**A Landscape-Level Assessment of Restoration Resource Allocation for the Eastern Monarch Butterfly**

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Appendix 4 – VENSIM CODE

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.Control

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

Simulation Control Parameters

(001) FINAL TIME = 9855

:GROUP .Control

(002) INITIAL TIME = 1

:GROUP .Control

(003) SAVEPER = 1 [0,?]

:GROUP .Control

(004) TIME STEP = 0.25 [0,?]

:GROUP .Control

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

.MOBU-SDyM

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

(005) "% Wet" =

Chance of Getting Wet

:GROUP .MOBU-SDyM

(006) "1997 check" =

ABS ( "1997"

- 18.19)

:GROUP .MOBU-SDyM

(007) "1997" =

SAMPLE IF TRUE( Time

= 1460,

OW Size ,

0)

:GROUP .MOBU-SDyM

(008) "2014 check" =

ABS ( "2014"

- 0.67)

:GROUP .MOBU-SDyM

(009) "2014" =

SAMPLE IF TRUE( Time

= 7665,

OW Size ,

0)

:GROUP .MOBU-SDyM

(010) "2019 check" =

ABS ( 6.045

- "2019" )

:GROUP .MOBU-SDyM

(011) "2019" =

SAMPLE IF TRUE( Time

= 9490,

OW Size ,

0)

:GROUP .MOBU-SDyM

(012) a =

ABS ( Std Deviates )

:GROUP .MOBU-SDyM

(013) Accum Improvement =

INTEG( I ,

0)

:GROUP .MOBU-SDyM

(014) Accum Stems =

INTEG( Daily MW Increase[North]

+ Daily MW Increase[Central]

+ Daily MW Increase[South] ,

0)

:GROUP .MOBU-SDyM

(015) Adjusted Trigger[South] =

if then else ( Sun angle[South]

< Sun Angle Trigger

:AND: Smoothed Temp[South]

< Temp Tresh South ,

1,

0)

Adjusted Trigger[Central] =

if then else ( Sun angle[Central]

< Sun Angle Trigger

:AND: Smoothed Temp[Central]

< Temp Tresh Central ,

1,

0)

Adjusted Trigger[North] =

if then else ( Sun angle[North]

< Sun Angle Trigger

:AND: Smoothed Temp[North]

< Temp Tresh North ,

1,

0)

:GROUP .MOBU-SDyM

(016) Adult Deaths[Region] =

max ( 0,

Sens Adult Deaths[Region]

\* ZIDZ ( Adults[Region] ,

Adult Longevity[Region] ) )

:GROUP .MOBU-SDyM

(017) Adult Longevity[Region] =

if then else ( xIDZ ( DD of Adults ,

Day Degrees[Region] ,

1)

> 50,

1,

xIDZ ( DD of Adults ,

Day Degrees[Region] ,

1) )

:GROUP .MOBU-SDyM

(018) Adults[South] =

INTEG( Maturing[South]

+ Spring Migration[South]

+ "Sum Disp South-Central"[South]

+ "Sum Disp South-North"[South]

- Adult Deaths[South]

- Spring Migration DR[South]

- "Sum Disp South-North"[North]

- "Sum Disp South-Central"[Central]

- Fall Migration DR[South]

- Begin Migration ,

0)

Adults[Central] =

INTEG( Maturing[Central]

+ Spring Migration[Central]

+ "Sum Disp South-Central"[Central]

+ "Sum Disp Central-North"[Central]

- Adult Deaths[Central]

- Spring Migration DR[Central]

- "Sum Disp South-Central"[South]

- "Sum Disp Central-North"[North]

- Fall Migration DR[Central] ,

0)

Adults[North] =

INTEG( Maturing[North]

+ Spring Migration[North]

+ "Sum Disp South-North"[North]

+ "Sum Disp Central-North"[North]

- Adult Deaths[North]

- Spring Migration DR[North]

- "Sum Disp South-North"[South]

- "Sum Disp Central-North"[Central]

- Fall Migration DR[North] ,

0)

:GROUP .MOBU-SDyM

(019) "Adults/patch"[Region] =

max ( 0,

SMOOTH ( ZIDZ ( Adults[Region] ,

Number of Patches[Region] ) ,

30) )

:GROUP .MOBU-SDyM

(020) AREA UTILITY =

( Colonies Area

- ( 2.25) )

/ 0.875

:GROUP .MOBU-SDyM

(021) Area with Milweed[Region] =

Total Milkweed Stems[Region]

/ Plant per ha[Region]

:GROUP .MOBU-SDyM

(022) "Area-Trend" =

( Rate of change

- 1)

\* Colonies Area

:GROUP .MOBU-SDyM

(023) ASC UTILITY ==

0.4015

:GROUP .MOBU-SDyM

(024) Avail Down[Region] =

if then else ( Day of year

> 360,

Improvement Available per Season[Region] ,

0)

:GROUP .MOBU-SDyM

(025) Avail Up[Region] =

if then else ( Fall Trigger[Region]

= 0,

Improvement Available[Region] ,

0)

:GROUP .MOBU-SDyM

(026) Available area[Region] =

Available Stems[Region]

/ Plant per ha[Region]

:GROUP .MOBU-SDyM

(027) Available patches[Region] =

ZIDZ ( Available area[Region] ,

Random Patch Area[Region] )

:GROUP .MOBU-SDyM

(028) Available Stems[Region] =

max ( 0,

Total Milkweed Stems[Region]

- Adults[Region] )

:GROUP .MOBU-SDyM

(029) Average OW Simulation Value =

Past Quantity Held OW

/ ( Averaging Time Real

\* 365)

:GROUP .MOBU-SDyM

(030) Average Real Value =

Past Quantity Held Real

/ ( Averaging Time Real

\* 365)

:GROUP .MOBU-SDyM

(031) Averaging Time Real = 3 [0,100,1]

:GROUP .MOBU-SDyM

(032) Avg Adult age[Region] =

min ( 50,

ZIDZ ( Maturing delay[Region] ,

Maturing[Region] ) )

:GROUP .MOBU-SDyM

(033) Avg Interpatch Distance[Region] =

xIDZ ( 0.5,

SQRT ( Available patches[Region]

/ ( Empty Area[Region]

\* sqmt per ha ) ) ,

30000)

\* Sens Interpatch Distance[Region]

:GROUP .MOBU-SDyM

(034) Begin Migration =

max ( 0,

Adults[South]

\* Fall Trigger[South] )

:GROUP .MOBU-SDyM

(035) Body Temperature While Overwintering =

( 1.078

\* Temperature Mex

- ( 0.034

\* Exposure

\* 100)

- 0.089)

\* Sens Body Temperature

:GROUP .MOBU-SDyM

(036) Central Habitat =

WITH LOOKUP( Simulation Year ,

([(0,0)-(2113,10)],(1993,2.25238e+09),(1994,2.24427e+09),(1995,2.23615e+09)

,(1996,2.21734e+09),(1997,2.19574e+09),(1998,2.15758e+09),(1999,2.11521e+09)

,(2000,2.07112e+09),(2001,2.02726e+09),(2002,1.98874e+09),(2003,1.95099e+09)

,(2004,1.90834e+09),(2005,1.86428e+09),(2006,1.81829e+09),(2007,1.77544e+09)

,(2008,1.73623e+09),(2009,1.70472e+09),(2010,1.6833e+09),(2011,1.66714e+09)

,(2012,1.65617e+09),(2013,1.64753e+09),(2014,1.63926e+09),(2015,1.63545e+09)

,(2016,1.63144e+09),(2017,1.62688e+09),(2018,1.62232e+09),(2019,1.61863e+09)

,(2020,1.6151e+09),(2021,1.61158e+09),(2022,1.60802e+09),(2023,1.6044e+09)

,(2024,1.60078e+09),(2025,1.59716e+09),(2026,1.59387e+09),(2027,1.59063e+09)

,(2028,1.58738e+09),(2029,1.58414e+09),(2030,1.5809e+09),(2031,1.57765e+09)

,(2032,1.57441e+09),(2033,1.57116e+09),(2034,1.56792e+09),(2035,1.56466e+09)

,(2036,1.56132e+09),(2037,1.55798e+09),(2038,1.55464e+09),(2039,1.5513e+09)

,(2040,1.54796e+09),(2041,1.54462e+09),(2042,1.54128e+09),(2043,1.53794e+09)

,(2044,1.53479e+09),(2045,1.53167e+09),(2046,1.52855e+09),(2047,1.52543e+09)

,(2048,1.52231e+09),(2049,1.51919e+09),(2050,1.51607e+09),(2051,1.51295e+09)

,(2052,1.50983e+09),(2053,1.50671e+09),(2054,1.50359e+09),(2055,1.50047e+09)

