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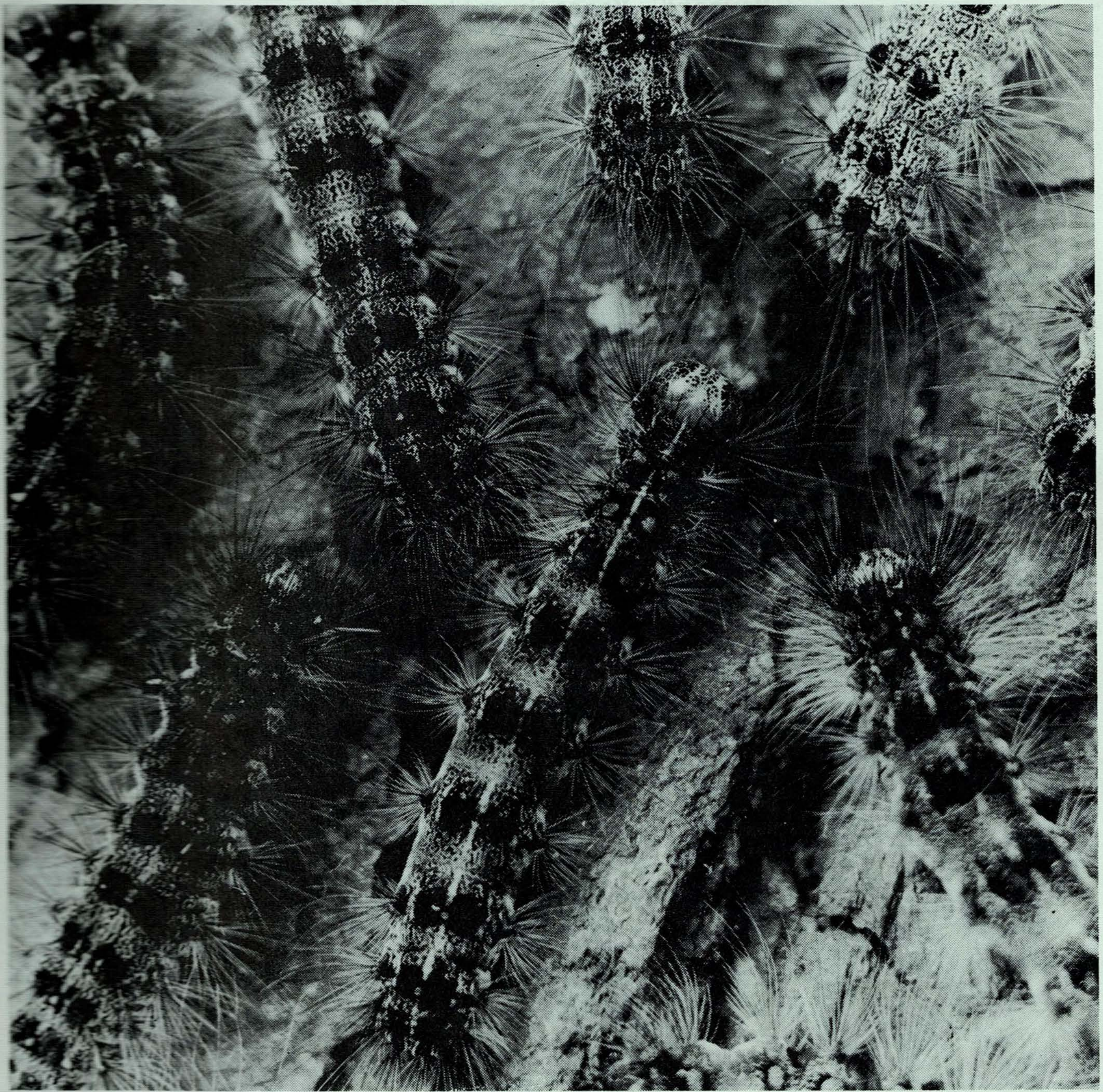

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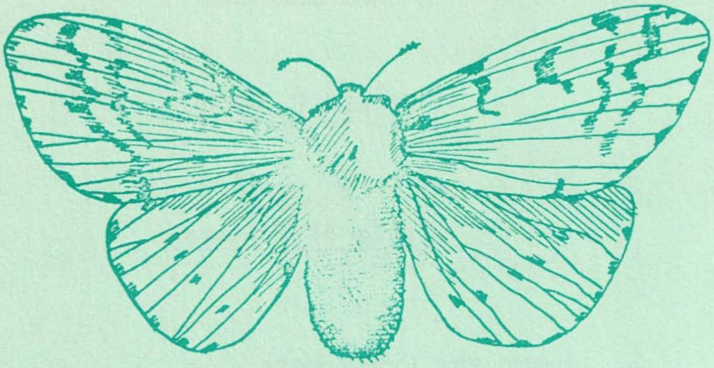
THREE MODELS OF POPULATION GROWTH

POP

RESOURCE MANUAL



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HUNTINGTON TWO COMPUTER PROJECT

30 March 1973

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POP SERIES

RESOURCE MANUAL

Table of Contents

The gypsy moth (Lymantria dispar) is a plant pest that has been responsible for complete defoliation of entire forests. Unfortunately it has become a common inhabitant of the New England woods and has been expanding its range into the Mid-Atlantic and Midwestern States.

The gypsy moth is native to Europe, Asia and northern Africa; in these areas it is also a plant pest. But in its native environment, it is usually kept under control by other insect parasites and predators. The gypsy moth was introduced into this country in 1869 in an effort to mate it to the silkworm, then a cornerstone in the economy of the New England mills. Eventually a number of the moths escaped from the Medford, Massachusetts, laboratory and established themselves in the local woods. By 1889 defoliation had increased to over 360 square miles. Today many thousands of square miles of forest are destroyed every year by this species.

The fantastic ability of the gypsy moth to strip the woods of its foliage is due to a number of factors. When brought into this country, it was freed from its natural enemies; the New England woods contained few predators to limit its growth. The caterpillars (larvae) of this species eat nearly any type of foliage, including conifers such as the pine and the spruce. While certain species of tree are preferred, nearly all foliage will be consumed if there are large numbers of larvae.

The female has the ability to produce up to 500 eggs that over-winter and hatch the next spring. Naturally not all these eggs survive the rigors of winter. (This is the reason that the figure of 15 offspring has been adopted in the *STUDENT MANUAL.*) These eggs are laid in a yellowish globular mass on any available surface that has some protection. Each egg is about 1 mm in diameter. Given a mild winter, most of these eggs will hatch into hungry caterpillars.

