III),XN(4,III),III
 1000 CONTINUE
C*********************************************************************
C                                                                    *
C     POPULATION DERIVATIVES - CENTERED IN TIME                      *
C                                                                    *
C*********************************************************************
      DO 2000 II=MMIN,MAX
      RIJ(1)=0.
      IF(II.EQ.3) GOTO 1950
      DO 1990 JJ=1,NOC
      DAMP(JJ)=0.
      BINJ(JJ)=0.
 1990 CONTINUE
C*****ACCUMULATE NEW CONSTANTS
      DO 1100 I=1,NOC
      DO 1099 J=1,NOC
      IF(I.EQ.J) GOTO 1099
      DAMP(I)=DAMP(I)+(B(I,J)*XN(J,II+1))
 1099 CONTINUE
```

```
      BINJ(I)=DAMP(I)/A(I)
 1100 CONTINUE
C*****CALCULATING CENTERED DERIVATIVES
 1950 DO 1900 J=1,NOC
      XK(J)=0.
      FOR(J)=0.
      A3(J)=0.
      A6(J)=0.
      A7(J)=0.
      XN(J,II+2)=0.
      XK(J)=R(J)/A(J)
      FOR(J)=((1/XMU(J))*((F(J)*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))+
     $        ((R(J)*RIJ(J))/XK(J))-DF(J)))+
     $        (WINF*((R(J)*(1-(BINJ(J)/XK(J))))-AL(J)))
      A3(J)=(R(J)*(1-(BINJ(J)/XK(J))))-AL(J)
      A6(J)=(RIJ(J)*A3(J))-DRIJ(J)
      A7(J)=RIJ(J)
      IF(XN(J,II+1).EQ.0) GOTO 1150
      XN(J,II+2)=((4*(DT**2))*(XN(J,II)*(FOR(J)/A2(J))))-
     $            (((2*DT)*(XN(J,II+1)-XN(J,II-1))*A7(J))/XN(J,II))+
     $            (((XN(J,II+1)-XN(J,II-1))**2)/XN(J,II))+
     $            ((2*DT)*(XN(J,II+1)-XN(J,II-1))*
     $            (A3(J)-(XN(J,II)*(A4(J)/A2(J)))))-
     $            ((XN(J,II)**2)*(((4*(DT**2))*A5(J))/A2(J)))-
     $            ((4*(DT**2))*A6(J))+
     $            (2*XN(J,II))-(XN(J,II-2))
      IF(XN(J,II+2))1150,1150,1200
 1150 XN(J,II+2)=.0
      GOTO 1200
 1200 XNDT(J,II+1)=0.
      DRIJ(J)=0.
      WT(J,II+2)=0.
      RIJ(J)=0.
      DF(J)=0.
      XNDT(J,II+1)=(XN(J,II+2)-XN(J,II))/(2*DT)
C      RIJ(J,II+2)=RIJ(1,II+2)+(FJ(J)*XN(J,II+2))
C      RIJ(1,II+2)=RIJ(1,II+2)+(FJ(J)*(WT(J,II+1)-WINF))
      IF(XN(J,II+1).EQ.0) GOTO 1202
      WT(J,II+2)=WINF+((1/XMU(J))*(F(I)+((1/XN(J,II+1)-
     $            RIJ(J)))))
 1202 BIOM(J,II+1)=XN(J,II+1)*WT(J,II+1)
      BDT(J,II)=(BIOM(J,II+1)-BIOM(J,II))/(2*DT)
C  297 FORMAT(7X,'DERIVATIVES AND WEIGHTS')
C      WRITE(*,192)XNDT(J,II+1),DRIJ(J),DF(J),
C     $            WT(J,II+2),RIJ(J)
C      WRITE(*,101)II+2
C  101 FORMAT(7X,I5)
 1900 CONTINUE
C*****TIME STEP PRINT TO DATA FILE
      III=II+2
      WRITE(4,1191)XN(1,III),XN(2,III),XN(3,III),III
      WRITE(5,1191)BIOM(1,II),BDT(1,II),WT(1,II),II
 1190 FORMAT(E15.4,E15.5,I5)
 1191 FORMAT(E15.4,E15.4,E15.4,I5)
C      WRITE(*,293)
```

```
C  293 FORMAT(7X,'POPULATION VALUES')
C       WRITE(*,191)XN(1,III),XN(2,III),XN(3,III),XN(4,III),III
C       WRITE(*,297)
 2000 CONTINUE
      WRITE(*,2010)
 2010 FORMAT(7X,'PHASE PLANE CALCULATIONS COMPLETED.....',/,
     $       7X,'NOW FILLING PLOTTING ARRAYS!')