,(2056,1.49735e+09),(2057,1.49423e+09),(2058,1.49111e+09),(2059,1.48799e+09)

,(2060,1.485e+09),(2061,1.48201e+09),(2062,1.47902e+09),(2063,1.47603e+09)

,(2064,1.47304e+09),(2065,1.47006e+09),(2066,1.46707e+09),(2067,1.46408e+09)

,(2068,1.46109e+09),(2069,1.4581e+09),(2070,1.45511e+09),(2071,1.45213e+09)

,(2072,1.44914e+09),(2073,1.44615e+09),(2074,1.44316e+09),(2075,1.44017e+09)

,(2076,1.43718e+09),(2077,1.43419e+09),(2078,1.43121e+09),(2079,1.42822e+09)

,(2080,1.42523e+09),(2081,1.42224e+09),(2082,1.41925e+09),(2083,1.41627e+09)

,(2084,1.41328e+09),(2085,1.41029e+09),(2086,1.4073e+09),(2087,1.40431e+09)

,(2088,1.40132e+09),(2089,1.39833e+09),(2090,1.39535e+09),(2091,1.39254e+09)

,(2092,1.38974e+09),(2093,1.38693e+09),(2094,1.38413e+09),(2095,1.38132e+09)

,(2096,1.37852e+09),(2097,1.37572e+09),(2098,1.37291e+09),(2099,1.37011e+09)

,(2100,1.3673e+09),(2101,1.3645e+09),(2102,1.36169e+09),(2103,1.35899e+09)

,(2104,1.35634e+09),(2105,1.35368e+09),(2106,1.35103e+09),(2107,1.34837e+09)

,(2108,1.34572e+09),(2109,1.34554e+09) )

)

:GROUP .MOBU-SDyM

(037) Chance of Getting Wet =

if then else ( Precipitation Mex

>= 0.1,

1,

0)

:GROUP .MOBU-SDyM

(038) Change in Sex Ratio = 1

:GROUP .MOBU-SDyM

(039) Change of Milkweed Availability Central = 1 [0,1e+07]

:GROUP .MOBU-SDyM

(040) Change of Milkweed Availability North = 1

:GROUP .MOBU-SDyM

(041) Change of Milkweed Availability South = 1

:GROUP .MOBU-SDyM

(042) Classes : MNL

:GROUP .MOBU-SDyM

(043) Clean[Region] =

if then else ( Fall Trigger[South]

= 1,

Migrating South[Region] ,

0)

:GROUP .MOBU-SDyM

(044) Colonies Area =

report

:GROUP .MOBU-SDyM

(045) Concerning population in Canada = 1.18572e+07

:GROUP .MOBU-SDyM

(046) Concerning population in The US = 3.7531e+07

:GROUP .MOBU-SDyM

(047) Contribution = 20

:GROUP .MOBU-SDyM

(048) CONTRIBUTION UTILITY =

( Contribution

- ( 76.25) )

/ 24.375

:GROUP .MOBU-SDyM

(049) D =

sum ( Daily MW Increase[Region!] )

:GROUP .MOBU-SDyM

(050) Daily MW Increase[Region] =

if then else ( Simulation Year

>= 2021,

Yearly MW Improvement[Region] ,

0)

/ 365

:GROUP .MOBU-SDyM

(051) Data LL =

ln ( 1

/ ( sd

\* SQRT ( 2

\* 3.14159) ) )

- ( Real report

- report )

^ 2

:GROUP .MOBU-SDyM

(052) Day Degrees[Region] =

if then else ( Temperature Breeding[Region]

> Heat Impairment Treshold

:OR: Temperature Breeding[Region]

< Developmental Zero ,

0,

Temperature Breeding[Region]

- Developmental Zero )

:GROUP .MOBU-SDyM

(053) Day of the month =

GET TIME VALUE ( 1,

0,

4)

:GROUP .MOBU-SDyM

(054) Day of year =

Day of the month

+ ( ( Month of the year

- 1)

\* 30.4167)

:GROUP .MOBU-SDyM

(055) Days to Eclode[Region] =

ZIDZ ( DD to Eclode ,

Day Degrees[Region] )

:GROUP .MOBU-SDyM

(056) Days to Hatch[Region] =

ZIDZ ( DD to Hatch ,

Day Degrees[Region] )

:GROUP .MOBU-SDyM

(057) Days to Pupate[Region] =

ZIDZ ( DD to Pupate ,

Day Degrees[Region] )

:GROUP .MOBU-SDyM

(058) DD of Adults = 330

:GROUP .MOBU-SDyM

(059) DD to Eclode = 180

:GROUP .MOBU-SDyM

(060) DD to Hatch = 45

:GROUP .MOBU-SDyM

(061) DD to Pupate = 112

:GROUP .MOBU-SDyM

(062) Deaths While Overwintering =

max ( 0,

Overwintering

\* Predation DR While Overwintering

+ ( Overwintering

\* Weather Related DR ) )

:GROUP .MOBU-SDyM

(063) Delayed Value OW =

DELAY FIXED ( report ,Averaging Time Real

\* 365,

report )

:GROUP .MOBU-SDyM

(064) Delayed Value Real =

DELAY FIXED ( Real report ,Averaging Time Real

\* 365,

Real report )

:GROUP .MOBU-SDyM

(065) Density Dependent DR[Region] =

( 1

- ( 1

/ ( 1

+ ( 1

/ ( EXP ( 1.0175

+ ( -0.1972

\* min ( 100,

Eggs per plant[Region] ) ) ) )

) ) ) )

\* Sens Density Dependent DR

:GROUP .MOBU-SDyM

(066) Depensatory Effect[Region] =

1

- ( 1

/ ( 1

+ EXP ( ( slope

/ midpoint )

\* ( min ( 3.5e+08,

Adults[Region] )

- midpoint ) ) ) )

\* Sens Depensatory

:GROUP .MOBU-SDyM

(067) Developmental Zero = 11.5

:GROUP .MOBU-SDyM

(068) Deviates =

INTEG( a ,

0)

:GROUP .MOBU-SDyM

(069) Dispersion Mortality Central[North] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival Central Mean[North] ,

Dispersion Survival Central SD[North] ,

NOISE SEED )

Dispersion Mortality Central[Central] = 0

Dispersion Mortality Central[South] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival Central Mean[South] ,

Dispersion Survival Central SD[South] ,

NOISE SEED )

:GROUP .MOBU-SDyM

(070) Dispersion Mortality Mexico[South] =

1

- RANDOM BETA ( 0,

1,

Dispersion Survival Mexico alpha[South] ,

Dispersion Survival Mexico beta[South] ,

0,

1,

NOISE SEED )

Dispersion Mortality Mexico[Central] =

1

- RANDOM BETA ( 0,

1,

Dispersion Survival Mexico alpha[Central] ,

Dispersion Survival Mexico beta[Central] ,

0,

1,

NOISE SEED )

Dispersion Mortality Mexico[North] = 1

:GROUP .MOBU-SDyM

(071) Dispersion Mortality North[South] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival North Mean[South] ,

Dispersion Survival North SD[South] ,

NOISE SEED )

Dispersion Mortality North[Central] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival North Mean[Central] ,

Dispersion Survival North SD[Central] ,

NOISE SEED )

Dispersion Mortality North[North] = 0

:GROUP .MOBU-SDyM

(072) Dispersion Mortality South[South] = 0

Dispersion Mortality South[Central] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival South Mean[Central] ,

Dispersion Survival South SD[Central] ,

NOISE SEED )

Dispersion Mortality South[North] =

RANDOM NORMAL ( 0,

1,

1

- Dispersion Survival South Mean[North] ,

Dispersion Survival South SD[North] ,

NOISE SEED )

:GROUP .MOBU-SDyM

(073) Dispersion Survival Central Mean[South] = 0.567

Dispersion Survival Central Mean[Central] = 1

Dispersion Survival Central Mean[North] = 0.742

:GROUP .MOBU-SDyM

(074) Dispersion Survival Central SD[South] = 0.128239

Dispersion Survival Central SD[Central] = 0

Dispersion Survival Central SD[North] = 0.135708

:GROUP .MOBU-SDyM

(075) Dispersion Survival Mexico alpha[South] = 1.21203

Dispersion Survival Mexico alpha[Central] = 0.50015

Dispersion Survival Mexico alpha[North] = 0

:GROUP .MOBU-SDyM

(076) Dispersion Survival Mexico beta[South] = 1.13232

Dispersion Survival Mexico beta[Central] = 2.05164

Dispersion Survival Mexico beta[North] = 0

:GROUP .MOBU-SDyM

(077) Dispersion Survival North Mean[South] = 0.25

Dispersion Survival North Mean[Central] = 0.5

Dispersion Survival North Mean[North] = 1

:GROUP .MOBU-SDyM

(078) Dispersion Survival North SD[South] = 0.190489

Dispersion Survival North SD[Central] = 0.190489

Dispersion Survival North SD[North] = 0

:GROUP .MOBU-SDyM

(079) Dispersion Survival South Mean[South] = 1

Dispersion Survival South Mean[Central] = 0.733

Dispersion Survival South Mean[North] = 0.544

:GROUP .MOBU-SDyM

(080) Dispersion Survival South SD[South] = 0

Dispersion Survival South SD[Central] = 0.136626

Dispersion Survival South SD[North] = 0.182836

:GROUP .MOBU-SDyM

(081) Distance effect[Region] =

1

/ ( EXP ( ( ( min ( 30000,

Avg Interpatch Distance[Region] ) )