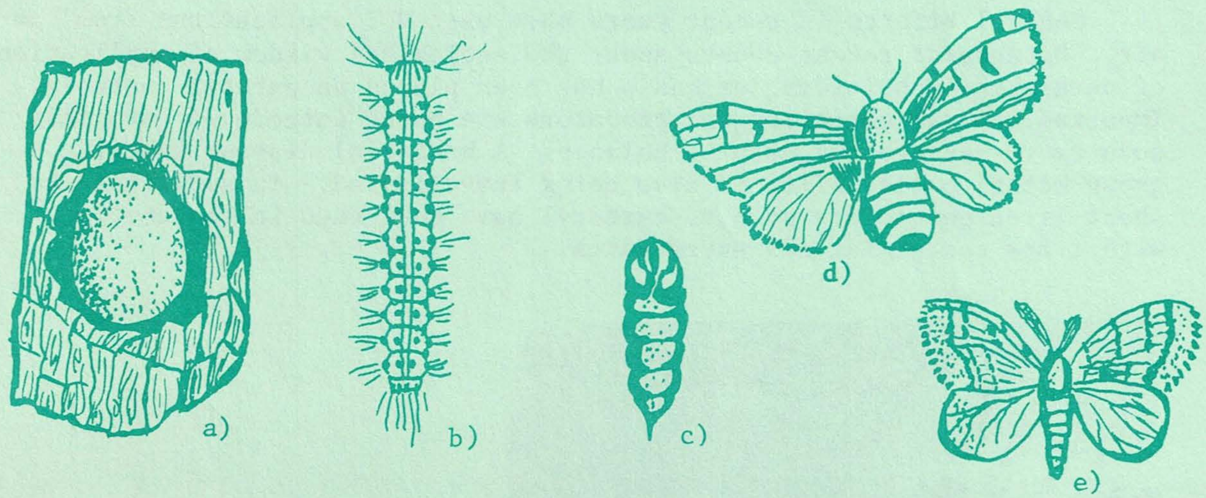


Figure 3.1. a) egg mass; b) larva; c) pupa; d) female adult; e) male adult.

Newly hatched larvae grow from about 1/16th of an inch up to nearly 2 inches in length during May and June; at this time they eat nearly non-stop any foliage available to them. The larvae are soot-colored with darker colored spots along the body. The yellow of the head is continued down the body by a central stripe. From tubercules along the sides of the larvae extend long hairs.

By early July these destructive larvae are ready to pupate. They remain in this "resting stage" from 7 to 17 days while they undergo metamorphosis into the adult form. The adults that hatch are not destructive, their role being to mate and lay eggs for the next generation.

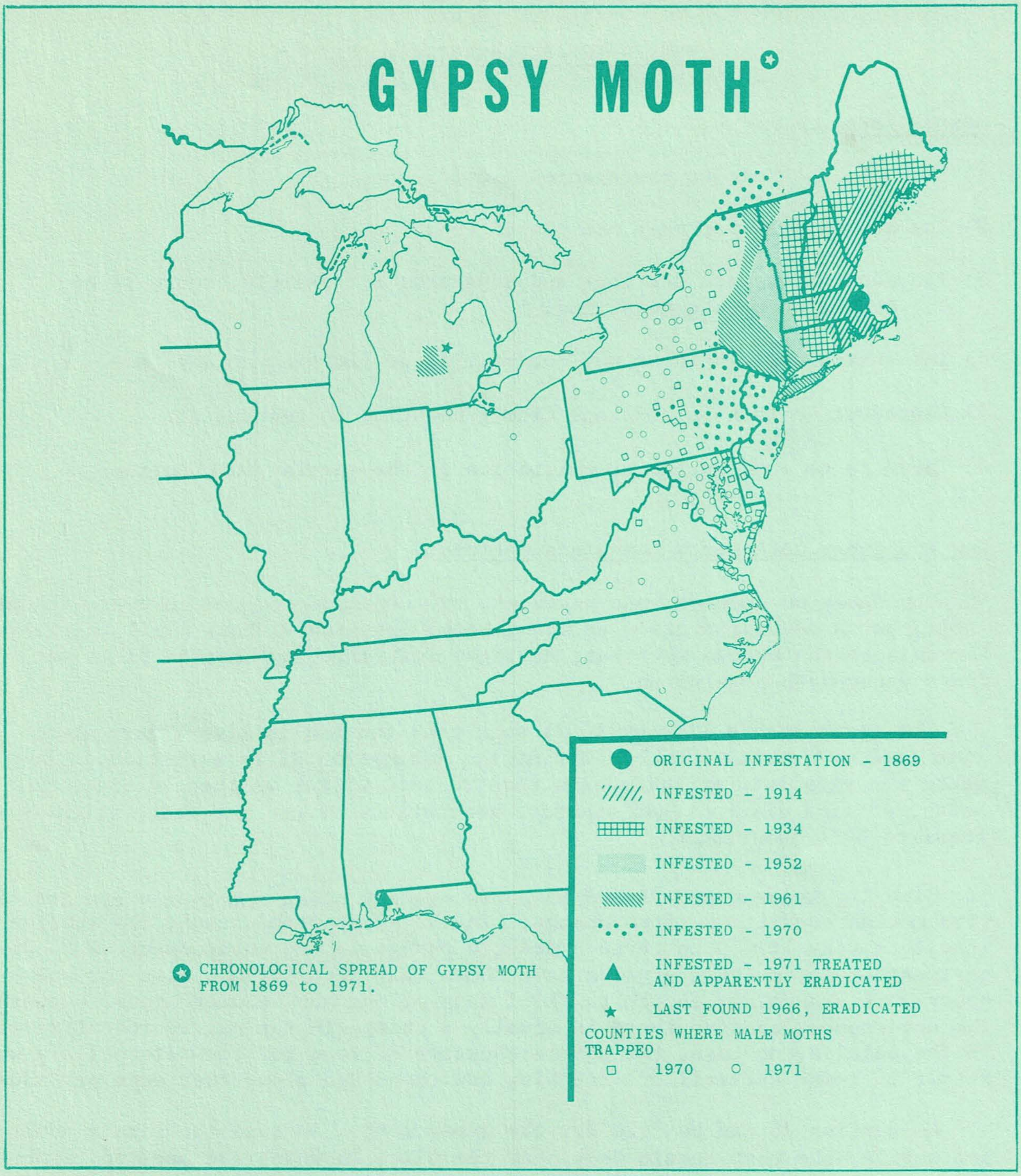
The appearance and the behavior of the males and females vary greatly. The male is brown in color, with light brown wings. The wings have wavy band markings with dark dots along the outer margin; wingspread is about 1½ inches. The female is white in color with a yellowish abdomen. She is much longer and heavier and is incapable of flight even though she is equipped with 2½-inch wings. She must wait for the male to locate and fertilize her, since she cannot move far from the location in which she pupated. After laying her eggs she dies.

The eggs are laid in late July or August but remain dormant until the following spring. Thus there is only one generation per year and the adults never interact with their offspring. (This is a critical assumption of the POP series programs.)

Because the female is immobile, most of the spread of the species across the United States occurs during the larval stage. Outbreaks far away from known infestations have been explained by storm winds blowing the light larvae many miles into a new area. Egg masses have also been transported to new areas by Christmas-tree shipments from infected areas.

Control efforts in recent years have used DDT applications from the air. Because of recent doubts about the ecological wisdom of applications of persistent pesticides, emphasis has been placed on natural controls. Imported natural parasites and predators are being introduced into this country to restore the natural balance. A bacterial disease specific to gypsy moths, called wilt, is also being investigated. In addition, new short-lived pesticides such as carbaryl have been used in conjunction with traps containing sex attractants.

