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ABSTRACT

Described is the population growth computer model "POP." This program is designed to allow a student with little mathematical background to explore various simple mathematical models of population growth. Student exercises revolve around the growth of a gypsy-moth population. Three variations of population modeling are included in POP: POP 1, simple exponential growth; POP 2, including an environmental limiting factor; and POP 3, a model with an environmental limiting factor and other modifications. (Author/RE)

STUDENT WORKBOOK $.30

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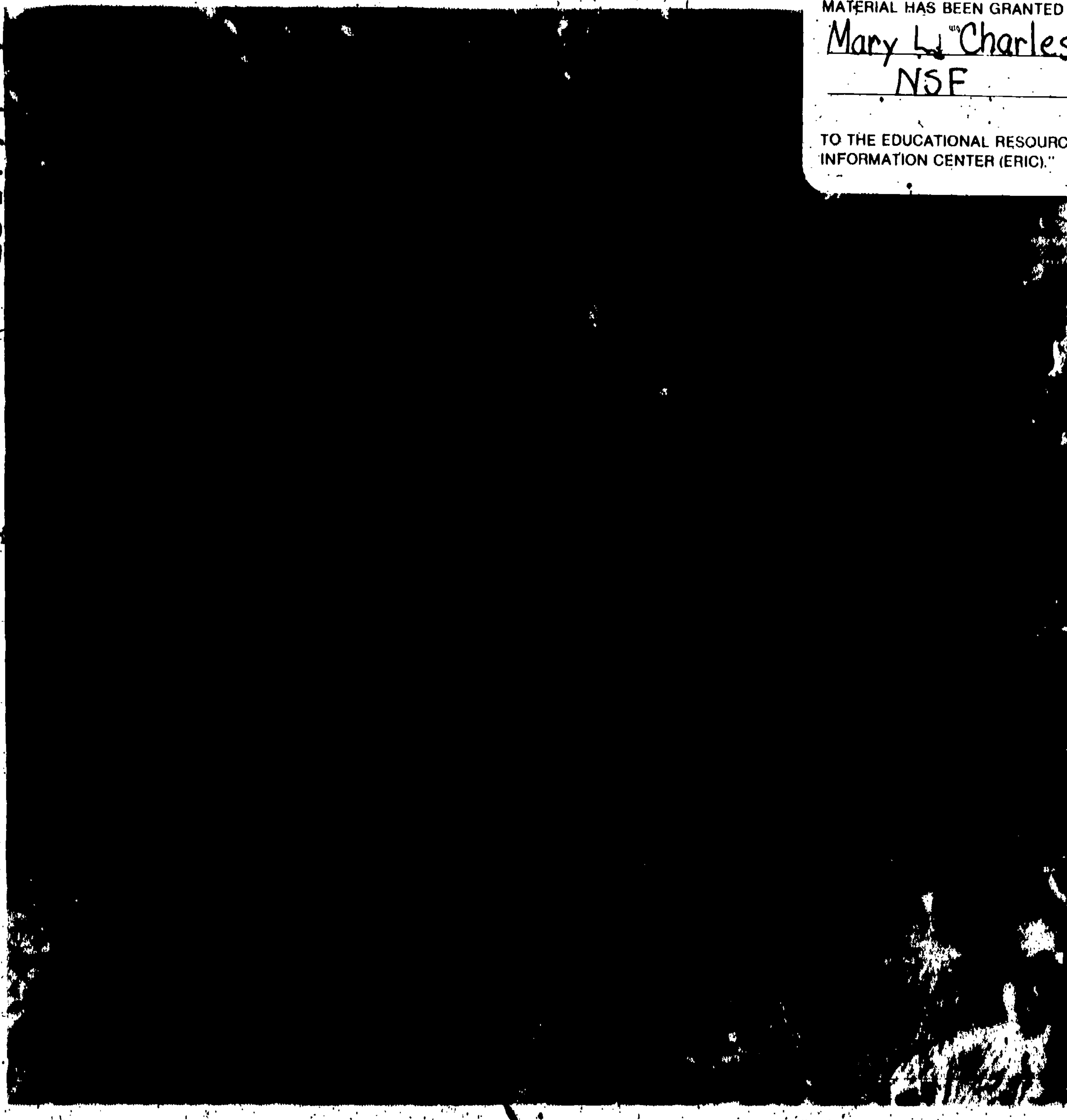
HUNTINGTON II Simulation Program—POP



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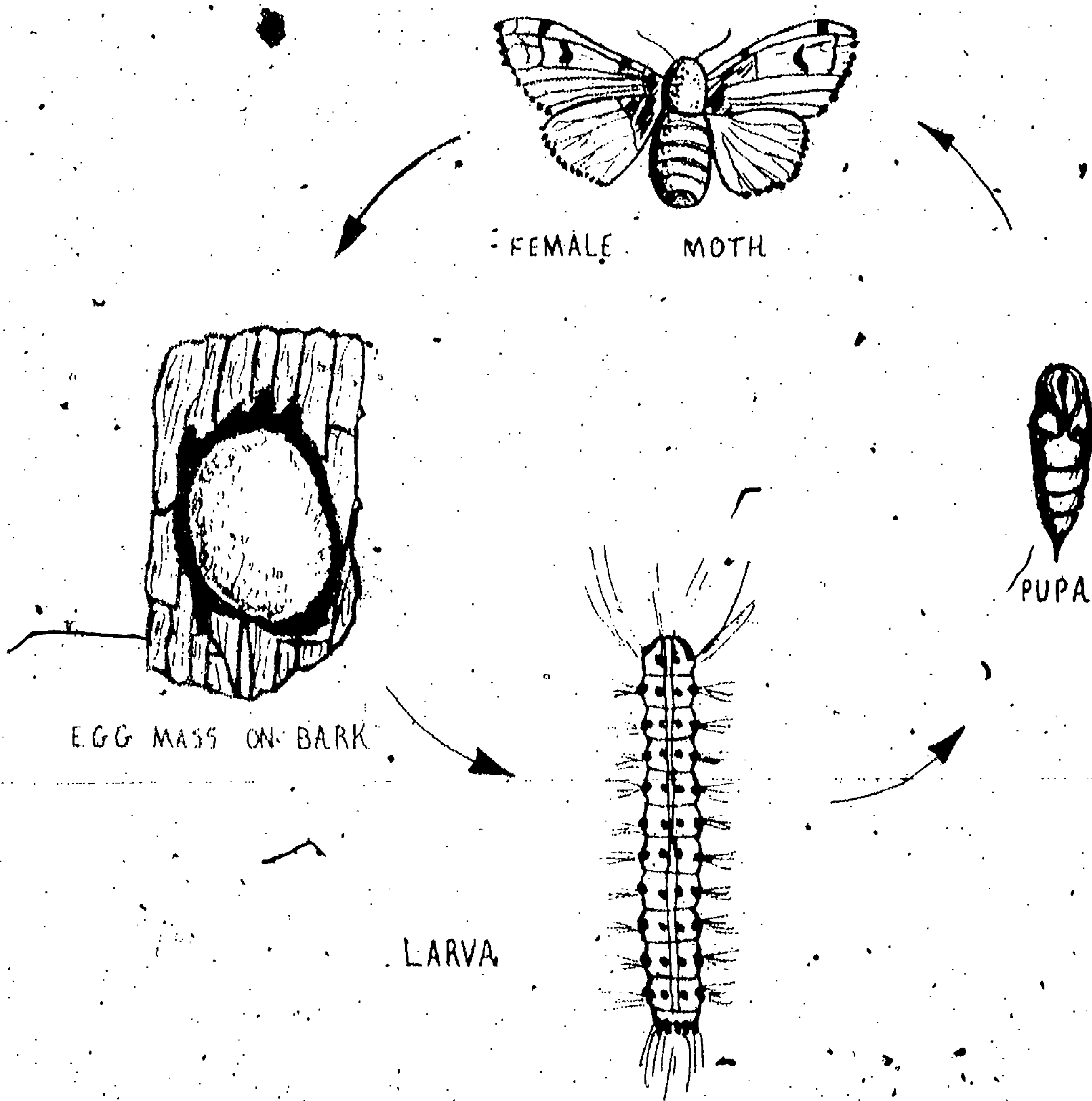
Program Paper Tape	1.00