/ 12000)

^ 3) )

:GROUP .MOBU-SDyM

(082) DR Dry =

WITH LOOKUP( Body Temperature While Overwintering ,

([(-100,0)-(100,10)],(-100,1),(-15,1),(-14,0.999),(-13,0.98),(-12,0.94)

,(-11,0.89),(-10,0.79),(-9,0.67),(-8,0.52),(-7,0.35),(-6,0.21),(-5,0.12)

,(-4,0.06),(-3,0.01),(-2,0.005),(-1,0),(0,0),(1,0),(2,0),(3,0),(4,0)

,(5,0),(6,0),(7,0),(8,0),(9,0),(10,0),(11,0),(12,0),(13,0),(14,0)

,(15,0),(16,0),(100,0) )

)

:GROUP .MOBU-SDyM

(083) DR Fall Migration Mean[South] = 0.31

DR Fall Migration Mean[Central] = 0.433

DR Fall Migration Mean[North] = 0.5

:GROUP .MOBU-SDyM

(084) DR Fall Migration SD[Region] = 0.159687, 0.128239, 0.190489

:GROUP .MOBU-SDyM

(085) DR Wet =

WITH LOOKUP( Body Temperature While Overwintering ,

([(-50,0)-(100,10)],(-50,1),(-15,1),(-14,1),(-13,1),(-12,1),(-11,1)

,(-10,1),(-9,1),(-8,0.999),(-7,0.98),(-6,0.92),(-5,0.78),(-4,0.3)

,(-3,0.05),(-2,0.01),(-1,0),(0,0),(1,0),(2,0),(3,0),(4,0),(5,0),(6,0)

,(7,0),(8,0),(9,0),(10,0),(11,0),(12,0),(13,0),(14,0),(15,0),(16,0)

,(100,0) )

)

:GROUP .MOBU-SDyM

(086) Educational Institution ==

0.0978

:GROUP .MOBU-SDyM

(087) Egg Laying[South] =

( ( 1

- Fall Trigger[South] )

\* max ( 0,

( Adults[South]

- sum ( Migrating South[Region!] ) )

\* "Sex Ratio (perc of females)"

\* Eggs per Female per day[South]

\* Distance effect[South]

\* Depensatory Effect[South] ) )

\* Sens Egg Laying[South]

Egg Laying[Central] =

( ( 1

- Fall Trigger[Central] )

\* max ( 0,

( Adults[Central] )

\* "Sex Ratio (perc of females)"

\* Eggs per Female per day[Central]

\* Distance effect[Central]

\* Depensatory Effect[Central] ) )

\* Sens Egg Laying[Central]

Egg Laying[North] =

( ( 1

- Fall Trigger[North] )

\* max ( 0,

( Adults[North] )

\* "Sex Ratio (perc of females)"

\* Eggs per Female per day[North]

\* Distance effect[North]

\* Depensatory Effect[North] ) )

\* Sens Egg Laying[North]

:GROUP .MOBU-SDyM

(088) Eggs[Region] =

max ( 0,

Immature[Region]

\* ( ZIDZ ( Days to Hatch[Region] ,

( Days to Eclode[Region]

+ Days to Hatch[Region]

+ Days to Pupate[Region] ) ) ) )

:GROUP .MOBU-SDyM

(089) Eggs per Female per day[Region] =

WITH LOOKUP( Avg Adult age[Region] ,

([(0,0)-(100000,50)],(0,50),(1,50),(2,48),(3,46),(4,44),(5,42),(6,40)

,(7,38),(8,36),(9,34),(10,32),(11,30),(12,28),(13,26),(14,24),(15,22)

,(16,20),(17,18),(18,16),(19,14),(20,12),(21,10),(22,8),(23,6),(24,4)

,(25,2),(26,0),(100000,0) )

)

:GROUP .MOBU-SDyM

(090) Eggs per plant[Region] =

max ( 0,

xIDZ ( Eggs[Region] ,

Total Milkweed Stems[Region] ,

Eggs[Region] ) )

:GROUP .MOBU-SDyM

(091) Empty Area[Region] =

Total Area[Region]

- Available area[Region]

:GROUP .MOBU-SDyM

(092) End Migration =

DELAY CONVEYOR ( Begin Migration ,

15,

Weather Fall mig DR ,init ,

0,

0)

:GROUP .MOBU-SDyM

(093) Exposure = 0 [-1,1]

:GROUP .MOBU-SDyM

(094) Exposure Prior PDF =

INITIAL( - ln ( mu5 ) )

:GROUP .MOBU-SDyM

(095) Fall Migration DR[South] =

max ( 0,

if then else ( Fall Trigger[South]

= 1,

min ( Adults[South] ,

RANDOM NORMAL ( 0,

1,

DR Fall Migration Mean[South] ,

DR Fall Migration SD[South] ,

NOISE SEED ) ) ,

0) )

Fall Migration DR[Central] =

max ( 0,

if then else ( Fall Trigger[Central]

= 1,

min ( Adults[Central] ,

RANDOM NORMAL ( 0,

1,

DR Fall Migration Mean[Central] ,

DR Fall Migration SD[Central] ,

NOISE SEED )

\* ABS ( "Sum Disp South-Central"[Central] ) ) ,

0) )

Fall Migration DR[North] =

max ( 0,

if then else ( Fall Trigger[North]

= 1,

min ( Adults[North] ,

RANDOM NORMAL ( 0,

1,

DR Fall Migration Mean[North] ,

DR Fall Migration SD[North] ,

NOISE SEED )

\* ABS ( "Sum Disp Central-North"[North] ) ) ,

0) )

:GROUP .MOBU-SDyM

(096) Fall Trigger[Region] =

( Adjusted Trigger[Region] )

:GROUP .MOBU-SDyM

(097) Fed Govt 0 ==

-0.1989

:GROUP .MOBU-SDyM

(098) Forecast Humidity LUT (

GET DIRECT LOOKUPS('LUTs.xlsx',

'Forecast Humidity',

'1',

'A2') )

:GROUP .MOBU-SDyM

(099) Geography = 2 [1,4,1]

:GROUP .MOBU-SDyM

(100) GEOGRAPHY UTILITY =

if then else ( Geography

= 1,

Mexico ,

if then else ( Geography

= 2,

My Country ,

if then else ( Geography

= 3,

The three countries ,

if then else ( Geography

= 4,

The Other country ,

0) ) ) )

:GROUP .MOBU-SDyM

(101) Habitat Change[South] =

WITH LOOKUP( Time ,

([(1,0)-(41976,2e+07)],(1,0),(366,310000),(731,310000),(1096,4.22e+06)

,(1461,5.23e+06),(1826,1.1e+07),(2191,1.1e+07),(2556,1.1e+07),(2921,1.1e+07)

,(3286,1.1e+07),(3651,1.1e+07),(4016,1.1e+07),(4381,1.1e+07),(4746,1.1e+07)

,(5111,1.1e+07),(5476,1.1e+07),(5841,8.53e+06),(6206,5.05e+06),(6571,3.32e+06)

,(6936,1.63e+06),(7301,1.63e+06),(7666,1.62e+06),(8031,1.63e+06),

(8396,1.63e+06),(8761,950000),(9126,420000),(9491,430000),(9856,430000)

,(10221,430000),(10586,420000),(10951,480000),(11316,880000),(11681,870000)

,(12046,870000),(12411,870000),(12776,1.03e+06),(13141,1.29e+06),

(13506,1.28e+06),(13871,1.17e+06),(14236,530000),(14601,530000),(14966,650000)

,(15331,760000),(15696,760000),(16061,760000),(16426,760000),(16791,790000)

,(17156,1.11e+06),(17521,1.12e+06),(17886,1.12e+06),(178860,1.12e+06)

)

)

Habitat Change[Central] =

WITH LOOKUP( Time ,

([(1,0)-(178900,5e+07)],(1,0),(366,8.11e+06),(731,8.15e+06),(1096,1.88e+07)