Figure 3.2. Gypsy Moth Trap



U.S. Dept. Agr. Coop Econ.
Ins. Rpt. 22(13):181, 1972

Figure 3.3. Map of Gypsy Moth Infestation

II. ASSUMPTIONS OF THE POP SERIES MODELS AND HOW THE GYPSY MOTH MEETS THEM

POP1 - THE EXPONENTIAL MODEL

Assumptions:

1) There is no limit to the species growth.

2) The adults live for only one generation.

3) The generations are distinct and separate; for example, there is no mating between generations.

4) The environment is in no way controlling or limiting at any time.

5) Reproductive rate is constant from generation to generation.

6) There is no immigration or emigration of the species in question.

How the gypsy moth meets these assumptions:

Obviously no species, man included, can continue to grow forever without limit; but a *new* infestation of gypsy moths can grow without limit initially. For this reason we can say that, at least initially, Assumption #1 is met for a gypsy-moth population.

The gypsy moth's life cycle is such that the adults live a very short time (see p. 6 this manual); therefore, Assumption #2 is satisfied. Because the eggs laid by the adults require cold winter weather in order to hatch, we find distinct and separate generations of one per year, which is required by Assumption #3.

Clearly, Assumptions #4 and #5 above are not often met by any species. Environmental conditions often change. In the gypsy moth's case, the species itself is very likely to cause a drastic change in the environment. U.S. Department of Agriculture studies have shown that defoliation, even for one gypsy-moth season, is enough to kill many of our more common trees. Whenever the environment changes there is usually a change in the net reproductive rate. In the defoliation case, the severe shortage of food for the caterpillars would result in fewer caterpillars reaching adulthood and also fewer eggs per adult.

Assumption #6 can be true for the gypsy moth. Because the female adult is not mobile, she must remain very near the place in which she pupated. Since it is the female that lays the eggs, the next generation will not occur far from the location of the previous generation. This is one reason that the spread of the gypsy moth has been so slow, up to recent years. The U.S.D.A. now believes that the increase in gypsy-moth infestations in widely separated areas is a result of increased human transport. Efforts are being made to make campers and others in the woods aware of the gypsy moth, so that they will inspect their equipment for egg masses. Should a single egg mass be transported into a new area, there is a possibility of a gypsy-moth infestation far from the current problem areas.

Assumptions:

Assumptions #2 and #3 from above.

7) The environment can support a constant number of the species from generation to generation; i.e., there is a fixed, unchanging carrying capacity.

8) At the carrying capacity the population is using the limiting resource as quickly as it becomes available.

9) As population increases towards the carrying capacity, reproductive rate will fall. At the carrying capacity reproductive rate will always equal one. (The population will remain constant in number.)

10) Should the population exceed the carrying capacity, the reproductive rate will fall lower than one. (The population will fall.)

11) Single individuals can reproduce, even with no mate present.

How the gypsy moth meets these additional assumptions:

While the environment can support a certain number of organisms at any particular time (the carrying capacity), this number does not remain fixed and constant. It is subject to variation from many sources, both biotic and abiotic. In the case of the gypsy moth, Assumption #7 fails most noticeably after the gypsy moths have exceeded the carrying capacity. The trees should have been defoliated and many of them should have died; this would lower the carrying capacity for the next year. POP2 keeps the carrying capacity constant, however. *THIS SHOULD BE POINTED OUT TO THE STUDENTS AS THEY QUESTION THE MODEL IN THE FOLLOW-UP DISCUSSION.*

The Assumptions #8, 9, and 10 are generally thought to be true for most species. At the carrying capacity there is just enough of the resource to support the population. If additional organisms are added, an equal number will in some way be eliminated as there is not enough of the resource to support the additional population.

Assumption #11 is definitely not true for the gypsy moth. A male must locate the female within the female's brief adult life in order for reproduction to take place.

POP3 - LOGISTIC MODEL WITH A LOW-DENSITY MODIFICATION

Assumptions:

Assumptions #2, 3, 7, 8, 9, 10 from above.

12) At low population densities, the reproductive rate will be depressed.

How the gypsy moth meets this additional assumption:

There is little data available to support this assumption for the gypsy moth, but such effects have been recorded for organisms as diverse as muskrats and flour beetles.

Actual research data indicates that the male can detect the presence of a virgin female gypsy moth over great distances. The female secretes a sex attractant known as a pheromone. When a male moth detects the sex attractant, he begins to fly upwind until he locates the non-flying female. Once the female has mated and laid her eggs, she dies.

This problem has been retained in the *STUDENT MANUAL* to maintain continuity. The student problem involves a study of a 10-square-mile forested area. We have made the assumption that 100 moths (50 male and 50 female) are required for easy mate location. While there is absolutely no data to support this contention, it may not be completely unreasonable.

For those individuals who feel accuracy is more important than continuity in this series, we have included on p.16 of this section two alternative animals which can be modeled: the muskrat and the heath hen. It should be pointed out, however, that no animal can truly meet the assumptions of these simple models.

SUMMARY

The gypsy moth does meet a surprising number of the above assumptions. But there is at least one assumption present for each model that is violated. To the extent that these violated assumptions are important, the POP Series cannot be expected to give an entirely accurate projection as to population changes in a true life situation.

But an extremely accurate model is not our goal. Our primary aim in the POP Series programs is to help students develop a critical attitude about population modeling, by presenting an example of the sequential method of refinement that is necessary to produce a viable model.

POP1

The so-called population explosion is modeled by POP1. This model assumes that the population under study is increasing without limit. In other words, the environmental factors are not affecting the reproductive rate of this species. A graph of reproductive rate vs. population size for this model would result in a straight line (see Figure 3.4 below).

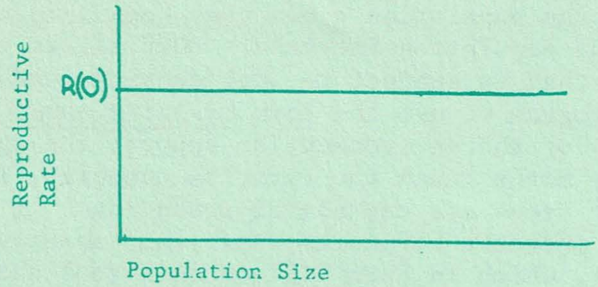


Figure 3.4.

This constant reproduction rate leads to a geometric rate of increase in population size. This model for population growth led Reverend Malthus to believe that if food supply increased arithmetically, there must come a time of extreme shortage of food and widespread starvation. This is the so-called Malthusian Dilemma.