      DO 2050 K=1,NOC
      DO 2020 I=1,MAX,INC
      XX=I
      WRITE(3,1190)XX,XN(K,I),K
 2020 CONTINUE
      WRITE(*,2030)K
 2030 FORMAT(7X,'ARRAY ',I3,' FILLED...')
 2050 CONTINUE
      END
```

```
C       NONLINEAR-WEIGHT/DENSITY DIFFERENTIAL                         *
C       EQUATIONS FOR AN N-COHORT POPULATION.                         *
C                                                                     *
C**********************************************************************
        REAL*8 XN(8,10000),DAMP(8),BINJ(8),A2(8),A3(8),A4(8),A5(8),
     $         A6(8),A7(8),FOR(8),RIJ(8),DRIJ(8),
     $         XMUT(8,10000),WT(8,10000),BIOM(8,10000),BDT(8,10000),
     $         SUMBIO(10000),SUMBDT(10000)
        DIMENSION R(8),A(8),B(8,8),F(8),XK(8),DF(8),FJ(8),
     $         AL(8),D(8),XMU(8),WINF(8)
        OPEN(UNIT=1,NAME='MCOHN.DAT',TYPE='OLD',READONLY)
        OPEN(UNIT=3,NAME='POPN.DAT',TYPE='NEW',DISP='KEEP')
        OPEN(UNIT=4,NAME='PHASEMC.DAT',TYPE='NEW',DISP='KEEP')
        OPEN(UNIT=5,NAME='BIOPHA.DAT',TYPE='NEW',DISP='KEEP')
C       OPEN(UNIT=7,NAME='NEWT.DAT',STATUS='NEW',DISP='KEEP')
        OPEN(UNIT=8,NAME='SUMBIO.DAT',STATUS='NEW',DISP='KEEP')
        OPEN(UNIT=9,NAME='RECRUITS.DAT',STATUS='NEW',DISP='KEEP')
        WRITE(6,1)
      1 FORMAT(7X,'EXECUTING READ ON DATA FILE MCOHN.DAT....'/)
        READ(1,10)
     $   R(1),A(1),B(1,2),B(1,3),B(1,4),B(1,5),F(1),AL(1),
     $   XMU(1),XN(1,1),XN(1,2),XN(1,3),XN(1,4),FJ(1),RIJ(1),RIJ(1),
     $   R(2),A(2),B(2,1),B(2,3),B(2,4),B(2,5),F(2),AL(2),
     $   XMU(2),XN(2,1),XN(2,2),XN(2,3),XN(2,4),FJ(2),RIJ(2),RIJ(2),
     $   R(3),A(3),B(3,1),B(3,2),B(3,4),B(3,5),F(3),AL(3),
     $   XMU(3),XN(3,1),XN(3,2),XN(3,3),XN(3,4),FJ(3),RIJ(3),RIJ(3)
        READ(1,13) DT,WINF(1),WINF(2),WINF(3)
        READ(1,11) NOC,MIN,MAX,INC,NPINC
     10 FORMAT(8F10.0)
     13 FORMAT(4F10.0)
     11 FORMAT(5I10)
        DO 5 I=1,NOC
        XK(I)=R(I)/A(I)
        WRITE(6,6)XK(I),R(I),A(I),XMU(I),AL(I),I
      5 CONTINUE
      6 FORMAT(7X,F13.5,2X,F8.5,2X,F8.5,2X,F8.5,2X,F8.5,2X,I3)
        MMIN=MIN+1
        WRITE(6,2)NOC
      2 FORMAT(7X,'CALCULATING ',I3,'-COHORT WEIGHT DENSITY PHASE PLANE
     $ RELATIONSHIP'/)
C*****ESTABLISH CONSTANT TERMS FOR FIRST TIME STEP
        DO 12 J=1,NOC
        DAMP(J)=0.