,(1461,2.16e+07),(1826,3.82e+07),(2191,4.24e+07),(2556,4.41e+07),

(2921,4.39e+07),(3286,3.85e+07),(3651,3.78e+07),(4016,4.27e+07),(4381,4.41e+07)

,(4746,4.6e+07),(5111,4.28e+07),(5476,3.92e+07),(5841,3.15e+07),(6206,2.14e+07)

,(6571,1.61e+07),(6936,1.1e+07),(7301,8.64e+06),(7666,8.26e+06),(8031,3.81e+06)

,(8396,4.01e+06),(8761,4.56e+06),(9126,4.56e+06),(9491,3.69e+06),

(9856,3.53e+06),(10221,3.52e+06),(10586,3.56e+06),(10951,3.62e+06)

,(11316,3.62e+06),(11681,3.62e+06),(12046,3.29e+06),(12411,3.24e+06)

,(12776,3.25e+06),(13141,3.24e+06),(13506,3.24e+06),(13871,3.25e+06)

,(14236,3.24e+06),(14601,3.25e+06),(14966,3.24e+06),(15331,3.26e+06)

,(15696,3.34e+06),(16061,3.34e+06),(16426,3.34e+06),(16791,3.34e+06)

,(17156,3.34e+06),(17521,3.34e+06),(178900,3.34e+06) )

)

Habitat Change[North] =

WITH LOOKUP( Time ,

([(1,0)-(41976,4e+07)],(1,0),(366,7.51e+06),(731,7.51e+06),(1096,1.03e+07)

,(1461,1.39e+07),(1826,1.87e+07),(2191,2.33e+07),(2556,2.56e+07),

(2921,2.45e+07),(3286,2.36e+07),(3651,2.32e+07),(4016,2.92e+07),(4381,3.02e+07)

,(4746,3.51e+07),(5111,3.54e+07),(5476,3.48e+07),(5841,2.37e+07),

(6206,1.58e+07),(6571,1.29e+07),(6936,8.41e+06),(7301,7.22e+06),(7666,3.59e+06)

,(8031,3.1e+06),(8396,2.05e+06),(8761,1.52e+06),(9126,1.53e+06),(9491,2.03e+06)

,(9856,2.05e+06),(10221,2.05e+06),(10586,2.06e+06),(10951,1.78e+06)

,(11316,1.78e+06),(11681,1.77e+06),(12046,1.77e+06),(12411,1.79e+06)

,(12776,1.77e+06),(13141,1.76e+06),(13506,1.77e+06),(13871,1.73e+06)

,(14236,1.66e+06),(14601,1.65e+06),(14966,1.65e+06),(15331,1.65e+06)

,(15696,1.65e+06),(16061,1.66e+06),(16426,1.65e+06),(16791,1.65e+06)

,(17156,1.65e+06),(171560,1.65e+06) )

)

:GROUP .MOBU-SDyM

(102) Heat Impairment Treshold = 32

:GROUP .MOBU-SDyM

(103) Humidity[South] =

Humidity Mean[South] ( Time )

Humidity[Central] =

Humidity Mean[Central] ( Time )

Humidity[North] =

Humidity Mean[North] ( Time )

:GROUP .MOBU-SDyM

(104) Humidity Mean[South] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'C2') )

Humidity Mean[Central] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'D2') )

Humidity Mean[North] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'E2') )

:GROUP .MOBU-SDyM

(105) Hurricanes Estimate = 0 [-1,1]

:GROUP .MOBU-SDyM

(106) I =

Improve

:GROUP .MOBU-SDyM

(107) Ideal Humidity for Milkweed Growth = 0.8

:GROUP .MOBU-SDyM

(108) Ideal Temperature for Milkweed Growth = 21.8647

:GROUP .MOBU-SDyM

(109) Immature[Region] =

INTEG( Egg Laying[Region]

- Maturing[Region]

- Immature Deaths[Region] ,

0)

:GROUP .MOBU-SDyM

(110) Immature Deaths[Region] =

if then else ( Temperature Breeding[Region]

> -10,

max ( 0,

( ( Egg Laying[Region]

\* Density Dependent DR[Region] )

+ ( Egg Laying[Region]

\* ( ( 1

- Immature Survival[Region] )

/ 15) ) ) ) ,

max ( 0,

Immature[Region] ) )

+ if then else ( Month of the year

= 11,

max ( 0,

Immature[Region] ) ,

0)

:GROUP .MOBU-SDyM

(111) Immature Survival[South] =

Immature Survival LUT[South] ( Month of the year )

Immature Survival[Central] =

Immature Survival LUT[Central] ( Month of the year )

Immature Survival[North] =

Immature Survival LUT[North] ( Month of the year )

:GROUP .MOBU-SDyM

(112) Immature Survival LUT[South] (

GET DIRECT LOOKUPS('LUTs.xlsx',

'Immature survival - S',

'1',

'A2') )

Immature Survival LUT[Central] (

GET DIRECT LOOKUPS('LUTs.xlsx',

'Immature Survival - C',

'1',

'A2') )

Immature Survival LUT[North] (

GET DIRECT LOOKUPS('LUTs.xlsx',

'Immature Survival - N',

'1',

'A2') )

:GROUP .MOBU-SDyM

(113) Improve =

( D

\* S )

+ ( if then else ( Simulation Year

> 2030,

if then else ( Average OW Simulation Value

< 5,

15000,

1)

\* ( 500

\* ( Average OW Simulation Value

- 6)

^ 2) ,

if then else ( Average OW Simulation Value

> 6,

1500,

0) ) )

:GROUP .MOBU-SDyM

(114) Improvement Available[Region] =

MW availability[Region]

\* Stems Improvement[Region]

:GROUP .MOBU-SDyM

(115) Improvement Available per Season[Region] =

INTEG( Avail Up[Region]

- Avail Down[Region] ,

0)

:GROUP .MOBU-SDyM

(116) init (

[(0,0)-(10,10)],(0,1),(1,1) )

:GROUP .MOBU-SDyM

(117) Initial Size = 6.23

:GROUP .MOBU-SDyM

(118) Intl NGO 0 ==

0.0833

:GROUP .MOBU-SDyM

(119) Leader = 1 [1,4,1]

:GROUP .MOBU-SDyM

(120) LEADER UTILITY =

if then else ( Leader

= 1,

Local NGO 0 ,

if then else ( Leader

= 2,

Intl NGO 0 ,

if then else ( Leader

= 3,

Fed Govt 0 ,

if then else ( Leader

= 4,

Educational Institution ,

0) ) ) )

:GROUP .MOBU-SDyM

(121) length of Season[Region] = 226, 171, 117

:GROUP .MOBU-SDyM

(122) Local NGO 0 ==

0.0178

:GROUP .MOBU-SDyM

(123) Logit Priors = 0

:GROUP .MOBU-SDyM

(124) Maturing[Region] =

max ( 0,

ZIDZ ( Immature[Region] ,

Days to Eclode[Region]

+ Days to Hatch[Region]

+ Days to Pupate[Region] ) )

:GROUP .MOBU-SDyM

(125) Maturing delay[Region] =

DELAY MATERIAL ( Maturing[Region] ,

Adult Longevity[Region] ,Maturing[Region] ,

10)

:GROUP .MOBU-SDyM

(126) Mean Improvement Available[Region] =

SAMPLE IF TRUE( Day of year

>= 320

:AND: Day of year

<= 321,

Improvement Available per Season[Region]

/ length of Season[Region] ,

0)

:GROUP .MOBU-SDyM

(127) Mean Milkweed Patch Area = 0.0703288 [0,1]

:GROUP .MOBU-SDyM

(128) Mean Stems per Season[Region] =

SAMPLE IF TRUE( Day of year

>= 320

:AND: Day of year

<= 321,

Stems per Season[Region]

/ length of Season[Region] ,

0)

:GROUP .MOBU-SDyM

(129) Mexico ==

-0.3078

:GROUP .MOBU-SDyM

(130) midpoint = 2.00768e+07 [0,4.5e+08,1e+06]

:GROUP .MOBU-SDyM

(131) Mig =

if then else ( Fall Trigger[North]

= 1,

"Sum Disp South-North"[South] ,

0)

+ if then else ( Fall Trigger[Central]

= 1,

"Sum Disp South-Central"[South] ,

0)

:GROUP .MOBU-SDyM

(132) Migrating =

INTEG( Begin Migration

- End Migration

- Weather Related Mig DR ,

0)

:GROUP .MOBU-SDyM

(133) Migrating South[Region] =

INTEG( Mig

- Clean[Region] ,

0)

:GROUP .MOBU-SDyM

(134) Moisture[Region] =

SMOOTH ( ( 1

/ ( 1

+ EXP ( -10

\* ( Soil Humidity Breeding[Region]