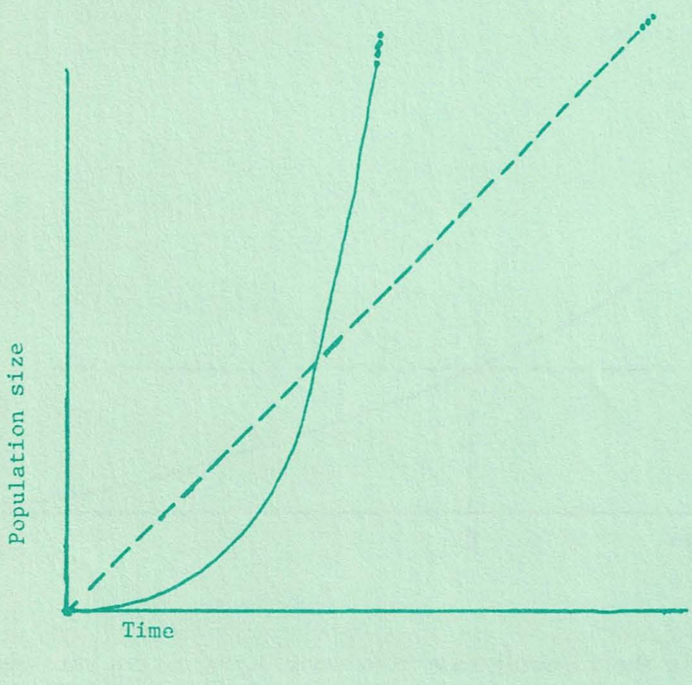


Figure 3.5. Dashed line (– – – –) indicates the arithmetic growth that Malthus predicted for food supply. The solid line (———) indicates the exponential growth expected of a population growing without limit. At the point where the lines cross, Malthus predicted that famine or some other disaster must take place.

POP2

Most populations are not increasing explosively however; clearly, something must be limiting the growth of these populations. Those conditions limiting population growth are called *limiting factors*. Food supply, amount of shelter and the like are called *density-dependent* limiting factors; they do not affect a population at very low population densities, but as the population grows they come into short supply and eventually limit the population increase. POP2 allows the student to model a population that is subject to such density-dependent limiting factors. In the program we use the term *carrying capacity* to represent the maximum ability of the environment to support the species in question. Thus when the gypsy moths reach the carrying capacity, they consume all the leaves that the trees are capable of producing. If their population should continue to increase beyond the carrying capacity, they will strip the trees of leaves, which in turn will cause a food shortage; this shortage will leave few gypsy moths to reproduce.

A plot of reproductive rate vs. population for POP2 would look like the graph in Figure 3.6 below. At low populations the reproductive rate is high, reflecting the good environmental conditions. As population continues to grow, conditions become less ideal and reproductive rate falls.

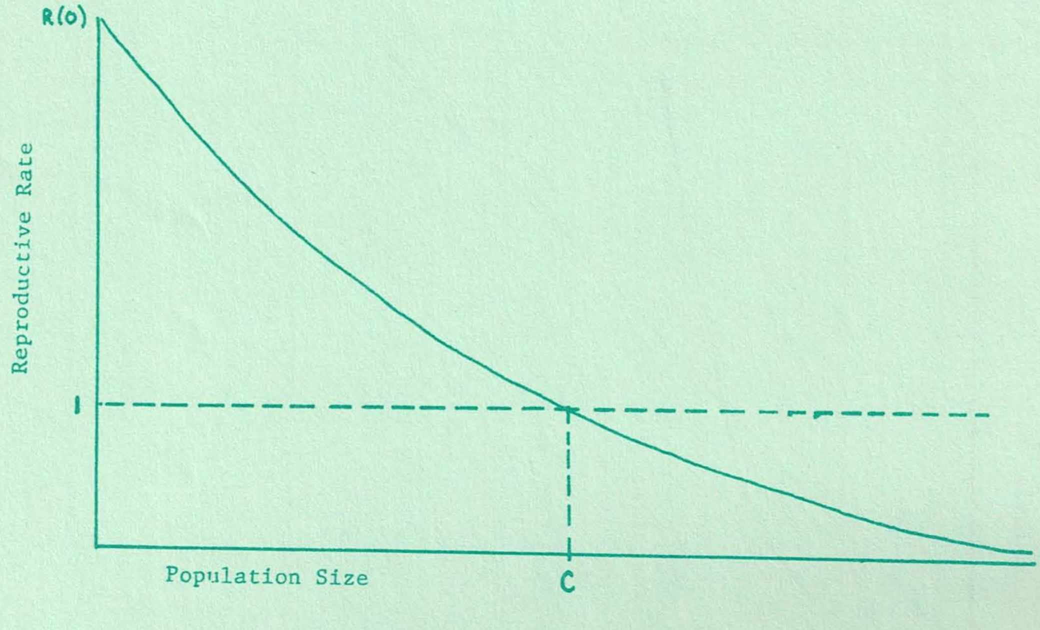


Figure 3.6. Only at the lowest populations does reproductive rate equal or near the biotic potential R(Ø). As population size increases, the actual reproductive rate drops, untul at the carrying capacity (C) the reproductive rate equals 1.

POP2 assumes that as the population reaches the carrying capacity, the reproductive rate falls to 1 offspring per generation per individual. This means the population of the (n + 1st) generation will be equal to the *n*th generation if the population equals the carrying capacity.

Should the population exceed the carrying capacity, the reproductive rate will fall below one and the next generation will be smaller in number than the current generation. This shifting of the reproductive rate can lead to many different population vs. time plots. For a population with a relatively low effective reproductive rate, we should expect a curve similar to (a) in Figure 3.7 below. For a more rapidly reproducing species, an oscillation about the carrying capacity is possible (b). For an exploding population completely out of control, (c) might occur. The section on further student investigations will allow students to explore the variable nature of the logistic model (see p. 21 this section).