THREE MODELS OF POPULATION GROWTH

POP

STUDENT MANUAL



HUNTINGTON TWO COMPUTER PROJECT

30 March 1973

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POP SERIES

STUDENT MANUAL

We are all interested in what will happen in the future. Can anyone foretell the future? We have all been told that that is impossible. Then how can newspapers make predictions on the population in the year 2000? Are these numbers true or false?

Obviously we will not know how true these projections are for many years, but it is possible to get some idea about their accuracy by examining how such projections are made. All projections are based on models. Just as a model airplane reflects many aspects of a real airplane, population models must take into account those things which influence populations in the real world.

A model airplane cannot be a true copy of the real thing. We wouldn't want a model airplane to be true to size, instrumentation, controls, etc. It would make the model too expensive and very hard to handle. The same is true of our population models. We must leave out many aspects of actual populations if we are to understand and handle the problem of making a prediction of future population size. Will leaving these aspects out seriously affect the accuracy of our prediction?

We have included three different models for you to examine. Each successive model incorporates an additional factor that might affect the population. Do these modifications affect the answer? In what ways?

POPULATION GROWTH MODEL #1 POP1

POP1 is based on a very simple model of population growth. The name given to this model is the exponential model. The population model includes birth rate (and death rate), number of offspring, and the time necessary for each generation to mature.

While these are all important factors, there are many factors that are not included in this model. Such factors as the amount of food and water, the quality of the environment, the amount of living space, etc., are not considered. For this reason it is said that the exponential model of population growth allows growth without limit.

Using POP1 - Before we can ask the computer to apply the exponential model and make a prediction as to the future population size of a plant or animal species, it is necessary to supply the computer with certain information on current conditions. When you ask the computer to RUN the program, the computer will ask:

P(Ø) = ? — Refers to the population at the current time (time = 0).

REPRO. RATE? — Refers to the *average* number of offspring that each individual in the population can be expected to produce for the next generation.

The key word is *average* number. For example, if in Town B each woman will have 4 children, what will be the reproductive rate? The answer is 2, since women make up only half of the population and we must divide the number of offspring by 2 in order to get the reproductive rate (offspring per person).

TIME UNIT PER GENERATION?
Refers to the time necessary for individuals to produce offspring of their own.

NO. OF GENERATIONS?
Refers to the number of generations into the future for which you want the population projected.

OUTPUT DESIRED) 1=CHART, 2=GRAPH, 3=BOTH?
Refers to the format of the output. The chart is more accurate, but the graph is better for understanding patterns of population change.

(NOTE: FOR EASE OF VIEWING, BE SURE TO TURN THE GRAPH SIDEWAYS.)

Here is the necessary information for a few animals that you may wish to investigate with POP1:

ANIMAL	REPRO. RATE	GENERATION TIME
Fruit Fly	about 250	about 12 days
Elephant	about 5	about 10 years
Bacteria	2	about 20 minutes

Your Problem - You may work on the sample problem given below or on another problem assigned by your teacher. After you have completed this task, you might try solving the same problem for some of the animals listed above.

Starting with one male and one female gypsy moth, how many generations will be required to produce 10,000 offspring in a single generation?

To be able to answer this question, you will need the following information:

The female gypsy moth lays about 15 eggs per season that survive to mate in the next generation. The adults generally live only one season, so that the time unit per generation is equal to one year.

Before you go to the computer, you can prepare your inputs using Input Chart #1.

INPUT CHART #1 (USE ONLY WITH POP1)

ANIMAL OR PLANT BEING MODELED ______________________________

Computer Input	Meaning	Correct Input
P(Ø)	Population at the beginning of the population study.	________
REPRO. RATE	Number of offspring produced by each female (divide by 2 if half of population is male).	________
TIME UNIT PER GEN.	Number of years (or weeks, or days) necessary for the females to produce offspring.	________
NO. OF GENERATIONS	The number of generations you want the computer to project into the future.	________
OUTPUT DESIRED: 1=CHART 2=GRAPH 3=BOTH	The chart gives more accurate numbers; the graph gives a better idea of patterns.	________

When you have completed this chart and checked it with your teacher (if necessary), you are ready to run the program POP1.

****

Some questions about POP1 results:

1) As we said before, every model must leave certain aspects of a problem out. Sometimes the aspects left out are so important that the answer the model gives is not realistic. Does the answer to the population problem given by POP1 seem realistic? Why or why not?

2) If you felt the solution offered by POP1 was unrealistic, what aspects of population control should be added to the model to make it give a realistic answer? (You may wish to reread the introduction to POP1.)

3) The model that POP1 is based on is called the exponential model of population growth. Does population grow at an even rate using this model?

4) Explain in your own words how population grows using the exponential growth model.

5) Do you think that it would be fair to use the exponential model to forecast man's population 100 years from now? Why or why not?

Population model #1, the exponential growth model, included only the very basic aspects of population control in making its projection. You may have noticed that many factors that are important in determining population size were left out.

POP1 allowed population growth *without limit*; but even in our everyday existence it is clear that limits almost always exist. For example, a population of deer cannot grow without limit. There is only a limited amount of food; there may be a limited amount of shelter or water for them. POP2 uses an exponential model that incorporates the idea of limiting factors. The term *limiting factors* is used to refer to these limits to growth.

In our example of the deer, we noted three possible limiting factors: food supply, shelter and water. These are examples of *density-dependent limiting factors*. When the population is low, the density-dependent limiting factors do not affect the population since there will be plenty of food, etc. But as the population increases, so do the effects of such limiting factors; and fewer and fewer offspring will be able to survive to reproduce in future generations.

When the limiting factor that is in shortest supply is being fully used by the population, no extra organisms can be added without serious consequences to the group as a whole. The population size at which the limiting factor is being consumed at the same rate that it is being produced is called the *carrying capacity*.

The POP2 model is called the *logistic model*. The logistic model behaves quite differently with different populations. If you wish to understand this model fully, it is important that you try several different organisms. But first you may want to continue with the gypsy-moth problem.

As you saw in POP1, the gypsy-moth population grows explosively when there is no limiting factor. What happens to such a population when it nears the carrying capacity?