- ( Ideal Humidity for Milkweed Growth

\* 0.5) ) ) ) )

\* ( 1

/ ( 1

+ EXP ( 1

\* ( Soil Humidity Breeding[Region]

- ( Ideal Humidity for Milkweed Growth

) ) ) ) )

\* ( 1

/ ( 1

+ EXP ( -0.2

\* ( Temperature Breeding[Region]

- ( Ideal Temperature for Milkweed Growth

\* 0.5) ) ) ) )

\* 1

/ ( 1

+ EXP ( 0.05

\* ( Temperature Breeding[Region]

- ( Ideal Temperature for Milkweed Growth

) ) ) ) ,

15)

:GROUP .MOBU-SDyM

(135) .68164}Moisture Index Estimate = 20.2517 [0,6]

:GROUP .MOBU-SDyM

(136) Monarch Trends =

Monarch Trends LUT ( Time )

:GROUP .MOBU-SDyM

(137) Monarch Trends LUT (

GET DIRECT LOOKUPS('LUTs.xlsx',

'Monarch Trends',

'1',

'A2') )

:GROUP .MOBU-SDyM

(138) Monarchs Density While Overwintering = 17 [0,2e+08]

:GROUP .MOBU-SDyM

(139) Month of the year =

GET TIME VALUE ( 1,

0,

3)

:GROUP .MOBU-SDyM

(140) Move from Central[South] =

WITH LOOKUP( Month of the year

\* Sens Move from central[South] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0.039),(6,0),(7,0),(8,0)

,(9,0.563),(10,1),(11,0),(12,1) )

)

Move from Central[Central] =

1

- ( Move from Central[South]

+ Move from Central[North]

+ Move Mexico[Central] )

Move from Central[North] =

WITH LOOKUP( Month of the year

\* Sens Move from central[North] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,0.667),(7,0.738)

,(8,0.438),(9,0),(10,0),(11,0),(12,0) )

)

:GROUP .MOBU-SDyM

(141) Move from North[South] =

WITH LOOKUP( Month of the year

\* Sens Move From North[South] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,0),(7,0),(8,0),

(9,0.125),(10,1),(11,1),(12,1) )

)

Move from North[Central] =

WITH LOOKUP( Month of the year

\* Sens Move From North[Central] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,0),(7,0.017),(8,0.084)

,(9,0.167),(10,1),(11,0),(12,0) )

)

Move from North[North] =

1

- ( Move from North[Central]

+ Move from North[South] )

:GROUP .MOBU-SDyM

(142) Move from South[South] =

1

- ( Move from South[Central]

+ Move from South[North] )

Move from South[Central] =

WITH LOOKUP( Month of the year

\* Sens Move from South[Central] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0.13),(6,0.355),(7,0.183)

,(8,0.18),(9,0),(10,0),(11,0),(12,0) )

)

Move from South[North] =

WITH LOOKUP( Month of the year

\* Sens Move from South[North] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,0.333),(7,0.169)

,(8,0.016),(9,0),(10,0),(11,0),(12,0) )

)

:GROUP .MOBU-SDyM

(143) Move Mexico[South] =

WITH LOOKUP( Month of the year

\* Sens Move from Mexico[South] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0.875),(5,0.697),(6,1),(7,1)

,(8,1),(9,0),(10,0),(11,0),(12,0) )

)

Move Mexico[Central] =

WITH LOOKUP( Month of the year

\* Sens Move from Mexico[Central] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0.348),(6,0),(7,0),(8,0)

,(9,0),(10,0),(11,0),(12,0) )

)

Move Mexico[North] =

WITH LOOKUP( Month of the year

\* Sens Move from Mexico[North] ,

([(0,0)-(12,10)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,0),(7,0),(8,0),

(9,0),(10,0),(11,0),(12,0) )

)

:GROUP .MOBU-SDyM

(144) Mu of shape parameter prior PDF = 2.1e+07

:GROUP .MOBU-SDyM

(145) mu1 = 27

:GROUP .MOBU-SDyM

(146) mu2 =

INITIAL( ln ( Mu of shape parameter prior PDF

^ 2

/ ( Mu of shape parameter prior PDF

^ 2

+ Sigma of scale parameter prior PDF

^ 2)

^ 0.5) )

:GROUP .MOBU-SDyM

(147) mu3 = 21

:GROUP .MOBU-SDyM

(148) mu5 = 1.72

:GROUP .MOBU-SDyM

(149) mu6 = 3

:GROUP .MOBU-SDyM

(150) MW availability[Region] =

( Moisture[Region]

\* Moisture Index Estimate )

:GROUP .MOBU-SDyM

(151) MW Change[South] =

( Habitat Change[South]

/ 365)

MW Change[North] =

( Habitat Change[North]

/ 365)

MW Change[Central] =

( Habitat Change[Central]

/ 365)

:GROUP .MOBU-SDyM

(152) MW Humidity Prior PDF =

INITIAL( - ln ( mu6 ) )

:GROUP .MOBU-SDyM

(153) Mw Improvement Logit[South] = 10

Mw Improvement Logit[Central] = 10

Mw Improvement Logit[North] = 10

:GROUP .MOBU-SDyM

(154) MW Stems[South] =

INTEG( Daily MW Increase[South]

- MW Change[South] ,

South Habitat )

MW Stems[Central] =

INTEG( Daily MW Increase[Central]

- MW Change[Central] ,

Central Habitat )

MW Stems[North] =

INTEG( Daily MW Increase[North]

- MW Change[North] ,

North Habitat )

:GROUP .MOBU-SDyM

(155) MW Temperature Prior PDF =

INITIAL( ( 1

/ ( sigma1

\* SQRT ( 2

\* 3.14159) ) )

\* EXP ( - ( ( ( Ideal Temperature for Milkweed Growth

- mu1 )

^ 2)

/ ( 2

\* sigma1

^ 2) ) ) )

:GROUP .MOBU-SDyM

(156) My Country ==

0.2416

:GROUP .MOBU-SDyM

(157) NOISE SEED = 30 [1,10000,1]

:GROUP .MOBU-SDyM

(158) NONE UTILITY ==

-0.4015

:GROUP .MOBU-SDyM

(159) North Habitat =

WITH LOOKUP( Simulation Year ,

([(0,0)-(2113,10)],(1993,1.74895e+09),(1994,1.74144e+09),(1995,1.73394e+09)

,(1996,1.72364e+09),(1997,1.70978e+09),(1998,1.69106e+09),(1999,1.66772e+09)

,(2000,1.64214e+09),(2001,1.61767e+09),(2002,1.59411e+09),(2003,1.57098e+09)

,(2004,1.54176e+09),(2005,1.51158e+09),(2006,1.47649e+09),(2007,1.44112e+09)

,(2008,1.40632e+09),(2009,1.38259e+09),(2010,1.36682e+09),(2011,1.35389e+09)

,(2012,1.34548e+09),(2013,1.33825e+09),(2014,1.33466e+09),(2015,1.33156e+09)

,(2016,1.3295e+09),(2017,1.32798e+09),(2018,1.32646e+09),(2019,1.32443e+09)

,(2020,1.32238e+09),(2021,1.32033e+09),(2022,1.31827e+09),(2023,1.31648e+09)

,(2024,1.3147e+09),(2025,1.31293e+09),(2026,1.31116e+09),(2027,1.30938e+09)

,(2028,1.30761e+09),(2029,1.30584e+09),(2030,1.30407e+09),(2031,1.30234e+09)

,(2032,1.30068e+09),(2033,1.29903e+09),(2034,1.29738e+09),(2035,1.29573e+09)

,(2036,1.29408e+09),(2037,1.29242e+09),(2038,1.29077e+09),(2039,1.28912e+09)

,(2040,1.28747e+09),(2041,1.28581e+09),(2042,1.28416e+09),(2043,1.28246e+09)

,(2044,1.28074e+09),(2045,1.27901e+09),(2046,1.27728e+09),(2047,1.27556e+09)

,(2048,1.27383e+09),(2049,1.27211e+09),(2050,1.27038e+09),(2051,1.26866e+09)

,(2052,1.26693e+09),(2053,1.26521e+09),(2054,1.26348e+09),(2055,1.26175e+09)

,(2056,1.26003e+09),(2057,1.2583e+09),(2058,1.25658e+09),(2059,1.25485e+09)

,(2060,1.25313e+09),(2061,1.2514e+09),(2062,1.24968e+09),(2063,1.24795e+09)

,(2064,1.24623e+09),(2065,1.2445e+09),(2066,1.24277e+09),(2067,1.24105e+09)

,(2068,1.23932e+09),(2069,1.2376e+09),(2070,1.23587e+09),(2071,1.23415e+09)

,(2072,1.23242e+09),(2073,1.2307e+09),(2074,1.22897e+09),(2075,1.22724e+09)