        BINJ(J)=0.
        FOR(J)=0.
        A2(J)=0.
        A3(J)=0.
        A4(J)=0.
        A5(J)=0.
        A6(J)=0.
        A7(J)=0.
     12 CONTINUE
        DO 20 I=1,NOC
        DO 18 J=1,NOC
        IF(I.EQ.J) GOTO 18
        DAMP(I)=DAMP(I)+(B(I,J)*XN(J,4))
     18 CONTINUE
        BINJ(I)=DAMP(I)
     20 CONTINUE
C*****DEVELOPING POPULATION EQUATION TERMS FOR J-COHORTS
        DO 30 J=1,NOC
        FOR(J)=((1/XMU(J))*((F(J)*(R(J)-BINJ(J)-AL(J)))+
     $         (A(J)*RIJ(J))-DF(J)))+
     $         (WINF(J)*(R(J)-BINJ(J)-AL(J)))
        A2(J)=1/XMU(J)
        A3(J)=R(J)-BINJ(J)-AL(J)
        A4(J)=A(J)/XMU(J)
        A5(J)=A(J)*(WINF(J)+(F(J)/XMU(J)))
        A6(J)=(RIJ(J)*A3(J))-DRIJ(J)
        A7(J)=RIJ(J)
     30 CONTINUE
C**********************************************************************
C                                                                     *
C       POPULATION DERIVATIVES - FORWARD IN TIME                      *
C                                                                     *
```

```
      IF(IT.EQ.3) GOTO 950
      DO 990  JJ=1,NOC
      DAMP(JJ)=0.
      BINJ(JJ)=0.
  990 CONTINUE
C*****ACCUMULATE NEW CONSTANTS
      DO 100 I=1,NOC
      DO 99  J=1,NOC
      IF(I.EQ.J) GOTO 99
      DAMP(I)=DAMP(I)+(B(I,J)*XN(J,IT+1))
   99 CONTINUE
      BINJ(I)=DAMP(I)
  100 CONTINUE
C*****CALCULATING FORWARD DERIVATIVES
  950 DO 900 J=1,NOC
      RIJ(J)=0.
      FOR(J)=0.
      A3(J)=0.
      A6(J)=0.
      A7(J)=0.
      XN(J,IT+2)=0.
      XK(J)=0.
      XK(J)=P(J)/A(J)
      FOR(J)=((1/XMU(J))*((F(J)*(R(J)-BINJ(J)-AL(J)))+
     $        (A(J)*RIJ(J))-DF(J)))+
     $        (WINF(J)*(R(J)-BINJ(J)-AL(J)))
      A3(J)=P(J)-BINJ(J)-AL(J)
      A6(J)=(RIJ(J)*A3(J))-DRIJ(J)
      A7(J)=RIJ(J)
      XN(J,IT+2)=((DT**2)*(XN(J,II)*(FOR(J)/A2(J))))-
     $              ((DT*(XN(J,II+1)-XN(J,II))*A7(J))/XN(J,II))+
     $              (((XN(J,IT+1)-XN(J,II))**2)/XN(J,II))+
     $              (DT*(XN(J,II+1)-XN(J,II))*
     $              (A3(J)-(XN(J,II)*(A4(J)/A2(J))))))-
     $              ((XN(J,II)**2)*(((DT**2)*A5(J))/A2(J)))-
     $              ((DT**2)*A6(J))+
     $              (2*XN(J,IT+1))-(XN(J,II))
      IF(XN(J,II+2))200,200,200
C  150 XN(J,II+2)=0.01
C      GOTO 200
  200 XNDT(J,II+1)=0.
      DRIJ(J)=0.