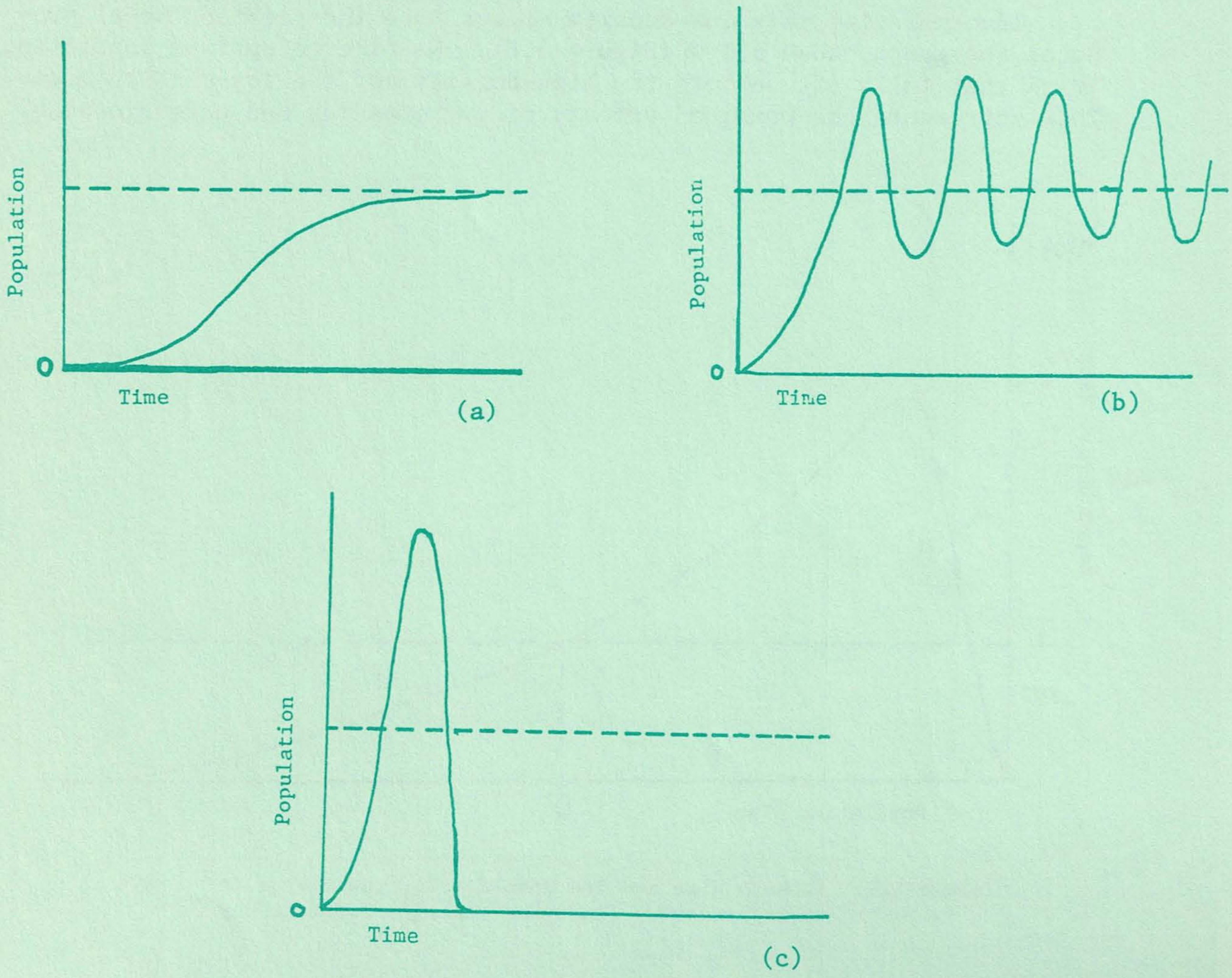


Figure 3.7. See text for details. Dotted lines (– – – –) indicate carrying capacity.

It is easy to see that overcrowding in an environment will cause a fall in the reproductive rate, but scientists have discovered that undercrowding can have a similar effect. POP3 is designed to let the student investigate how the added feature of a low-density reproductive effect changes the response of a population model.

One problem that can result from undercrowding is that the males and the females have a poor chance of locating one another for mating, since a male and female may not even meet each other during a mating season. Another problem was discovered by studying grasshoppers. When the grasshopper population was large, there was a very small chance of being eaten by a bird, so the chances for reproduction were high. But as the population size decreased, the chance of being eaten increased, so that the chance of reproduction became smaller. Scientists call this *predation pressure.*

Incorporating this low-density effect into the previous model produces the graph shown below (Figure 3.8). We find an optimum population level that falls off on both the high-density and the low-density sides. This represents the combined effects of overcrowding and undercrowding.

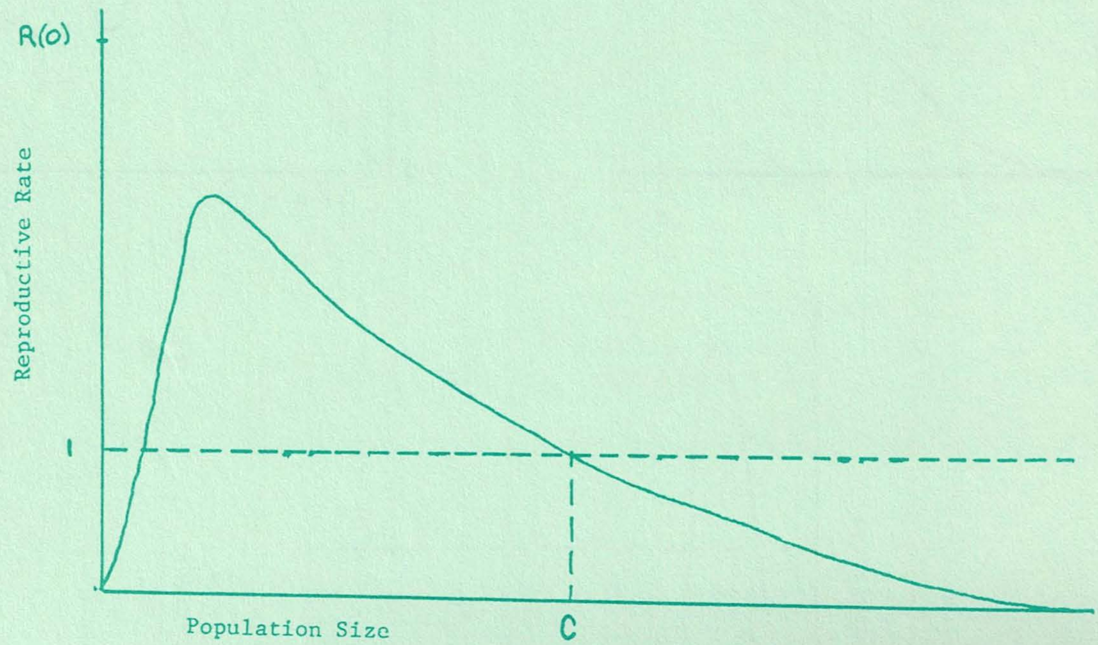


Figure 3.8. At both high and low populations, the reproductive rate is suppressed. (Carrying capacity indicated by C.)

Suggestions for further investigation of this model can be found on p. 22 of this section.

NOTE: THE ACTUAL SHAPE OF ALL THE GRAPHS SHOWN IN THIS SECTION WILL VARY FOR DIFFERENT SPECIES.

IV. PROGRAMMING CONSTANTS AND FORMULAE

Variables

A = low-density population correction factor

A1 = low-density effect limiting population

E = environmental carrying capacity

I = current generation being modeled

M = log (RØ)

M2 = mode of output

N = number of generations to be modeled

P = population size

P2 = initial population size (P(Ø))

P3 = maximum population size

RØ = reproductive potential in offspring/organism/generation

R = actual reproductive rate

Z = A*P/E

Z9 = population model number

Y = time unit per generation

Formulae

The basic formula for calculating the population is given by the following expression:

P(I + 1) = R * P (I)

i.e., the population of the current generation is equal to the active reproductive rate times the population of the last generation.

The actual reproductive rate (R) is different for each model:

<u>For POP1</u> R = RØ

The reproductive rate is a constant equal to the reproductive potential.

<u>For POP2</u> R = RØ * EXP (-M * P/E)

The reproductive rate varies in such a way that it is equal to the reproductive potential (RØ) where the population is zero, but less than RØ when the population is greater than zero.

<u>For POP3</u> R = RØ * EXP (-MP/E) * (1-EXP (-Z))

The reproductive rate varies exponentially at both low and high population densities.