,(2076,1.22552e+09),(2077,1.22379e+09),(2078,1.22207e+09),(2079,1.22034e+09)

,(2080,1.21862e+09),(2081,1.21689e+09),(2082,1.21517e+09),(2083,1.21344e+09)

,(2084,1.21171e+09),(2085,1.20999e+09),(2086,1.20826e+09),(2087,1.20654e+09)

,(2088,1.20481e+09),(2089,1.20309e+09),(2090,1.20136e+09),(2091,1.19976e+09)

,(2092,1.19847e+09),(2093,1.19718e+09),(2094,1.19589e+09),(2095,1.1946e+09)

,(2096,1.19331e+09),(2097,1.19202e+09),(2098,1.19064e+09),(2099,1.18909e+09)

,(2100,1.18754e+09),(2101,1.18599e+09),(2102,1.18444e+09),(2103,1.18289e+09)

,(2104,1.18121e+09),(2105,1.17952e+09),(2106,1.17783e+09),(2107,1.17614e+09)

,(2108,1.17446e+09),(2109,1.17435e+09) )

)

:GROUP .MOBU-SDyM

(160) Number of Patches[Region] =

ZIDZ ( Area with Milweed[Region] ,

( Random Patch Area[Region] ) )

:GROUP .MOBU-SDyM

(161) Overwintering =

INTEG( ( End Migration )

- Deaths While Overwintering

- ( Spring Migration[South] ) ,

Initial Size

\* EXP ( Monarchs Density While Overwintering ) )

:GROUP .MOBU-SDyM

(162) OW Density Prior PDF =

INITIAL( ( 1

/ ( sigma2

\* SQRT ( 2

\* 3.14159) ) )

\* EXP ( - ( ( ( Monarchs Density While Overwintering

- mu2 )

^ 2)

/ ( 2

\* sigma2

^ 2) ) ) )

:GROUP .MOBU-SDyM

(163) OW Size =

if then else ( Month of the year

> 9

:OR: Month of the year

< 3,

Overwintering

/ EXP ( Monarchs Density While Overwintering ) ,

0)

:GROUP .MOBU-SDyM

(164) Past Quantity Held OW =

INTEG( report

- Delayed Value OW ,

report

\* Averaging Time Real

\* 365)

:GROUP .MOBU-SDyM

(165) Past Quantity Held Real =

INTEG( Real report

- Delayed Value Real ,

Real report

\* Averaging Time Real

\* 365)

:GROUP .MOBU-SDyM

(166) Patch size in sqmt[Region] =

sqmt per ha

\* Random Patch Area[Region]

:GROUP .MOBU-SDyM

(167) "PDI Anomalies (Hurricanes)" =

PDI LUT ( Simulation Month )

:GROUP .MOBU-SDyM

(168) PDI LUT (

GET DIRECT LOOKUPS('LUTs.xlsx',

'PDI',

'1',

'A2') )

:GROUP .MOBU-SDyM

(169) Plant per ha[Region] = 33030

:GROUP .MOBU-SDyM

(170) PPT Mean Mex Forecast (

[(0,0)-(10,10)],(1,40.9789),(2,35.4235),(3,31.4438),(4,58.4051),(5,148.66)

,(6,158.236),(7,153.752),(8,225.442),(9,265.732),(10,111.33),(11,60.6776)

,(12,44.251) )

:GROUP .MOBU-SDyM

(171) Ppt Mean Mex Historical (

GET DIRECT LOOKUPS('LUTs.xlsx',

'PPT LogMean Mex',

'1',

'A2') )

:GROUP .MOBU-SDyM

(172) PPT Mex Mean LUT (

GET DIRECT LOOKUPS('LUTs.xlsx',

'PPT LogMean Mex',

'1',

'A2') )

:GROUP .MOBU-SDyM

(173) Precipitation Mex =

if then else ( Time

< 9855,

Ppt Mean Mex Historical ( Simulation Month ) ,

PPT Mean Mex Forecast ( Month of the year )

/ 30.25)

:GROUP .MOBU-SDyM

(174) Predation DR While Overwintering =

RANDOM NORMAL ( 0,

1,

0.041

/ 150

/ TIME STEP ,

0.0173

/ 150

/ TIME STEP ,

NOISE SEED )

\* Sens Predation OW DR

:GROUP .MOBU-SDyM

(175) "Price/Km^2" = 2.5e+08

:GROUP .MOBU-SDyM

(176) Prior Exposure =

INITIAL( - ( ( ( Exposure

- 0.3)

/ 0.3)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(177) Prior Hurricanes =

INITIAL( - ( ( ( Hurricanes Estimate

- 0)

/ 1)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(178) Prior Monarch Density =

INITIAL( - ( ( ( Monarchs Density While Overwintering

- 17.5)

/ 1)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(179) Prior MW Humid =

INITIAL( - ( ( ( Ideal Humidity for Milkweed Growth

- 0.04)

/ 0.25)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(180) Prior MW Temp =

INITIAL( - ( ( ( Ideal Temperature for Milkweed Growth

- 28)

/ 1.5)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(181) Prior Payoff =

Prior Exposure

+ Prior MW Humid

+ Prior Hurricanes

+ Prior Monarch Density

+ Prior MW Temp

+ Prior Temp Mig

:GROUP .MOBU-SDyM

(182) Prior Temp Mig =

INITIAL( - ( ( ( Temperature Migration Treshold

- 21)

/ 0.9)

^ 2)

/ 2 )

:GROUP .MOBU-SDyM

(183) r Real =

ZIDZ ( Real report ,

Delayed Value Real )

:GROUP .MOBU-SDyM

(184) r Simulated =

SMOOTH ( ZIDZ ( report ,

Delayed Value OW ) ,

365

\* 5)

:GROUP .MOBU-SDyM

(185) Random Patch Area[Region] =

EXP ( RANDOM NORMAL ( -100,

100,

ln ( Mean Milkweed Patch Area ) ,

ln ( 2) ,

NOISE SEED ) )

\* Sens Patch[Region]

:GROUP .MOBU-SDyM

(186) Rate of change =

r Simulated

- 1

:GROUP .MOBU-SDyM

(187) "real egg/adult"[Region] =

ZIDZ ( Egg Laying[Region] ,

Adults[Region] )

:GROUP .MOBU-SDyM

(188) real immature DR[Region] =

ZIDZ ( Immature Deaths[Region] ,

Immature[Region] )

:GROUP .MOBU-SDyM

(189) Real report :=

GET XLS DATA('LUTs.xlsx',

'Monarch Trends',

'1',

'A2')

:GROUP .MOBU-SDyM

(190) Recommended Area = 6

:GROUP .MOBU-SDyM

(191) Region : South,Central,North

:GROUP .MOBU-SDyM

(192) report =

SAMPLE IF TRUE( Day of year

= 30,

OW Size ,

OW Size )

:GROUP .MOBU-SDyM

(193) Reproducing Adults[South] =

max ( 0,

Adults[South]

- sum ( Migrating South[Region!] ) )

Reproducing Adults[North] =

max ( 0,

Adults[North] )

Reproducing Adults[Central] =

max ( 0,

Adults[Central] )

:GROUP .MOBU-SDyM

(194) Research = 0.2 [0,0.5]

:GROUP .MOBU-SDyM

(195) RESEARCH UTILITY =

( Research

- ( -0.225) )

/ 0.125

:GROUP .MOBU-SDyM

(196) ROC Real =

if then else ( Real report

> Delayed Value Real ,

1,

0)

:GROUP .MOBU-SDyM

(197) ROC Sim =

if then else ( report

> Delayed Value OW ,

1,

0)

:GROUP .MOBU-SDyM

(198) e-19}�S = 1 [0,0.0001]

:GROUP .MOBU-SDyM

(199) sd = 0.3

:GROUP .MOBU-SDyM

(200) Sens Adult Deaths[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(201) Sens Body Temperature = 1 [-1,1]

:GROUP .MOBU-SDyM

(202) Sens Density Dependent DR = 1 [-1,1]

:GROUP .MOBU-SDyM

(203) Sens Depensatory = 1

:GROUP .MOBU-SDyM

(204) Sens Egg Laying[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(205) Sens Interpatch Distance[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(206) Sens Move from central[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(207) Sens Move from Mexico[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(208) Sens Move From North[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(209) Sens Move from South[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(210) Sens Patch[Region] = 1

:GROUP .MOBU-SDyM

(211) Sens PPT Mex = 1

:GROUP .MOBU-SDyM

(212) Sens Predation OW DR = 1 [-1,1]

:GROUP .MOBU-SDyM

(213) Sens Spring Migration DR[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(214) Sens Temp Mex = 1