Your Problem - Again starting with two gypsy moths, one male and one female, how will population size vary over ten generations, if the 10-square-mile forest in which the moths live can support only 500,000 moths?

Remember that each female moth produces about 15 eggs which survive to reproduce, and that the life span is only one year.

Before you try this model you may want to enter your inputs on Input Chart #2.

INPUT CHART #2 (USE ONLY WITH POP2)

ANIMAL OR PLANT BEING MODELED ______________________________

Computer Input	Meaning	Correct Input
P(Ø)	Population at the beginning of the population study.	________
REPRO. RATE	Number of offspring produced by each female (divide by 2 if the population is half male and half female).	________
TIME UNIT PER GEN.	Number of years (or weeks, or days) necessary for the females to produce offspring.	________
CARRYING CAPACITY	The size of the population that uses up the limiting factor as fast as it becomes available. *(BE SURE TO USE NO COMMAS IN INPUTTING THIS FIGURE.)*	________
NO. OF GENERATIONS	The number of generations you want the computer to project into the future.	________
OUTPUT DESIRED: 1=CHART 2=GRAPH 3=BOTH		________

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Some questions about POP2 results:

1) Does the POP2 model give a more realistic prediction of population change than POP1? What is still unrealistic about the model?

2) In our problem, the limiting factor was food supply. Do gypsy moths, who live by eating the leaves from trees, ever reach this limiting factor? (Some reading in the library may be necessary if there are no gypsy moths in your area.)

3) In reality, are the limiting factors the same all year round for an animal such as the gypsy moth? How would they change?

4) Are all limiting factors in the environment density-dependent?

5) If you investigated the POP2 model further, what differences did you find between species with low rates of reproduction and species with high rates, such as the gypsy moth?

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As we said at the beginning of this manual, each new model would include a new feature that might be important in producing a more accurate prediction of population change. POP1 examined how a population would grow without limiting factors. POP2 examined the effect of a limiting factor in the environment on population growth. POP3 adds another consideration: low-density problems -- i.e., problems associated with populations that are too small.

Let's return to our gypsy-moth problem. In each case, we started with only two moths (one male and one female) in a whole forest. If the male and the female were released in distant locations, what is the chance that the male would find the female in time to mate? Even though the moths are equipped with a very good system for mate location (as your teacher may have told you), it would seem that the chances of mating would not be good. This is a problem of low mating density. When there are many in the population, the density is said to be high and mates are easy to find; when there are few in the population and the density is low, mate location can be very difficult. In addition to mating problems, what other problems arise for populations at low densities?

When you run POP3, the computer will ask for the following additional piece of information, so that it may figure out the low mating-density effect:

AT WHAT POPULATION ARE LOW-DENSITY EFFECTS FIRST NOTED?

This means that the computer is asking for the minimum number of moths that are required for mating to occur easily.

Your Problem - What is the lowest number of moths that will result in a growing population, in the first five years?

To answer this question, you need the following information:

In our particular 10-square-mile forest, it is estimated that 100 moths are required for easy mate location. Under ideal conditions, each female lays about 15 eggs that will hatch for the next generation. Each generation takes one year. There is enough food to support 500,000 moths.

Before using the computer, you can map out your inputs for POP3 on Chart #3.

INPUT CHART #3 (USE ONLY WITH POP3)

ANIMAL OR PLANT BEING MODELED ______________________________

Computer Input	Meaning	Correct Input
P(Ø)	Population at the beginning of your problem.	__________
REPRO. RATE	Number of offspring produced by each female (divide by 2 if the population is half male and half female).	__________
TIME UNIT PER GEN.	Number of years (or weeks, or days) necessary for females to produce the next generation of offspring.	__________
CARRYING CAPACITY	The size of the population that just uses up the limiting factor.	__________
AT WHAT POPULATION ARE LOW-DENSITY EFFECTS FIRST NOTED	What is the size of the population necessary for easy mate location?	__________
NO. OF GENERATIONS	The number of generations you want the computer to project into the future.	__________
OUTPUT DESIRED: 1=CHART 2=GRAPH 3=BOTH		__________

****

Some questions about POP3 results:

1) If the POP3 model is accurate in its prediction of population change, is it necessary to kill all the animals in a population in order to kill the population off? Why?

2) What other problems besides mating might animals (or plants) have at low densities?

3) How do many wild populations, such as deer or buffalo, avoid the problems of low mating densities?

4) What other refinements do you think would be necessary before POP3 could be used to accurately predict the population of man in the year 2000?

TEACHER'S GUIDE $.30

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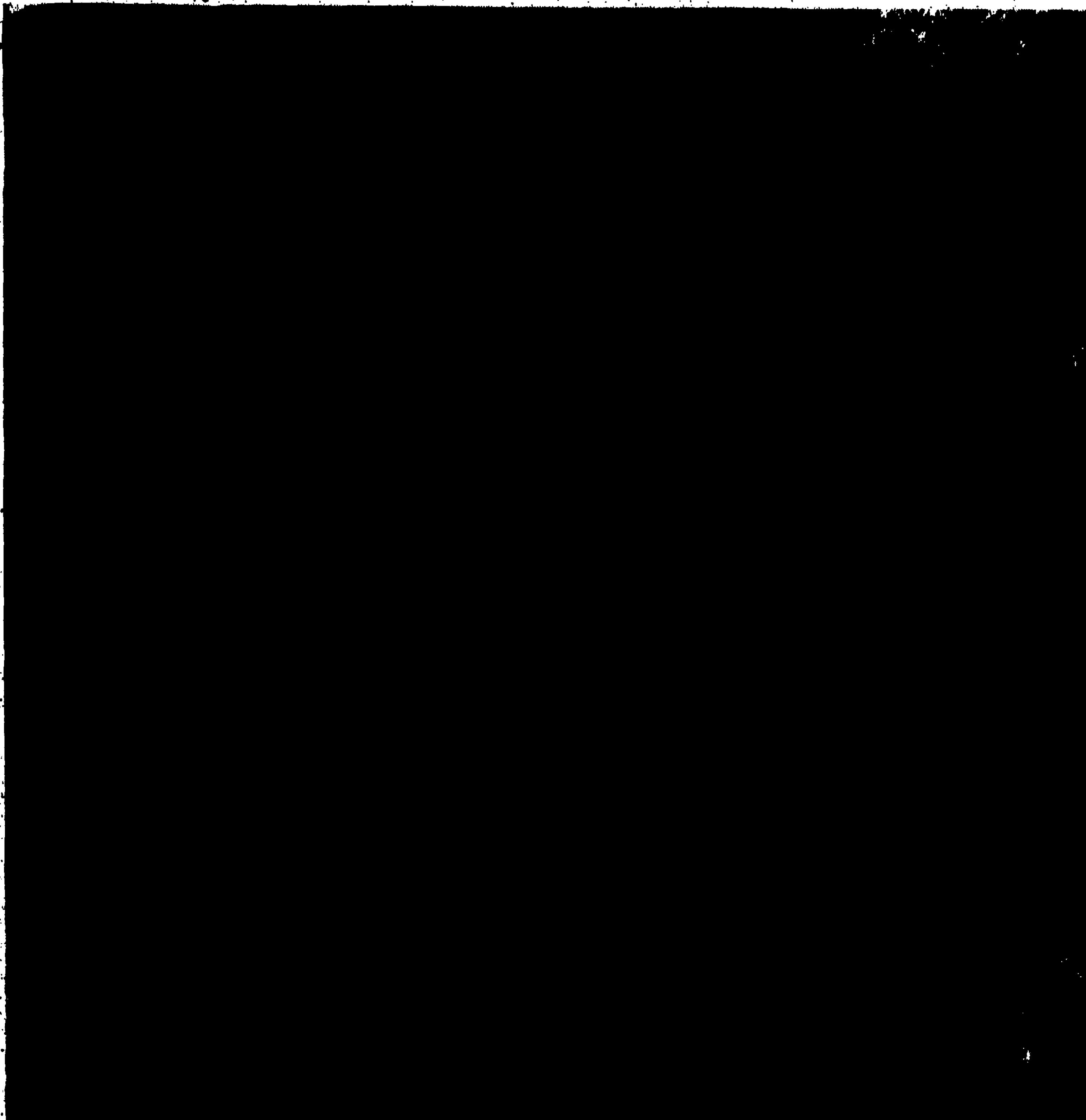