The actual population equations for the three models are given below:

<u>For POP1</u> P = RØ * P

<u>For POP2</u> P = INT[RØ * EXP (-M * P/E) * P + .5]

<u>For POP3</u> P = INT[RØ * EXP (-M P/E) * (1-EXP (-Z)) * P + .5]

V. PROGRAM LISTING

```
100 REM POP - THREE POPULATION MODELS
110 REM     - 1 EXPONENTIAL MODEL
120 REM     - 2 EXPONENTIAL MODEL ADJUSTED FOR LIMITING FACTORS
130 REM     - 3 MODEL MODIFIED FOR LOW POP. DENSITY EFFECTS
140 REM COPYRIGHT 1972 STATE UNIVERSITY OF NEW YORK
150 REM DEVELOPED BY L. BRAUN
160 REM PROGRAMMED BY L. BRAUN , J. FRIEDLAND, S. HOLLANDER
170 REM LATEST REVISION 9-5-72
180 PRINT
190 PRINT" ","POPULATION GROWTH SIMULATION"
200 PRINT
210 PRINT"WHICH POPULATION MODEL? (1, 2, OR 3). TYPE IN NUMBER";
220 INPUTZ9
230 IF(Z9-1)*(Z9-2)*(Z9-3)<>0THEN190
240 LET I=0
250 PRINT
260 PRINT
270 PRINT "P(0)=";
280 INPUT P
290 IF P<>INT (P) THEN 270
300 IF P<=0 THEN 270
310 LET P2=P
320 LET P3=P
330 PRINT "REPRO RATE=";
340 INPUT R0
350 LET M=LOG(R0)
360 PRINT "TIME UNIT PER GENERATION";
370 INPUT Y
380 IFZ9=1THEN460
390 PRINT "CARRYING CAPACITY";
400 INPUT E
410 IFZ9<3THEN460
420 PRINT "AT WHAT POP. DO LOW DENSITY EFFECTS FIRST BEGIN";
430 INPUT A
440 IF A<>INT(A) THEN 420
450 LET A=3*E/A
460 PRINT "NO. OF GENERATIONS";
470 INPUT N
480 IF N<>INT(N) THEN 460
490 IF N<0THEN460
500 PRINT "OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH";
510 INPUT M2
520 IF (M2-1)*(M2-2)*(M2-3)<>0 THEN 500
530 PRINT
540 IF M2=2 THEN 580
550 PRINT "GEN.","TIME","POP."
560 PRINT "------","------","------"
570 PRINT I,I*Y,P
580 FOR I=1 TO N
590 GOSUB 1130
600 IFP<1E36 THEN640
610 IFM2=2THEN730
620 PRINT"POPULATION IS GREATER THAN CAN BE RECORDED"
630 GOTO730
640 IF P<=0 THEN 710
650 IF P<P3 THEN 670
660 LET P3=P
670 IF M2=2 THEN 690
680 PRINT I,I*Y,INT(P+.5)
```

```
690 NEXT I
700 GOTO 730
710 IF M2=2 THEN 730
720 PRINT I,I*Y,P,"POPULATION DIED OUT"
730 IF M2=1 THEN 1050
740 PRINT
750 PRINT
760 LET P=P2
770 LET E2=INT(E*50/P3+6.5)
780 PRINT"      0";TAB(24);"<-- POPULATION -->            ";INT(P3+.5)
790 PRINT"GEN. +I+++++++++++++++++++++++++++++++++++++++++++++++++I+++"
800 FOR I=0 TO N
810 IF INT(I/2)<>I/2THEN830
820 PRINT I;
830 LET P4=INT(50*P/P3+6)
840 IFZ9=1THEN880
850 IF E2>61 THEN 880
860 IF E2<P4 THEN 900
870 IF E2>P4 THEN 920
880 PRINT TAB(5);"+";TAB(P4);"*"
890 GOTO 930
900 PRINT TAB(5);"+";TAB(E2);"C";TAB(P4);"*"
910 GOTO 930
920 PRINTTAB(5);"+";TAB(P4);"*";TAB(E2);"C"
930 GOSUB 1130
940 IFP<1E36THEN970
950 PRINT"POPULATION IS GREATER THAN CAN BE RECORDED"
960 GOTO 1050
970 IF P<=0 THEN 1010
980 PRINTTAB(5);"+"
990 NEXT I
1000 GOTO 1050
1010 PRINTTAB(5);"+"
1020 IFINT(I+1/2)<>(I+1)/2THEN1040
1030 PRINT I+1;
1040 PRINTTAB(5);"+*      POPULATION DIED OUT"
1050 PRINT
1060 PRINT "ANOTHER RUN? (YES=1, NO=0)";
1070 INPUT Z9
1080 IFZ9=1THEN200
1090 FOR I=1 TO 8
1100 PRINT
1110 NEXT I
1120 GOTO1240
1130 IFZ9>1THEN1160
1140 LETP=R0*P
1150 GOTO1230
1160 LETZ8=1
1170 IFZ9<3THEN1220
1180 LETZ=A*P/E
1190 IFZ<50THEN1210
1200 LETZ=50
1210 LETZ8=1-EXP(-Z)
1220 LETP=INT(R0*EXP(-M*P/E)*Z8*P+.5)
1230 RETURN
1240 END
```

VI. USING OTHER ANIMALS OR PLANTS IN THE POP SERIES PROGRAMS

Many teachers will want to substitute a more familiar plant or animal for their students to use in their study of population modeling. Again it is important to emphasize that the POP Series is not designed to give "correct" answers to population sizes, but is designed to allow students to investigate several simple population growth models. As long as this is kept in mind, it is often possible to substitute another organism for student study.

A good source for appropriate information on plants and animals is the *Fieldbook of Natural History* by E. Laurence Palmer.* If this book is not in the teacher's library, copies may be available in a local library. Many other natural history guidebooks will also furnish equivalent information. To use each of the POP Series programs, the following information must be developed:

POP1 : Reproduction rate and generation time

POP2 : Reproduction rate, generation time, and carrying capacity of the environment

POP3 : Above information and low-density mating effect.

Information on the last two factors is always difficult to find. Carrying capacity is highly dependent on environmental factors and because of this can vary over a wide range. Figures for low-density mating factors can occasionally be found in ecology texts. The best procedure may be for the teacher and the class to make an acceptable estimate for both the equilibrium population and the population for which there will be low-density mating problems, after discussing any information they may have been able to gather concerning the plant or animal in question.

Other animals which may be modeled with the POP Series

NOTE: Not all the animals listed below meet the assumptions of the POP Series programs as well as the gypsy moth. This will present few problems if both the teacher and the student are aware of the basic objective of the POP Series: to introduce the concept of population growth modeling.

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*Palmer, E. Laurence, *Fieldbook of Natural History*. New York: McGraw Hill Book Company, 1949.

POP1

ORGANISMS	REPRO. RATE*	TIME/GEN.	CARRYING CAP.	LOW DENSITY
Bacteria	2	20 (min.)		
Oyster	10,000**	1 (year)		
Elephant	5	10 (years)		
Fruit Fly	250	12 (days)		

POP2

ORGANISMS	REPRO. RATE*	TIME/GEN.	CARRYING CAP.	LOW DENSITY
Paramecium	about 2	1 (day)	375 (/ml)	
Yeast Cells	2	2 (hours)	665 (/ml)	
Sheep in Australia	(have students investigate this)		7 million	

POP3

ORGANISMS	REPRO. RATE*	TIME/GEN.	CARRYING CAP.	LOW DENSITY
Muskrat	4 (up to 20)	1 (year)	300 (Estimated)	130

(The above approximation is based on 150 acres of marsh. Any figures that seem appropriate for the users' location should be adopted.)