      WT(J,IT+2)=0.
      DF(J)=0.
      RIJ(J)=0.
C     RTJ(1,II+2)=RTJ(1,II+2)+(FJ(J)*XN(J,II+2))
      RIJ(1)=RTJ(1)+(FJ(J)*(WT(J,IT+1)-WINF(J)))
      XNDT(J,II+1)=(XN(J,IT+2)-XN(J,II+1))/DT
      WT(J,II+2)=WINF(J)+((1/XMU(J))*(F(J)+((1/XN(J,II+1))*
     $               (XNDT(J,II+1)-RIJ(J)))))
      BIOM(J,IT+1)=XN(J,II+1)*WT(J,IT+1)
      BDT(J,II)=(BIOM(J,IJ+1)-BIOM(J,II))/DT
C      WRITE(6,197)
C  197 FORMAT(7X,'DERIVATIVES AND WEIGHTS')
C      WRITE(6,192)XNDT(J,II+1),DRIJ(J,II+2),DF(J),
C     $                 WT(J,II+2),RIJ(J,II+2)
  900 CONTINUE
C*****TIME STEP PRINT-TO DATA FILE
      III=II+2
C     WRITE(4,190)XN(1,III),XN(2,III),III
  192 FORMAT(7X,E12.4,3X,E12.4,3X,F5.1,3X,F12.4,3X,E10.4)
  190 FORMAT(E15.4,E15.4,I5)
  191 FORMAT(7X,E12.4,5X,E12.4,3X,E12.4,3X,E12.4,I5)
C     WRITE(6,193)
C  193 FORMAT(7X,'POPULATION VALUES')
C     WRITE(6,191)XN(1,III),XN(2,III),XN(3,III),III
 1000 CONTINUE
C*******************************************************************
C                                                                  *
C     POPULATION DERIVATIVES - CENTERED IN TIME                    *
C                                                                  *
C*******************************************************************
      DO 2000 II=MMIN,MAX
      RIJ(1)=0.
      SUMBTO(IT+1)=0.
      SUMBDT(II)=0.
```

```
      BINJ(J,J)=0.
 1990 CONTINUE
C*****ACCUMULATE NEW CONSTANTS
      DO 1100 I=1,NUC
      DO 1099 J=1,NUC
      IF(I.EQ.J) GOTO 1099
      DAMP(I)=DAMP(I)+(B(I,J)*XN(J,II+1))
 1099 CONTINUE
      BINJ(I)=DAMP(I)
 1100 CONTINUE
C*****CALCULATING CENTERED DERIVATIVES
 1950 DO 1900 J=1,NUC
      XK(J)=0.
      FOR(J)=0.
      A3(J)=0.
      A6(J)=0.
      A7(J)=0.
      XN(J,II+2)=0.
      XK(J)=P(J)/A(J)
      FOR(J)=((1/XMU(J))*((F(J)*(R(J)-BINJ(J)-AL(J)))+
     S          (A(J)*RIJ(J))-DF(J)))+
     S          (WINF(J)*(R(J)-BINJ(J)-AL(J)))
      A3(J)=P(J)-BINJ(J)-AL(J)
      A6(J)=(RIJ(J)*A3(J))-DPIJ(J)
      A7(J)=PIJ(J)
      IF(XN(J,II+1).EQ.0) GOTO 1150
      XN(J,II+2)=((4*(DT**2))*(XN(J,II)*(FOR(J)/A2(J))))-
     S               (((2*DT)*(XN(J,II+1)-XN(J,II-1))*A7(J))/XN(J,II))+
     S               (((XN(J,II+1)-XN(J,II-1))**2)/XN(J,II))+
     S               ((2*DT)*(XN(J,II+1)-XN(J,II-1))*
     S               (A3(J)-(XN(J,II)*(A4(J)/A2(J)))))-
     S               ((XN(J,II)**2)*(((4*(DT**2))*A5(J))/A2(J)))-
     S               ((4*(DT**2))*A6(J))+
     S               (2*XN(J,II))-(XN(J,II-2))
      IF(XN(J,II+2))1150,1150,1200
 1150 XN(J,II+2)=0.0
      GOTO 1200
 1200 XNDT(J,II+1)=0.
      DRIJ(J)=0.