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Science	1.00
Business and Social Studies	1.00
Plotting	1.00
Huntington I Application Programs	
MATHEMATICS	$2.00
TEACHER ASSISTANCE	1.00
Huntington I Simulation Programs	
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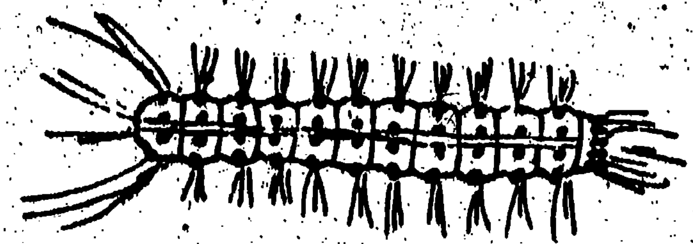
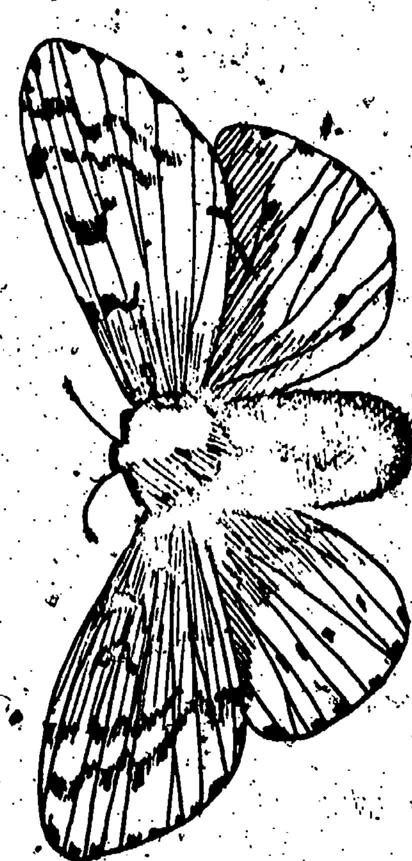


THREE MODELS OF POPULATION GROWTH

POP

TEACHER

MANUAL



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HUNTINGTON TWO COMPUTER PROJECT

30 March 1973

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POP SERIES

TEACHER MANUAL

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POP SERIES

TEACHER MANUAL

I. BASIC INFORMATION ABOUT THE UNIT

Subject Area: Biology

Specific Topic: Population Growth Modeling

Grade Level: 10 - 12

Coordinated Computer Programs: POP 1, POP 2, POP 3

Computer Language: BASIC

Abstract:

The *POP SERIES* programs are designed to allow a student with little mathematical background to explore various simple mathematical models of population growth. Student exercises revolve about studies of the growth of a gypsy-moth population. The gypsy moth was chosen as the primary animal for investigation because of its current ecological interest as an important species with few natural enemies and because its population meets the assumptions of the models presented in the *POP SERIES*.

The following models are explored in the *POP SERIES*.

POP1 - simple exponential growth (population explosion)

POP2 - logistic model (environmental limiting factor)

POP3 - logistic model with a low-density modification

Each of these programs is general enough so that it can be used to model other plant and animal populations. The necessary information for using the *POP SERIES* programs with a number of other organisms can be found in the RESOURCE MANUAL.

II. INTRODUCTION TO TEACHER MANUAL

The materials in this section were written under the assumption that you will be using the *STUDENT MANUAL* as the first part of the documentation for the programs. For other applications of the POP Series programs, please skip first to the *RESOURCE MANUAL*.

All students are concerned with the future world in which they will have to live. Often they read or hear predictions of the vast populations that will be present by the year 2000:

> "Today there are some three billion human beings on the planet. About 270,000 infants are born daily, or a population increase every month equivalent to that of Chicago...this sort of population cannot continue much longer...by the year 2000 the world's population would double today's."*

How are such figures arrived at? The POP Series attempts to acquaint students with the strengths, as well as the weaknesses, of population projection by examining how three different population-growth models give vastly different projections for a sample population's growth. At the same time the student is introduced to the concept of successive refinement of a model, since each successive POP Series model is a refinement of the previous model.

While the whole POP Series used together provides an introduction to population modeling, the POP programs can also be used separately. For example, a teacher currently presenting the Malthusian Theory might elect for his students to study only POP1, since the POP1 model gives the geometrical increase that Reverend Malthus predicted for population growth. More information on these single applications appears in the *RESOURCE MANUAL*.

*From *ECOLOGY*, Peter Farb and editors of Time-Life Books. Time-Life Books, New York, 1969, p.167.

III. SAMPLE RUN OF POP SERIES

NOTE: THE FOLLOWING ARE ANSWER RUNS TO THE 3 PROBLEMS POSED IN THE STUDENT MANUAL. THE INDIVIDUAL POINTS ON EACH GRAPH HAVE BEEN CONNECTED FOR EASY VIEWING.