ORGANISMS	REPRO. RATE*	TIME/GEN.	CARRYING CAP.	LOW DENSITY
Heath Hen on Martha's Vineyard	5 (up to 10 eggs)	1 (year)	2000	300

Since figures for low-density populations are difficult to obtain, these figures are based on many assumptions which may vary from one location to another.

*For sexual species you may divide this number in 2.
**Actually the oyster can produce over 100,000,000 eggs per year.

VII. USING MAN AS A STUDY ORGANISM IN THE *POP* SERIES PROGRAMS*

While many teachers will feel that man should be treated as the study organism in the POP Series, man was not used because he violates key assumptions made in the POP Series models (see pp. 4-6). The assumption that one generation does not reproductively interact with the next is not strictly true of man. In addition, man's generations are not distinct as was the case with the gypsy moth; generations overlap to such an extent that it is difficult to separate one generation from another.

While objections to using man in the POP Series are serious, they do not rule out using man as a study organism provided the students are highly critical of both the inputs and the results.

Suggested Inputs for POP1, 2, and 3

P(Ø) = 545 — We suggest this number since in the year 1650 there were approximately 545 million people in the world and all numbers can be multiplied by one million to contrast results of model to actual data.

Alternate suggestions for P(Ø) include P(Ø)=2, for a projection of the future population starting off with 2 individuals (1 male and 1 female, of course); or P(Ø)=3, to represent the 3 billion persons in the world today.

REPRO.RATE = Select a number based on the students in your class. Remember to divide the number of children per family by 2, as man is a sexual animal. Also take into account the fact that your students may not be from families that are complete; that is, more children may be born into these families at a later date. It might be best to ask: "How many children do you think your parents will have?"

TIME UNIT PER GENERATION = 35(years).

This figure may seem to be too high, but it is based on the assumption that many couples have children starting at about age 25 and are finished with their families by 45 years of age.

CARRYING CAPACITY = ?

Again it will be necessary to talk to your students about what factors limit man's population and how these factors are changing. Many scientists feel that man's population is increasing at a much faster rate than his resources. Others feel that man will be able to extend his resources in time to allow his increasing population to exist far into the future. The ultimate limit to man's population is currently a very controversial scientific question; so when using POP2 or POP3 with your students, *be sure to stress the hypothetical nature of the equilibrium population of man.*

*Another HUNTINGTON TWO simulation, *USPOP*, will attempt to model a human population.

AT WHAT POPULATION ARE LOW-DENSITY EFFECTS FIRST NOTICED?

The response to this question rests on what convention you are following for the P(Ø). If you are following our convention, you might reword the question to read: HOW MANY PEOPLE SPREAD ACROSS THE FACE OF THE EARTH WOULD BE NECESSARY FOR EASY MATE LOCATION? (Remember to divide by one million, as in the P(Ø) convention.) Best results can be obtained by discussion of this hypothetical question with your students.

The last two questions will be important only if you elect to use POP2 or POP3.

Alternate Approaches to Human Population

Using POP1 may make it possible for your students to investigate how a change in family size could affect the future population size of the world. This can be accomplished by setting P(Ø) equal to the current population of the world (3 representing 3 billion people), setting time unit per generation equal to 35 years, and varying the reproductive rate. The years can be keyed in the following fashion:

Gen.	Year
0	1960
1	1995
2	2030
3	2065
4	2100
5	2135
6	2170, etc.

It is important to keep the following considerations in mind when modeling human populations with the POP Series:

1) The POP Series will only give the population *increase* in each generation. It makes the assumption that the parents of the offspring are no longer in the population.

   As you know, this may have been true when the life expectancy was very low; but due to the long life expectancy of man, adjustments must be made in the answers given by the programs.

2) The POP Series are essentially static programs. The models on which the POP Series are based assume no changes due to limiting factors or low-density effects other than in the reproductive rate. This

means that changes in food production, economic conditions, and societal structure cannot be represented. For these reasons the POP Series' projections might, at best, be valid for only very short periods of time, because man has created a world based on change.

3) The POP Series assumes a population with a uniform age structure. This is definitely not the case for man. Man's current population structure has many more young than is accounted for in the POP Series. This is the reason that even if man should cut his reproductive rate to 2 children per couple (1 per person per generation), the population will continue to rise until at least the year 2000.

4) The assumptions on which each program of the POP Series is based were given on pp. 4-6. These assumptions should also be kept in mind.

VIII. FURTHER STUDENT INVESTIGATIONS

The POP Series programs are designed with the hope that they will stimulate interested students to perform further investigations. These investigations could take one of several paths, but two possibilities occur to us at the outset.

First of all, some students may wish to research one of the subject organisms they used in class; if, for example, they used the gypsy moth they might want to investigate the behavior of the moths in order to confirm or deny the behavior of the POP Series models. This research could take the form of either library work or field study, and either approach could lead to useful reports.

Other students may want to investigate the POP Series models in greater detail, varying birthrates and the like, or run the POP Series programs using other organisms.

The following sections are written for the student and will attempt to suggest activities with appeal for a wide range of ability levels. These suggestions may in turn lead to other student investigations.

A. Basic Investigations

1. Using POP1

a) How does POP1 predict population changes for different organisms?

In the *STUDENT MANUAL* there are listed several other animals that you may want to use for comparison. The information you'll need for correct inputs can also be found on these pages.

If you want to model other animals, your teacher may be able to guide you to proper books in your library. These books should allow you to estimate correct inputs.

Since you are interested in a comparison, you may want to compile all your results onto a single graph so that differences will be easy to see.

b) How would a change in birthrate affect the growth of a gypsy-moth population as predicted by POP1?

If you have not already done so, carry out the gypsy-moth investigation in the _STUDENT MANUAL_. In that investigation you set the birthrate equal to 15, but in nature the birthrate is not always constant. For example, after a very cold winter the birthrate will be much lower since many of the eggs will be killed; after a mild winter, however, the birthrate may be much higher since fewer than the normal number of eggs will have been harmed by the cold.

To answer the above question, you may have to run several experiments using a different birthrate each time. After you have gathered your data, decide the best way to present your results.

2. Using POP2

a) How do different carrying capacities affect the behavior of the gypsy-moth population as predicted by POP2?

If you have not already done so, carry out the POP2 problem in the _STUDENT MANUAL_. In this investigation we used a carrying capacity of 500,000 moths. In reality the carrying capacity must vary from year to year, because environmental conditions do not remain the same. Your job is to investigate how the POP2 model reacts to changes in the carrying capacity.

To carry out this investigation you will have to run POP1 several times, changing the carrying capacity each time but holding all other variables constant.

Once you have gathered your data, you may wish to present it on a single graph for easy comparison. For this reason it is important to obtain your output in table form; this will give you numbers which you can put on the same graph.

b) How does POP2 behave for other animal populations?