      WT(J,II+2)=0.
      PIJ(J)=0.
      DF(J)=0.
      XNDT(J,II+1)=(XN(J,II+2)-XN(J,II))/(2*DT)
      PIJ(1)=RIJ(1)+(FJ(J)*(WT(J,II)-WINF(J)))
      IF(XN(J,II+1).EQ.0) GOTO 1202
      WT(J,II+1)=WINF(J)+((1/XMU(J))*(F(J)+((1/XN(J,II+1))*
     S                (XNDT(J,II+1)-RIJ(J)))))
 1202 BIOM(J,II+1)=XN(J,II+1)*WT(J,II+1)
      BDT(J,II)=(BIOM(J,II+1)-BIOM(J,II-1))/(2*DT)
C 297 FORMAT(7X,'DERIVATIVES AND WEIGHTS')
C     WRITE(6,192)XNDT(J,II+1),DRIJ(J,II+1),DF(J),
C    S                 WT(J,II+2),RIJ(J,II+2)
C     WRITE(6,101)II+2
C 101 FORMAT(7X,I5)
 1900 CONTINUE
C     IF(PIJ(1).GT.0) GOTO 1201
C     RIJ(1)=0.
 1201 SUMBIO(II+1)=0.
      SUMBDT(II)=0.
      DO 1901 J=1,NUC
      SUMBIO(II+1)=SUMBIO(II+1)+BIOM(J,II+1)
 1901 CONTINUE
      IF(II.LE.MMIN+2) GOTO 1902
      SUMBDT(II)=(SUMBIO(II+1)-SUMBIO(II-1))/(2*DT)
C*****TIME STEP PRINT TO DATA FILE
 1902 III=II+1
      XX=II
      WRITE(4,1190)BIOM(1,III),BIOM(2,III),1
      WRITE(9,1190)XX,RIJ(1),1
 1190 FORMAT(E15.4,E15.4,I5)
C     WRITE(6,293)
C 293 FORMAT(7X,'POPULATION VALUES')
C     WRITE(6,191)XN(1,III),XN(2,III),XN(3,III),III
C     WRITE(6,297)
 2000 CONTINUE
      WRITE(6,2010)
```