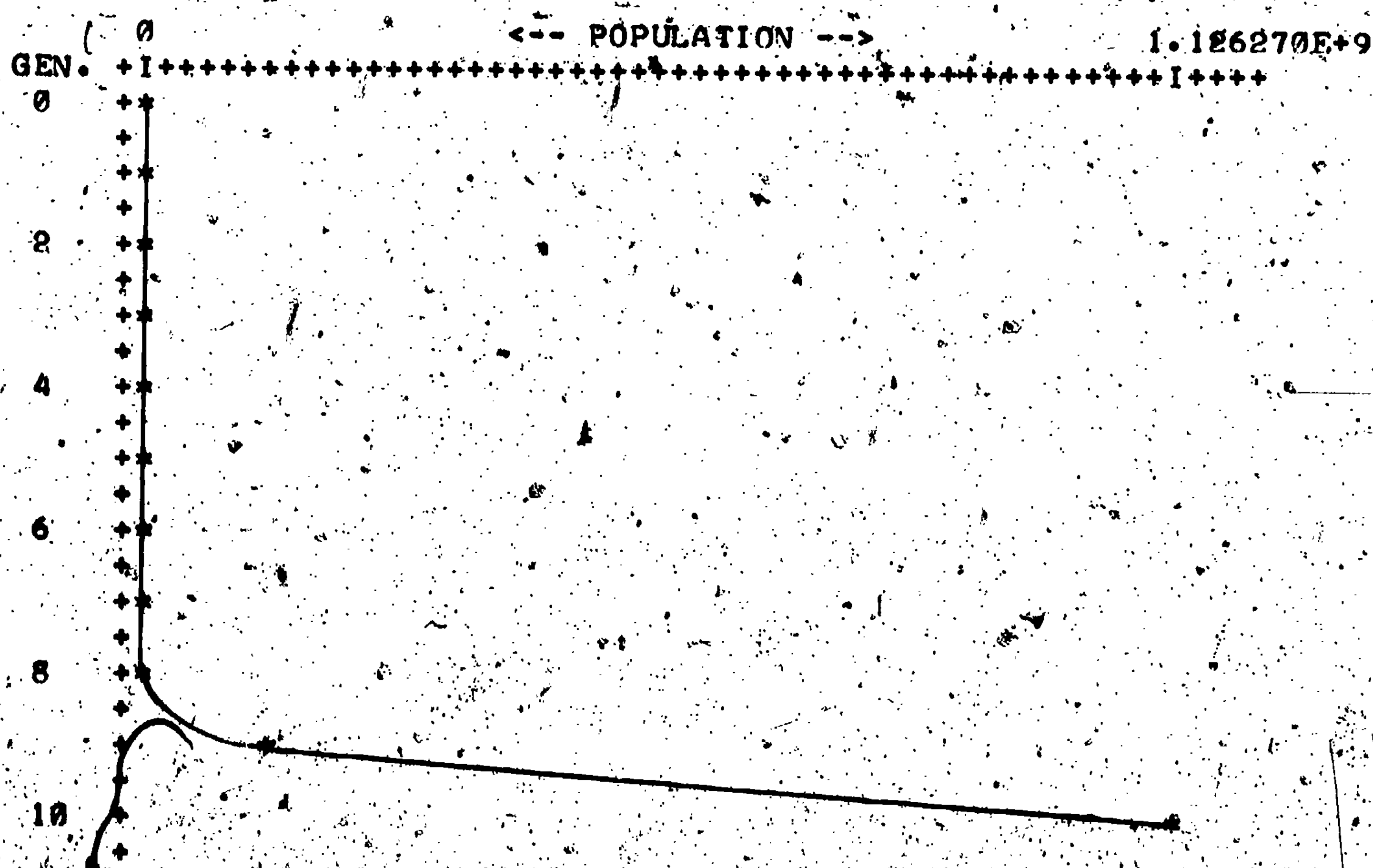
RUN 1

```
RUN

                POPULATION GROWTH SIMULATION

WHICH POPULATION MODEL? (1, 2, OR 3). TYPE IN NUMBER? 1


P(0)=? 2
REPRO.RATE=? 7.5
TIME UNIT PER GENERATION? 1
NO. OF GENERATIONS? 10
OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH? 3
GEN.            TIME            POP.
------          ------          ------
 0               0               2
 1               1               15
 2               2               113
 3               3               844
 4               4               6328
 5               5               47461
 6               6               355957
 7               7               2.669678E+6
 8               8               2.002258E+7
 9               9               1.501694E+8
 10              10              1.126270E+9
```

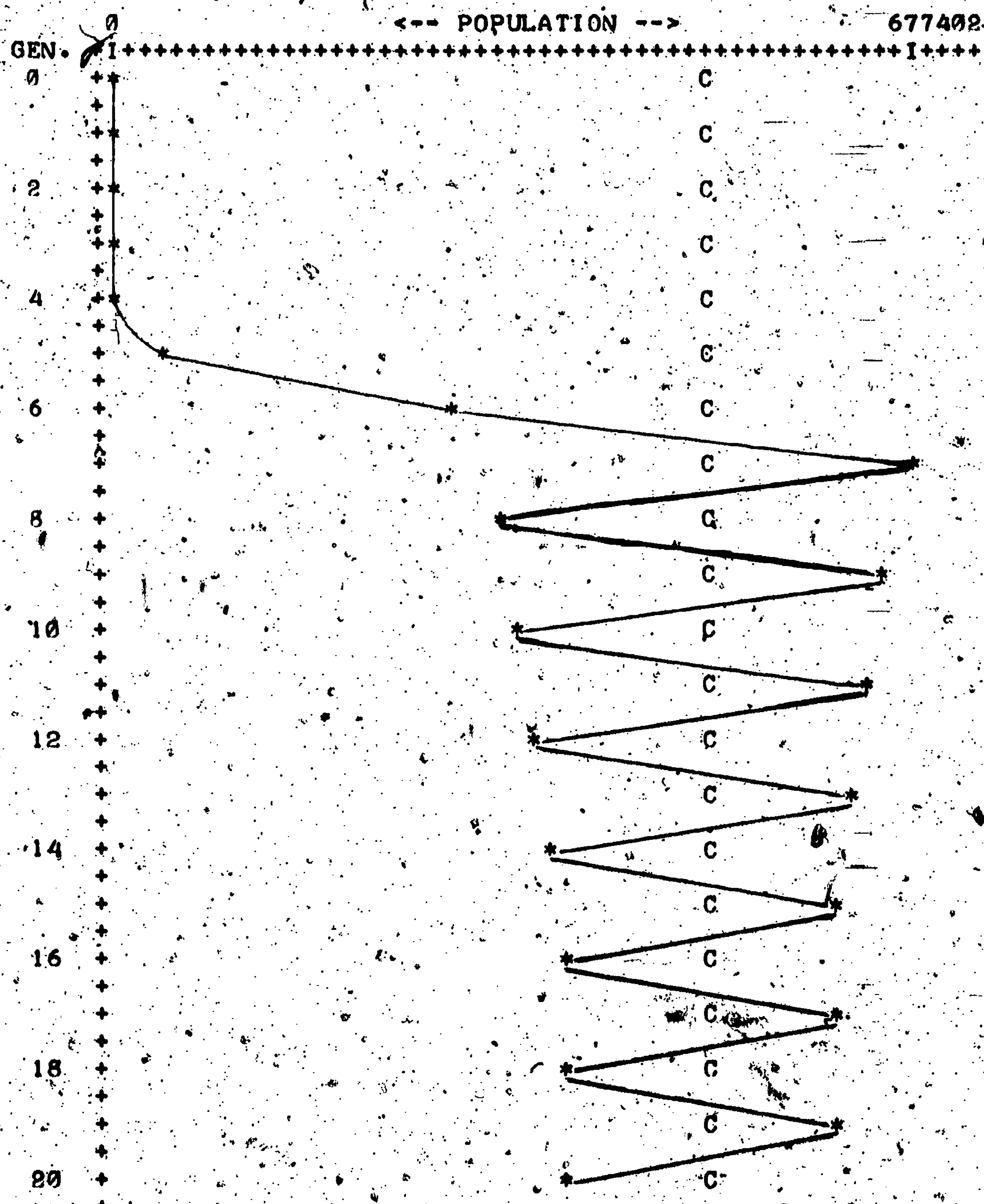



```
ANOTHER RUN? (YES=1, NO=0)? 1
```

```
WHICH POPULATION MODEL? (1, 2, OR 3). TYPE IN NUMBER? 2

P(0)=? 2
REPRO. RATE=? 7.5
TIME UNIT PER GENERATION? 1
CARRYING CAPACITY? 500000
NO. OF GENERATIONS? 20
OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH? 2
```