:GROUP .MOBU-SDyM

(215) Sens Temperature on Breeding Grounds[Region] = 1, 1, 1 [-1,1]

:GROUP .MOBU-SDyM

(216) "Sex Ratio (perc of females)" =

if then else ( Sex test ON

= 1,

LOOKUP EXTRAPOLATE ( Sex Ratio LOOKUP ,

( Simulation Year ) )

\* Change in Sex Ratio ,

LOOKUP EXTRAPOLATE ( Sex Ratio LOOKUP ,

( Simulation Year ) ) )

:GROUP .MOBU-SDyM

(217) Sex Ratio LOOKUP (

[(1975,0.4)-(2100,0.6)],(1975,0.525),(2010,0.434),(2100,0.4) )

:GROUP .MOBU-SDyM

(218) Sex test ON = 1 [0,1,1]

:GROUP .MOBU-SDyM

(219) Sigma of scale parameter prior PDF = 4

:GROUP .MOBU-SDyM

(220) sigma1 = 1.4

:GROUP .MOBU-SDyM

(221) sigma2 =

INITIAL( ( ln ( 1

+ ( Sigma of scale parameter prior PDF

/ Mu of shape parameter prior PDF )

^ 2) )

^ 0.5 )

:GROUP .MOBU-SDyM

(222) sigma3 = 0.7

:GROUP .MOBU-SDyM

(223) sigma5 = 4.35

:GROUP .MOBU-SDyM

(224) sigma6 = 3

:GROUP .MOBU-SDyM

(225) Simulation Month =

TIME BASE ( 1,

0.0328767) [1,0.0328767]

:GROUP .MOBU-SDyM

(226) Simulation Year =

TIME BASE ( 1994,

0.00273973) [1994,0.00273973]

:GROUP .MOBU-SDyM

(227) slope = 2.95073 [0.2,10,0.1]

:GROUP .MOBU-SDyM

(228) Slope Real =

TREND ( Average Real Value ,

FINAL TIME ,

0)

:GROUP .MOBU-SDyM

(229) Slope Simulation =

TREND ( Average OW Simulation Value ,

FINAL TIME ,

0)

:GROUP .MOBU-SDyM

(230) Smooth time = 3.27988

:GROUP .MOBU-SDyM

(231) Smoothed Temp[Region] =

SMOOTH ( Temperature Breeding[Region] ,

Smooth time )

:GROUP .MOBU-SDyM

(232) Soil Humidity Breeding[Region] =

Humidity[Region]

:GROUP .MOBU-SDyM

(233) South Habitat =

WITH LOOKUP( Simulation Year ,

([(1993,0)-(2113,1.448e+09)],(1993,1.44841e+09),(1994,1.4481e+09)

,(1995,1.4478e+09),(1996,1.44358e+09),(1997,1.43837e+09),(1998,1.42741e+09)

,(1999,1.41644e+09),(2000,1.40548e+09),(2001,1.39452e+09),(2002,1.38354e+09)

,(2003,1.37256e+09),(2004,1.36158e+09),(2005,1.35059e+09),(2006,1.33961e+09)

,(2007,1.32863e+09),(2008,1.31765e+09),(2009,1.30911e+09),(2010,1.30406e+09)

,(2011,1.30073e+09),(2012,1.2991e+09),(2013,1.29747e+09),(2014,1.29585e+09)

,(2015,1.29422e+09),(2016,1.29259e+09),(2017,1.29164e+09),(2018,1.29122e+09)

,(2019,1.29079e+09),(2020,1.29036e+09),(2021,1.28993e+09),(2022,1.28951e+09)

,(2023,1.28903e+09),(2024,1.28815e+09),(2025,1.28728e+09),(2026,1.28641e+09)

,(2027,1.28554e+09),(2028,1.28451e+09),(2029,1.28322e+09),(2030,1.28194e+09)

,(2031,1.28077e+09),(2032,1.28024e+09),(2033,1.27971e+09),(2034,1.27906e+09)

,(2035,1.2783e+09),(2036,1.27754e+09),(2037,1.27678e+09),(2038,1.27602e+09)

,(2039,1.27523e+09),(2040,1.27412e+09),(2041,1.273e+09),(2042,1.27188e+09)

,(2043,1.27076e+09),(2044,1.26964e+09),(2045,1.26854e+09),(2046,1.26744e+09)

,(2047,1.26633e+09),(2048,1.26523e+09),(2049,1.26413e+09),(2050,1.26302e+09)

,(2051,1.26192e+09),(2052,1.26082e+09),(2053,1.25971e+09),(2054,1.25861e+09)

,(2055,1.25751e+09),(2056,1.2564e+09),(2057,1.2553e+09),(2058,1.2542e+09)

,(2059,1.25309e+09),(2060,1.25199e+09),(2061,1.25089e+09),(2062,1.24978e+09)

,(2063,1.24868e+09),(2064,1.24757e+09),(2065,1.24647e+09),(2066,1.24537e+09)

,(2067,1.24426e+09),(2068,1.24316e+09),(2069,1.24206e+09),(2070,1.24095e+09)

,(2071,1.23985e+09),(2072,1.23869e+09),(2073,1.23749e+09),(2074,1.23629e+09)

,(2075,1.23509e+09),(2076,1.2339e+09),(2077,1.2327e+09),(2078,1.2315e+09)

,(2079,1.2303e+09),(2080,1.22876e+09),(2081,1.22698e+09),(2082,1.2252e+09)

,(2083,1.22341e+09),(2084,1.22163e+09),(2085,1.22072e+09),(2086,1.21986e+09)

,(2087,1.21901e+09),(2088,1.21815e+09),(2089,1.21721e+09),(2090,1.21554e+09)

,(2091,1.21387e+09),(2092,1.2122e+09),(2093,1.21053e+09),(2094,1.20948e+09)

,(2095,1.20845e+09),(2096,1.20742e+09),(2097,1.20638e+09),(2098,1.20535e+09)

,(2099,1.20408e+09),(2100,1.20268e+09),(2101,1.20128e+09),(2102,1.19988e+09)

,(2103,1.19848e+09),(2104,1.19708e+09),(2105,1.19569e+09),(2106,1.19429e+09)

,(2107,1.19289e+09),(2108,1.19149e+09),(2109,1.19139e+09) )

)

:GROUP .MOBU-SDyM

(234) Spring Migration[Region] =

Move Mexico[Region]

\* ( Overwintering )

/ if then else ( Month of the year

< 5,

30,

1)

:GROUP .MOBU-SDyM

(235) Spring Migration DR[South] =

( Spring Migration[South]

\* Dispersion Mortality Mexico[South] )

+ ( "Sum Disp South-Central"[South]

\* Dispersion Mortality Central[South] )

\* Sens Spring Migration DR[South]

Spring Migration DR[Central] =

( "Sum Disp South-Central"[Central]

\* Dispersion Mortality South[Central] )

+ ( Spring Migration[Central]

\* Dispersion Mortality Mexico[Central] )

+ ( "Sum Disp Central-North"[Central]

\* Dispersion Mortality North[Central] )

\* Sens Spring Migration DR[Central]

Spring Migration DR[North] =

( "Sum Disp South-North"[North]

\* Dispersion Mortality South[North] )

+ ( "Sum Disp Central-North"[North]

\* Dispersion Mortality Central[North] )

\* Sens Spring Migration DR[North]

:GROUP .MOBU-SDyM

(236) sqmt per ha = 10000

:GROUP .MOBU-SDyM

(237) Std Deviates =

ABS ( r Real

- r Simulated )

:GROUP .MOBU-SDyM

(238) Stems down[Region] =

if then else ( Day of year

> 360,

Stems per Season[Region] ,

0)

:GROUP .MOBU-SDyM

(239) Stems Improvement[Region] =

Yearly MW Improvement[Region]

:GROUP .MOBU-SDyM

(240) Stems per Season[Region] =

INTEG( Stems up[Region]

- Stems down[Region] ,

0)

:GROUP .MOBU-SDyM

(241) Stems up[Region] =

if then else ( Fall Trigger[Region]

= 0,

Total Milkweed Stems[Region] ,

0)

:GROUP .MOBU-SDyM

(242) Success =

min ( 6,

report )

/ 6 [0.4,0.9]

:GROUP .MOBU-SDyM

(243) SUCCESS UTILITY =

( Success

- ( 0.6) )

/ 0.15

:GROUP .MOBU-SDyM

(244) "Sum Disp Central-North"[Central] =

Adults[North]

\* Move from North[Central]

"Sum Disp Central-North"[North] =

Adults[Central]

\* Move from Central[North]

:GROUP .MOBU-SDyM

(245) "Sum Disp South-Central"[South] =

Adults[Central]

\* Move from Central[South]

"Sum Disp South-Central"[Central] =

Adults[South]