```
      DO 2020 I=1,MAX,NPINC
      XX=I
      WRITE(3,1190)XX,XN(K,I),K
      IF(I.LE.MAIN+2) GOTO 2020
      WRITE(5,1190)BTOM(K,I),BDT(K,I),K
C     WRITE(7,1190)XX,WT(K,I),K
      IF(K.NE.NOC) GOTO 2020
      WRITE(8,1190)SUMBIO(I),SUMBDT(I),K
2020  CONTINUE
      WRITE(6,2030)K
2030  FORMAT(7X,'ARRAY ',I3,' FILLED...')
2050  CONTINUE
      END
```

PROGRAM SECTIONS

	NAME	BYTES	ATTRIBUTES
0	$CODE	3572	PIC CON REL LCL SHR EXE RD NOWRT LONG
1	$PDATA	343	PIC CON REL LCL SHR NOEXE RD NOWRT LONG
2	$LOCAL	3361536	PIC CON REL LCL NOSHR NOEXE RD WRT QUAD

TOTAL SPACE ALLOCATED 3365451

ENTRY POINTS

ADDRESS	TYPE	NAME
0-00000000		MCOHN

VARIABLES

ADDRESS	TYPE	NAME	ADDRESS	TYPE	NAME	ADDRESS	TYPE	NAME	ADDRESS	TYPE	NAME
2-00334A00	R*4	DT	**	I*4	I	2-00334A1C	I*4	II	**	I*4	III
2-00334A10	I*4	INC	**	I*4	J	**	I*4	JJ	**	I*4	K
2-00334A0C	I*4	MAX	2-00334A08	I*4	MIN	2-00334A18	I*4	MMIN	2-00334A04	I*4	NOC
2-00334A14	I*4	NPINC	**	R*4	XX						

ARRAYS

ADDRESS	TYPE	NAME	BYTES	DIMENSIONS
2-003347E0	R*4	A	32	(8)
2-0009C480	R*8	A2	64	(8)
2-0009C4C0	R*8	A3	64	(8)
2-0009C500	R*8	A4	64	(8)
2-0009C540	R*8	A5	64	(8)
2-0009C580	R*8	A6	64	(8)
2-0009C5C0	R*8	A7	64	(8)
2-00334990	R*4	AL	32	(8)
2-00334800	R*4	B	256	(8, 8)
2-002712C0	R*8	BDT	640000	(8, 10000)
2-0009C440	R*8	BINJ	64	(8)
2-001D4EC0	R*8	BIOM	640000	(8, 10000)
2-000001F0	R*4	D	32	(8)
2-0009C400	R*8	DAMP	64	(8)
2-00334940	R*4	DF	32	(8)
2-0009C680	R*8	DRIJ	64	(8)
2-00334900	R*4	F	32	(8)
2-00334960	R*4	FJ	32	(8)
2-0009C600	R*8	FOR	64	(8)
2-003347C0	R*4	K	32	(8)
2-0009C640	R*8	RIJ	64	(8)
2-00320E40	R*8	SUMBDT	80000	(10000)
2-0030D6C0	R*8	SUMBIO	80000	(10000)
2-003349E0	R*4	WINF	32	(8)
2-00138AC0	R*8	WT	640000	(8, 10000)
2-00334920	R*4	XK	32	(8)
2-003349C0	R*4	XMU	32	(8)

5

LABELS

ADDRESS	LABEL	ADDRESS	LABEL	ADDRESS	LABEL	ADDRESS	LABEL	ADDRESS	LABEL	ADDRESS	LABEL
1-00000046	1'	1-000000A4	2'	**	5	1-00000086	6'	1-00000075	10'	1-00000081	11'
**	12	1-0000007B	13'	0-00000522	18	**	20	**	30	0-0000068E	99
**	100	**	190'	**	191'	**	192'	**	200	**	900
0-0000069C	950	**	990	**	1000	0-0000090E	1099	**	1100	0-00000AF4	1150
1-000000E9	1190'	0-00000AFF	1200	**	1201	0-000008BF	1202	**	1900	**	1901
0-00000C22	1902	0-0000091C	1950	**	1990	**	2000	1-000000F2	2010'	0-00000DBE	2020
1-0000013E	2030'	**	2050								

FUNCTIONS AND SUBROUTINES REFERENCED

```
  TYPE  NAME
        FOR$OPEN
```

COMMAND QUALIFIERS

```
  FOR/LIST MCUHN

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP,NODICTIONARY,SINGLE)
  /WARNINGS=(GENERAL,NODECLARATIONS,NOULTRIX)
  /CONTINUATIONS=19  /NOCROSS_REFERENCE  /NOD_LINES  /NOEXTEND_SOURCE  /F77
  /NOG_FLOATING  /I4  /NOMACHINE_CODE  /OPTIMIZE  /NOANALYSIS
```

COMPILATION STATISTICS

```
  RUN TIME:           8.29 SECONDS
  ELAPSED TIME:       9.94 SECONDS
  PAGE FAULTS:        1329
  DYNAMIC MEMORY:     614 PAGES
```