RUN 2




```
ANOTHER RUN? (YES=1, NO=0)? 1
```

RUN 3(a)

```
WHICH POPULATION MODEL? (1, 2, OR 3). TYPE IN NUMBER? 3

P(0)=? 2
REPRO. RATE=? 7.5
TIME UNIT PER GENERATION? 1
CARRYING CAPACITY? 500000
AT WHAT POP. ARE LOW DENSITY EFFECTS FIRST NOTED?  100
NO. OF GENERATIONS? 10
OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH? 3

GEN.              TIME              POP.
------            ------            ------
 0                 0                 2
 1                 1                 1
 2                 2                 0         POPULATION DIED OUT

         0                   <-- POPULATION -->                  2
GEN.   +I+++++++++++++++++++++++++++++++++++++++++++++++++++++++++I++++
 0     +                                                          *
       +
       +                             *
       +
       ++*    POPULATION DIED OUT

ANOTHER RUN? (YES=1, NO=0)? 1
```

```
WHICH POPULATION MODEL? (1, 2, OR 3). TYPE IN NUMBER? 3
```

RUN 3(b)

```
P(0)=? 5
REPRO. RATE=? 7.5
TIME UNIT PER GENERATION? 1
CARRYING CAPACITY? 500000
AT WHAT POP. ARE LOW DENSITY EFFECTS FIRST NOTED?  100
NO. OF GENERATIONS? 10
OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH? 1

GEN.              TIME              POP.
-----             ------            ------
 0                 0                 5
 1                 1                 5
 2                 2                 5
 3                 3                 5
 4                 4                 5
 5                 5                 5
 6                 6                 5
 7                 7                 5
 8                 8                 5
 9                 9                 5
 10                10                5

ANOTHER RUN? (YES=1, NO=0)? 1
```

```
WHICH POPULATION MODEL? (1, 2, OR 3) TYPE IN NUMBER? 3

P(0)=? 6
REPRO. RATE=? 7.5
TIME UNIT PER GENERATION? 1
CARRYING CAPACITY? 500000
AT WHAT POP. ARE LOW DENSITY EFFECTS FIRST NOTED? 100
NO. OF GENERATIONS? 10
OUTPUT DESIRED: 1=TABLE, 2=GRAPH, 3=BOTH? 1
```

RUN 3(c)

GEN.	TIME	POP.
0	0	6
1	1	7
2	2	10
3	3	19
4	4	62
5	5	393
6	6	2943
7	7	21812
8	8	149825
9	9	614375
10	10	387492

```
ANOTHER RUN? (YES=1, NO=0)? 0
```

IV. RUNNING POP SERIES PROGRAMS

The POP series programs are supplied on a single paper tape; however, each program functions independently of the others and can be used separately.

> POP1 is a simple exponential (Malthusian) model.
>
> POP2 is a logistic model, with a density-dependent limiting factor.
>
> POP3 is a modified logistic model with a low-density correction that limits reproduction of the population at very low population densities.

Since instructions within the body of the computer program are minimal, it is essential that the materials in the *STUDENT MANUAL* be used along with the program. This holds true even if some plant or animal population other than the gypsy moth is used. In addition to instructions the *STUDENT MANUAL* includes background information, input sheets, and follow-up questions for each program.

Each program will begin by asking a certain number of questions. Explanations of these questions are found in the *STUDENT MANUAL*. Once these questions have been answered, the computer program carries out all the necessary mathematical operations and outputs the population information either as a chart, a graph or both. The chart is more accurate, but the graph displays dramatically the explosive nature of the gypsy moth's population growth.

To aid in the input of correct answers to the computer question, student input sheets have been designed. These are found in the appropriate sections of the *STUDENT MANUAL*.

V. USING THE POP SERIES PROGRAMS IN THE CLASSROOM

A. Necessary Background for Students

1. Concept of a biological population

2. Concept of a generation

   generation time - the time necessary for a generation to produce its own offspring (the next generation).

3. Concept of birthrate

   a) When the birthrate exactly equals the deathrate, population size should stabilize. (This is only true in simple populations such as the gypsy moth; in man's case the situation is not this simple.)

b) The POP series use of *birthrate* refers to the average number of offspring each individual will contribute to the next generation:

i) If the population is half male, the average number of offspring per female will have to be divided in half.

Example: If in Town A, every female dog has about 14 puppies in her lifetime, the average birthrate is 15/2 or 7.5 puppies per dog per generation.

ii) If the birthrate equals one, each individual is just being replaced in the next generation. This means population size will be constant.

4. Concept of exponential growth

(Optional - your students may be allowed to develop their own ideas during investigation of the POP model.)

B. Classroom Use

The *POP SERIES* programs were designed with three possible approaches in mind: 1) as a classroom tool; 2) as a laboratory; and 3) for individual or small group usage, perhaps as extra work. While we agree that we have not been totally successful in all these areas, we think that you will find at least one of the above approaches satisfactory with your students.

1. As a classroom tool - The POP Series programs have been made as general as possible. While the objective of the entire series is to have students develop a critical sense about population projection, any single part of the series may provide the teacher with a valuable demonstration tool within the classroom. A possible example of this might revolve about the Malthusian concept of geometrical growth in population. While a teacher may attempt to give an example of this type of growth, the students generally will pose "What if..." types of questions. If the teacher has POP1 available to him in the classroom, many of these "what if" questions can be answered. (Data for possible animals that a teacher may wish to use with POP1 are given on pages 15-16 of the *RESOURCE MANUAL*.)

2. As a laboratory - There are several approaches that have proved useful for different teachers. Some teachers will find it easiest to use a POP Series program in conjunction with another laboratory, rotating the class through each set of exercises over several laboratory periods. Other teachers will prefer to have their entire class use a single POP Series program within a laboratory session. POP Series materials were designed in such a way that either approach could be attempted.

a) Rotation with another experiment - It should be possible for you to devote a majority of your time to the bulk of the class carrying out the regular laboratory, especially if your students have used a computer simulation previously. Those students doing the POP Series laboratory should be issued the *STUDENT MANUAL* at least one day before the lab period. In that time they should design their inputs on the computer input sheets (see *STUDENT MANUAL*) so that they will be prepared to start when they enter the lab. After using the computer, they can answer the follow-up questions and submit the package as a laboratory report to you.

b) Laboratory for the entire class - Instead of attempting the entire POP Series, it is suggested that you attempt one program at a time. (It is best to start with POP1.)

Divide the class into small groups, and issue to the students the portion of the *STUDENT MANUAL* to be covered in lab; this should be done at least one day before the lab session. If the students design their inputs on the computer input sheets before class, each student should be able to receive and interpret his results during a single laboratory session. In addition to the laboratory report, you might have your students ask for a tabular output in each case in addition to the computer graph. This will allow students to regraph the results in a more conventional form and yield more accurate graphs at the same time. (This activity will also give groups that have had first access to the computer something useful to do in the meantime.)

If you feel it important that each group have a different problem, you may be interested in alternative model animals listed in the *STUDENT MANUAL* and on pages 15-16 of the *RESOURCE MANUAL*.