\* Move from South[Central]

:GROUP .MOBU-SDyM

(246) "Sum Disp South-North"[South] =

Adults[North]

\* Move from North[South]

"Sum Disp South-North"[North] =

Adults[South]

\* Move from South[North]

:GROUP .MOBU-SDyM

(247) Sum Real =

INTEG( Monarch Trends LUT ( Simulation Year ) ,

0)

:GROUP .MOBU-SDyM

(248) Sum simulation =

INTEG( OW Size ,

0)

:GROUP .MOBU-SDyM

(249) Summer distance[Region] =

if then else ( Month of the year

> 2

:OR: Month of the year

< 10,

Distance effect[Region] ,

0)

:GROUP .MOBU-SDyM

(250) Sun angle[South] =

WITH LOOKUP( Day of year ,

([(0,0)-(400,100)],(0,36.59),(1,37.03),(8,37.82),(15,38.96),(22,40.42)

,(29,42.18),(35,44.21),(42,46.45),(49,48.87),(56,51.44),(65,54.11)

,(72,56.84),(79,59.61),(86,62.37),(92,65.09),(99,67.73),(106,70.27)

,(113,72.67),(120,74.9),(127,76.93),(134,78.73),(141,80.27),(148,81.53)

,(154,82.48),(161,83.11),(168,83.41),(175,83.38),(182,83),(189,82.3)

,(196,81.29),(203,79.98),(210,78.41),(216,76.58),(223,74.54),(230,72.31)

,(237,69.92),(243,67.4),(250,64.78),(257,62.1),(264,59.38),(271,56.65)

,(278,53.96),(285,51.33),(292,48.81),(299,46.41),(305,44.2),(312,42.2)

,(319,40.45),(326,38.99),(333,37.85),(340,37.05),(347,36.63),(354,36.59)

,(370,36.59) )

)

Sun angle[Central] =

WITH LOOKUP( Day of year ,

([(0,0)-(400,100)],(0,26.59),(1,27.03),(8,27.82),(15,28.96),(22,30.42)

,(29,32.18),(35,34.21),(42,36.45),(49,38.87),(56,41.44),(65,44.11)

,(72,46.84),(79,49.61),(86,52.37),(92,55.09),(99,57.73),(106,60.27)

,(113,62.67),(120,64.9),(127,66.93),(134,68.73),(141,70.27),(148,71.53)

,(154,72.48),(161,73.11),(168,73.41),(175,73.38),(182,73),(189,72.3)

,(196,71.29),(203,69.98),(210,68.41),(216,66.58),(223,64.54),(230,62.31)

,(237,59.92),(243,57.4),(250,54.78),(257,52.1),(264,49.38),(271,46.65)

,(278,43.96),(285,41.33),(292,38.81),(299,36.41),(305,34.2),(312,32.2)

,(319,30.45),(326,28.99),(333,27.85),(340,27.05),(347,26.63),(354,26.59)

,(370,26.59) )

)

Sun angle[North] =

WITH LOOKUP( Day of year ,

([(0,0)-(400,100)],(0,16.59),(1,17.03),(8,17.82),(15,18.96),(22,20.42)

,(29,22.18),(35,24.21),(42,26.45),(49,28.87),(56,31.44),(65,34.11)

,(72,36.84),(79,39.61),(86,42.37),(92,45.09),(99,47.73),(106,50.27)

,(113,52.67),(120,54.9),(127,56.93),(134,58.73),(141,60.27),(148,61.53)

,(154,62.48),(161,63.11),(168,63.41),(175,63.38),(182,63),(189,62.3)

,(196,61.29),(203,59.98),(210,58.41),(216,56.58),(223,54.54),(230,52.31)

,(237,49.92),(243,47.4),(250,44.78),(257,42.1),(264,39.38),(271,36.65)

,(278,33.96),(285,31.33),(292,28.81),(299,26.41),(305,24.2),(312,22.2)

,(319,20.45),(326,18.99),(333,17.85),(340,17.05),(347,16.63),(354,16.59)

,(370,16.59) )

)

:GROUP .MOBU-SDyM

(251) Sun Angle Trigger = 52

:GROUP .MOBU-SDyM

(252) Temp Mex Forecast =

WITH LOOKUP( Month of the year ,

([(0,0)-(10,10)],(1,1.15071),(2,1.5799),(3,1.18804),(4,1.08032),(5,1.09672)

,(6,0.713593),(7,1.16586),(8,1.51807),(9,1.39137),(10,0.899547),(11,0.365031)

,(12,-0.526776) )

)

:GROUP .MOBU-SDyM

(253) Temp Mexico Historical (

GET DIRECT LOOKUPS('Temperature\_Mex.csv',

',',

'B',

'C2') )

:GROUP .MOBU-SDyM

(254) Temp Tresh Central =

Temperature Migration Treshold

:GROUP .MOBU-SDyM

(255) Temp Tresh North =

Temperature Migration Treshold [15,25]

:GROUP .MOBU-SDyM

(256) Temp Tresh South =

Temperature Migration Treshold

:GROUP .MOBU-SDyM

(257) Temperature[Region] =

Temperature Mean[Region] ( Time )

:GROUP .MOBU-SDyM

(258) Temperature Breeding[Region] =

Temperature[Region]

:GROUP .MOBU-SDyM

(259) Temperature Mean[South] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'F2') )

Temperature Mean[Central] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'G2') )

Temperature Mean[North] (

GET DIRECT LOOKUPS('SplinedForecast.csv',

',',

'B',

'H2') )

:GROUP .MOBU-SDyM

(260) Temperature Mex =

if then else ( Time

< 9855,

Temp Mexico Historical ( Time ) ,

Temp Mex Forecast )

:GROUP .MOBU-SDyM

(261) Temperature Migration Treshold = 18.135 [0,30,0.01]

:GROUP .MOBU-SDyM

(262) Temperature Treshold Prior PDF =

INITIAL( ( 1

/ ( sigma3

\* SQRT ( 2

\* 3.14159) ) )

\* EXP ( - ( ( ( Temperature Migration Treshold

- mu3 )

^ 2)

/ ( 2

\* sigma3

^ 2) ) ) )

:GROUP .MOBU-SDyM

(263) The Other country ==

-0.3512

:GROUP .MOBU-SDyM

(264) The three countries ==

0.4174

:GROUP .MOBU-SDyM

(265) Total Area[Region] = 1.57137e+08, 1.63844e+08, 1.77015e+08

:GROUP .MOBU-SDyM

(266) Total LL =

Data LL

+ if then else ( Time

= INITIAL TIME ,

( Exposure Prior PDF ) ,

0)

+ if then else ( Time

= INITIAL TIME ,

( MW Humidity Prior PDF ) ,

0)

+ if then else ( Time

= INITIAL TIME ,

( MW Temperature Prior PDF ) ,

0)

+ if then else ( Time

= INITIAL TIME ,

( OW Density Prior PDF ) ,

0)

+ if then else ( Time

= INITIAL TIME ,

( Temperature Treshold Prior PDF ) ,

0)

:GROUP .MOBU-SDyM

(267) Total Milkweed Stems[South] =

( ( MW availability[South]

\* MW Stems[South] )

+ ( MW availability[South]

\* MW Stems[South]

\* ( Change of Milkweed Availability South

- 1) ) )

Total Milkweed Stems[Central] =

( ( MW availability[Central]

\* MW Stems[Central] )

+ ( MW availability[Central]

\* MW Stems[Central]

\* ( Change of Milkweed Availability Central

- 1) ) )

Total Milkweed Stems[North] =

( ( MW availability[North]

\* MW Stems[North] )

+ ( MW availability[North]

\* MW Stems[North]

\* ( Change of Milkweed Availability North

- 1) ) )

:GROUP .MOBU-SDyM

(268) Total Monarchs =

sum ( Adults[Region!] )

+ Overwintering

:GROUP .MOBU-SDyM

(269) TRENDS UTILITY =

( Rate of change

- ( -0.1) )

/ 0.15

:GROUP .MOBU-SDyM

(270) Weather Fall mig DR =

SMOOTH ( "PDI Anomalies (Hurricanes)"

\* Hurricanes Estimate ,

15)

:GROUP .MOBU-SDyM

(271) Weather Related DR =

( ( 1

- "% Wet" )

\* DR Dry )

+ ( "% Wet"

\* DR Wet )

:GROUP .MOBU-SDyM

(272) Weather Related Mig DR =

min ( Migrating ,

max ( 0,

Migrating

\* Weather Fall mig DR ) )

:GROUP .MOBU-SDyM

(273) Yearly MW Improvement[South] = 0

Yearly MW Improvement[Central] = 0

Yearly MW Improvement[North] = 0 [0,?]

:GROUP .MOBU-SDyM