You may have already investigated the POP2 model for population growth of the gypsy moth and wondered if POP2 would behave the same way for other animals.

In the POP1 section of the _STUDENT MANUAL_, there is a table with the necessary information for using other animals. This table will give you proper inputs for

P(O), REPRO. RATE, and TIME UNIT PER GENERATION. Use a carrying capacity of 500,000 for all your runs so that you can compare the population growth (or decline) of these other animals with the behavior of the gypsy-moth population.

Present your results for all the animals used, including the gypsy moth, on a single graph. (You may wish to plot the number of offspring on the y-axis and the generation number on the x-axis; using a different-colored pencil for each animal will produce a clearer -- and more interesting -- graph.) Since you will need actual numbers for plotting your graph, be sure to ask for your output in table form.

3. Using POP3

a) How does POP3 behave for other animal populations?

Your teacher can supply you with information on other populations you can model using the POP3 program. This information can be found on pp. 15-16 of the *RESOURCE MANUAL*.

First design your inputs just as you did before. Again you are to determine what minimum population is necessary to allow the population to grow during the first 5 years.

b) Does the carrying capacity affect the minimum population necessary to maintain a growing population?

First carry out either the investigation in the *STUDENT MANUAL* (p. 9), or the investigation listed above. Establish the minimum population that is necessary for growth when the carrying capacity is 250,000.

To answer the above question (3b), it will be necessary for you to run POP3 several times, keeping all inputs the same each time except for the input to the question: "AT WHAT POPULATION ARE LOW-DENSITY EFFECTS FIRST NOTICED?"

After you have arrived at an answer to your question, try to decide if POP3 is accurate in its prediction.

B. Advanced Investigations

1. Using POP1 - Investigation as to the role of life span in population growth.

Each of the POP Series programs assumes that all the adults die after reproduction. While this is true of the gypsy moth and several other species (such as salmon) this is clearly incorrect for many of the more familiar plants and animals. In this modified investigation, we will make the following assumption: adults do not die after one generation but they do not carry out further reproduction.

To make the investigation more meaningful, select a slower-growing species. You can either make one up or use the values for the elephant in the *STUDENT MANUAL* (p. 2). Information for other slower-growing species can be investigated in the library.

Design the inputs for your sample organism and decide how many generations the animal will live. Enter your inputs into the computer and ask for your output in either the table form or combined form (the table and the graph), since you will need the actual numbers.

The table will give only the number of offspring produced for the current generation, not the entire population for the current generation. To obtain the total population, it will be necessary for you to add the number of offspring for the current generation to the remaining number of offspring from previous generations.

For example, Organism A lives a total of 5 generations. The computer has outputed the following information about an Organism A population:

GEN.	TIME	POP.
0	0	2
1	1	4
2	2	8
3	3	16
4	4	32
5	5	64
6	6	128
7	7	256
.	.	.
.	.	.
.	.	.

Total population can be figured in the following way:

GEN 0	2 (since we assume no previous generations in area)	
GEN 1	2+4=6	
GEN 2	2+4+8=14	
GEN 3	2+4+8+16=30	
GEN 4	2+4+8+16+32=62	
GEN 5	4+8+16+32+64=124	(the first 2 are missing since they died after 5 generations.)
GEN 6	8+16+32+64+128=248	

Your question asked you to investigate the effect of different life spans (be sure to include a life span of 1 generation) on total population growth. To do this you may want to run POP1 several times, each time with a different life span, and then compare the results of each run. Once you have compiled all your data, you will have to decide on a method that will allow for each comparison.

(After you have completed this investigation, you may want to go further by allowing reproduction over more than one generation. To do this you will either have to modify the POP1 program, write a new program, or re-run POP1 for each year. If you select the third option, run POP1 for one generation, figure out your reproducing population, and then run POP1 again with P(Ø) equal to the reproducing population. The program will give you the number of offspring for the next generation. By repeating the above process, you can obtain the number of offspring for any number of generations.)

2. <u>Using POP2</u> - <u>Investigation of the role of carrying capacity in determining reproductive rate in the POP2 model.</u>

As you may have noticed when you first tried POP2, the population does not necessarily grow at the same rate at the same times, as it did in POP1. When the population density is far below the carrying capacity, the actual reproductive rate is near the number that you inputted as REPRO. RATE; when the population nears the carrying capacity of the environment, the reproductive rate seems to drop.

The reason for this behavior is as follows: The number that you entered into the computer is called the potential reproductive rate; this means that this rate can exist only under ideal conditions. In reality these ideal conditions never exist, and there are always some offspring that die. Actual reproductive rate is therefore always less than the potential reproductive rate. This is true even in man. In this investigation you are asked to determine how the POP2 population growth model relates actual reproductive rate and carrying capacity.

Procedure

You may elect to run this experiment using the gypsy-moth example found in the *STUDENT MANUAL*, or you may decide to use another species as your experimental animal. In any case the answer will be clearer if you select a species with a large reproductive rate, as changes in the rate will be more noticeable.

Once you have chosen your species, decide on the proper inputs for the computer. A proper investigation will require a number of runs of the POP2 program. As in the previous investigations, be sure to keep all inputs constant except for the one factor being investigated: *carrying capacity*.

There are several methods of solution; three possibilities are given below:

a) Try plotting population vs. carrying capacity for a certain year, e.g., year 5. This will not give you an exact answer, but it will give you an idea of how carrying capacity affects reproductive rate, since the higher the population at a particular time the higher the reproductive rate must have been.

b) Run POP1 and POP2 with the same values for the inputs they have in common and plot the results for both runs on the same graph (population vs. generations). Since POP1 allows growth without limit and POP2 limits growth because of carrying capacity, any difference in the answer between POP1 and POP2 must be due to changes in the reproductive rate due to changes in the carrying capacity. If you repeat this procedure for many different carrying capacities, a pattern should emerge.

c) Figure the actual reproductive rate for each generation in your experimental run, using the following formula:

$$R_{\substack{\text{actual}\\ \text{in nth}\\ \text{generation}}} = \frac{POP_{\text{nth generation}}}{POP_{\text{(n-1)st generation}}} \qquad \text{where } n=1,2,3....$$

3. Using POP3 - Investigation of explosive and non-explosive population growths.

If you have carried out the POP2 investigation, you may have noticed that the moths go through cycles of explosive growth followed by periods of sharply declining population. Is this true of all species modeled with the POP2 population growth model? To convince yourself that there is another kind of growth model, try modeling a bacteria population (if you have not already done so). These are the proper inputs:

P(Ø)? 2

REPRO.RATE=? 7.5

TIME UNIT PER GENERATION=? 1 (year)

CARRYING CAPACITY? 500000

NO. OF GENERATIONS? (in this investigation we will use 20)

OUTPUT DESIRED? (choose the output you think best suited to answer the question)

By varying reproductive rate for each run, you should be able to determine exactly how the reproductive rate influences the pattern of growth.

IX. BIBLIOGRAPHY

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Holt, Rinehart and Winston, New York (1970).

p.36: Explosive exponential growth.

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