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3. With individual students or small groups of students on their own - The *STUDENT MANUAL* should be sufficient for the student with average ability to function on his own, if he has had any experience with other simulations. For students of average ability, investigations using the POP Series programs with other animals may prove interesting and enlightening. Suggestions for other animal populations to model can be found on pp. 15-16 of the *RESOURCE MANUAL*.

VI. OUTCOME FOR THE POP SERIES

A. Correct Inputs for POP1 (If using gypsy-moth problem)

QUESTION: Starting with one male and one female gypsy moth, how many generations will be required to produce 10,000 offspring in a single generation? Assume that the female moth lays 15 eggs that hatch and that these young live one year.

Computer Question	Correct Input
P(Ø)?	2
REPRO. RATE?	7.5 (*NOTE:* answer equals 15/2 since one half of the population is male.)
TIME UNIT PER GENERATION?	1 (Year is understood)
NO. OF GENERATIONS?	____ Any number greater than 4 and less than 20
OUTPUT DESIRED: 1=CHART, 2=GRAPH, 3=BOTH?	1, 2, or 3

ANSWER FOR POP1 STUDENT QUESTION

The 5th generation of offspring will be greater than 10,000. The actual number in the 5th generation will be over 47,000. (See Sample Run 1 (p.3) for the actual output for the above.)

Suggested answers to POP1 questions: (It is important to note that these are only *examples* of correct responses.)

1) *AS WE SAID BEFORE, EVERY MODEL MUST LEAVE CERTAIN ASPECTS OF A PROBLEM OUT. SOMETIMES THE ASPECTS LEFT OUT ARE SO IMPORTANT THAT THE ANSWER THE MODEL GIVES IS NOT REALISTIC. DOES THE ANSWER TO THE POPULATION PROBLEM GIVEN BY POP1 SEEM REALISTIC? WHY OR WHY NOT?*

After the 6th generation, there are over a million gypsy moths in the 10-square-mile forest. This would lead to severe food shortages and the population growth would have to slow.

2) *IF YOU FELT THE SOLUTION OFFERED BY POP1 WAS UNREALISTIC, WHAT ASPECTS OF POPULATION CONTROL SHOULD BE ADDED TO THE MODEL TO MAKE IT GIVE A REALISTIC ANSWER? (YOU MAY WISH TO REREAD THE INTRODUCTION TO POP1.)*

(Answer for this question depends on the responses above.) A necessary corrective factor could limit high populations in some way. (This is actually done by limiting the reproductive capacity at high population densities.)

3) *THE MODEL THAT POP1 IS BASED ON IS CALLED THE EXPONENTIAL MODEL OF POPULATION GROWTH. DOES POPULATION GROW AT AN EVEN RATE USING THIS MODEL?*

No, the rate of population growth, while constant, causes the population to grow at an ever-increasing number per unit time.

4) *EXPLAIN IN YOUR OWN WORDS HOW POPULATION GROWS USING THE EXPONENTIAL GROWTH MODEL.*

Any answer that indicates that population grows slowly at first and then more rapidly as time goes on should be acceptable.

5) *DO YOU THINK THAT IT WOULD BE FAIR TO USE THE EXPONENTIAL MODEL TO FORECAST MAN'S POPULATION 100 YEARS FROM NOW? WHY OR WHY NOT?*

This is a matter of opinion among demographers; it is included to stimulate discussion.

B. Correct Inputs for POP2 (If using gypsy-moth problem)

QUESTION: Starting again with two gypsy moths, one male and one female, how will the population vary over twenty generations, if the forest in which they live has enough food to support only 500,000 moths? The female moth produces about 15 eggs that survive the winter to hatch and reproduce the next year. The life span is only one year.

Computer Question	Correct Input
P(O)?	2
REPRO. RATE?	7.5 (See POP1)
TIME UNIT PER GENERATION?	1
CARRYING CAPACITY?	500000 (Make sure no commas are used)
NO. OF GENERATIONS	20
OUTPUT DESIRED: 1=CHART, 2=GRAPH, 3=BOTH?	1, 2, or 3

SAMPLE ANSWER FOR POP2 QUESTION

Every time the population exceeds the carrying capacity, the population for the next year drops below the carrying capacity. At this point the cycle repeats itself. (See Sample Run 2.)

Suggestion: Have the students select either the graph output or the graph and table (output selection #3), since this question is involved with a pattern of growth. Once they have the output, suggest to them that they connect the points on the graph. (This makes the pattern much clearer.)

It may be necessary to explain that with computer graphs, points are only approximate; that is, if a point is on the zero line the number may be near zero, but not necessarily equal to zero. The point marked by "C" on the graph is the carrying capacity.

Suggested answers to POP2 questions

1) *DOES THE POP2 MODEL GIVE A MORE REALISTIC PREDICTION OF POPULATION CHANGE THAN POP1? WHAT IS STILL UNREALISTIC ABOUT THE MODEL?*

POP2 gives a more realistic answer than POP1, but the answer is still unrealistic. For instance, the overpopulation of moths should reduce the carrying capacity of the forest as trees will be destroyed.

2) *IN OUR PROBLEM, THE LIMITING FACTOR WAS FOOD SUPPLY. DO GYPSY MOTHS, WHO LIVE BY EATING THE LEAVES FROM TREES, EVER REACH THIS LIMITING FACTOR? (SOME READING IN THE LIBRARY MAY BE NECESSARY IF THERE ARE NO GYPSY MOTHS IN YOUR AREA.)*

Yes, many areas of New England and certain areas in the Mid-Atlantic and Midwestern States have been defoliated by the gypsy moth. (See bibliography for references in periodical literature.)

3) *IN REALITY, ARE THE LIMITING FACTORS THE SAME ALL YEAR ROUND FOR AN ANIMAL SUCH AS THE GYPSY MOTH? HOW WOULD THEY CHANGE?*

No, not always. For example, in certain seasons such as spring, food might be more available than in the summer or the fall. This would mean a lower carrying capacity in the summer or the fall.

4) *ARE ALL LIMITING FACTORS IN THE ENVIRONMENT DENSITY-DEPENDENT?*

No. An example of a density-independent limiting factor would be one that would affect populations of any size in the same manner. An example of this might be the temperature.

5) *IF YOU INVESTIGATED THE POP2 MODEL FURTHER, WHAT DIFFERENCES DID YOU FIND BETWEEN SPECIES WITH LOW RATES OF REPRODUCTION AND SPECIES WITH HIGH RATES, SUCH AS THE GYPSY MOTH?*

Answer would depend on which animals were investigated.

C. Correct Inputs for POP3 (If using gypsy-moth problem)

NOTE: POP3 requires student investigation. To arrive at a correct solution to the following question, several trial runs will be required; thus this program may not be appropriate for a class laboratory.

QUESTION: What's the smallest number of moths that will result in a growing population during the first 5 years?

To answer this question you need the following information. In our particular forest it has been estimated that 100 moths are required for easy mate location. Each female moth lays about 15 eggs that hatch to form the next generation. Each generation takes one year. There is enough food to support 500,000 moths.

NOTE: THIS QUESTION HAS BEEN INCLUDED TO ALLOW CONTINUITY OF SUBJECT FOR THE ENTIRE POP SERIES. A FIGURE FOR THE REQUIRED MINIMUM DENSITY IN THE CASE OF THE GYPSY MOTH IS NOT AVAILABLE. IF ACCURACY IS MORE IMPORTANT THAN CONTINUITY, SEE P.17 IN THE RESOURCE MANUAL FOR ALTERNATE ORGANISMS FOR POP3 MODELING.

Computer Question	Correct Input	
P(Ø)?	____	(Any number that the student feels might be an answer to the question.)
REPRO. RATE?	7.5	
TIME UNIT PER GENERATION?	1	(Year)
CARRYING CAPACITY?	500000	(Make sure no commas are used.)
AT WHAT POPULATION ARE LOW-DENSITY EFFECTS FIRST NOTED?	100	(No commas)
NO. OF GENERATIONS?	____	(5 or more; any number acceptable)
OUTPUT DESIRED: 1=CHART, 2=GRAPH, 3=BOTH?	1 or 3	desirable (any response allowable)

SAMPLE ANSWER FOR POP3 QUESTION

Any population of less than 5 dies out. A population of 5 organisms remains at that number. A population of 6 organisms results in growth. (See Sample Runs 3a, b, and c.)

Suggested answers to the POP3 questions

1) *IF THE POP3 MODEL IS ACCURATE IN ITS PREDICTION OF POPULATION CHANGE, IS IT NECESSARY TO KILL ALL THE ANIMALS IN A POPULATION IN ORDER TO KILL THE POPULATION OFF? WHY?*

According to POP3, it is not necessary to kill every animal to cause the population to die off. If the population is reduced to very low levels, low-density effects may cause the extinction of the population without any additional slaughter.

2) *WHAT OTHER PROBLEMS BESIDES MATING MIGHT ANIMALS (OR PLANTS) HAVE AT LOW DENSITIES?*

Animals that use large numbers for protection would have problems at low densities. Also animals with complex social organizations, such as man or the bee, would have low-density problems if there were too few individuals to fill the necessary roles in the society.

3) *HOW DO MANY WILD POPULATIONS, SUCH AS DEER OR BUFFALO, AVOID THE PROBLEMS OF LOW MATING DENSITIES?*

Deer and buffalo keep their densities high; either by herding or by congregating in certain locations at mating seasons. (Many other species exhibit such grouping activities; have students investigate to see if the reasons for these activities might be to avoid low-density problems.)

4) *WHAT OTHER REFINEMENTS DO YOU THINK WOULD BE NECESSARY BEFORE POP3 COULD BE USED TO ACCURATELY PREDICT THE POPULATION OF MAN IN THE YEAR 2000?*

Man does not live for just one generation; neither are all the children produced in a single year. Other modifications which could be made include the following:

a) A life span factor

b) A changing limiting factor

c) A factor for the number of people not having families

d) A factor for the time after birth that marriage takes place.

Many other modifications should be suggested by the students. The objective of this question is to demonstrate that modeling human populations is a vastly difficult enterprise even with the help of computers.

RESOURCE HANDBOOK $.50

DIGITAL EQUIPMENT CORPORATION

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HUNTINGTON II Simulation Program--POP

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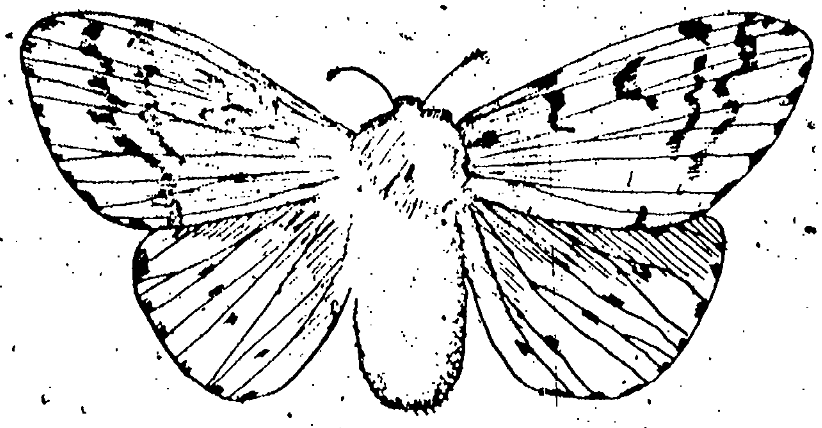
THREE MODELS OF POPULATION GROWTH

POP

RESOURCE MANUAL



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HUNTINGTON TWO COMPUTER PROJECT

30 March 1973

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POP SERIES

RESOURCE MANUAL

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I. ABOUT THE GYPSY MOTH

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 those 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.

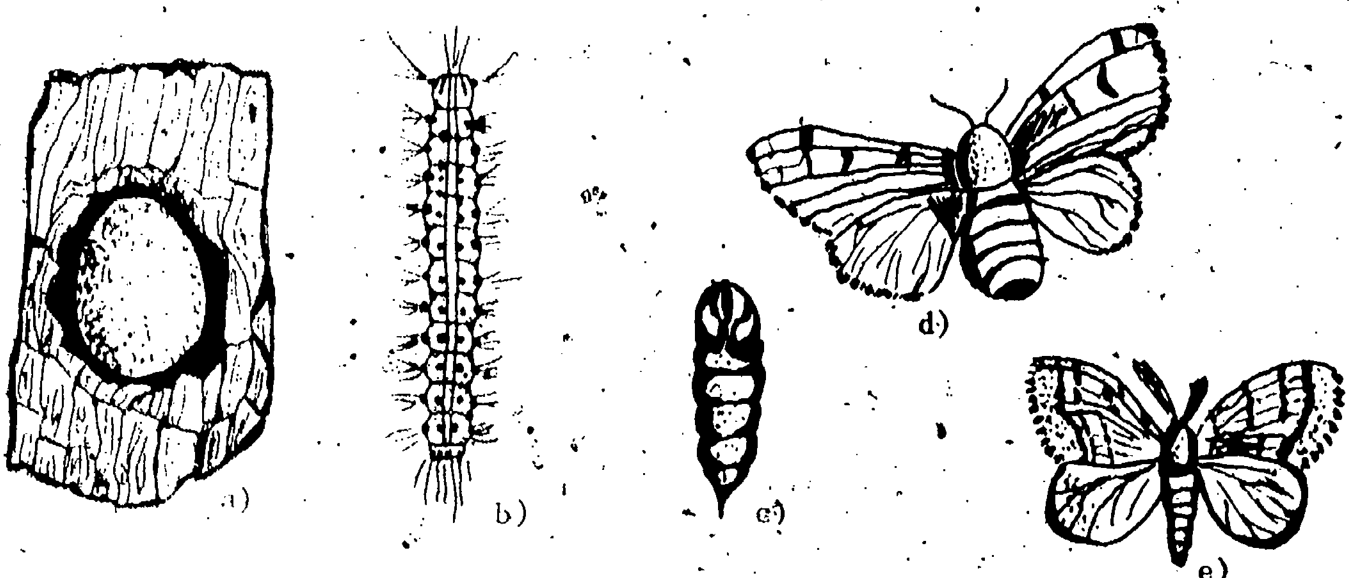


Figure 3.1. a) egg mass; b) larva; c) pupa; d) female adult; e) male adult.

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.

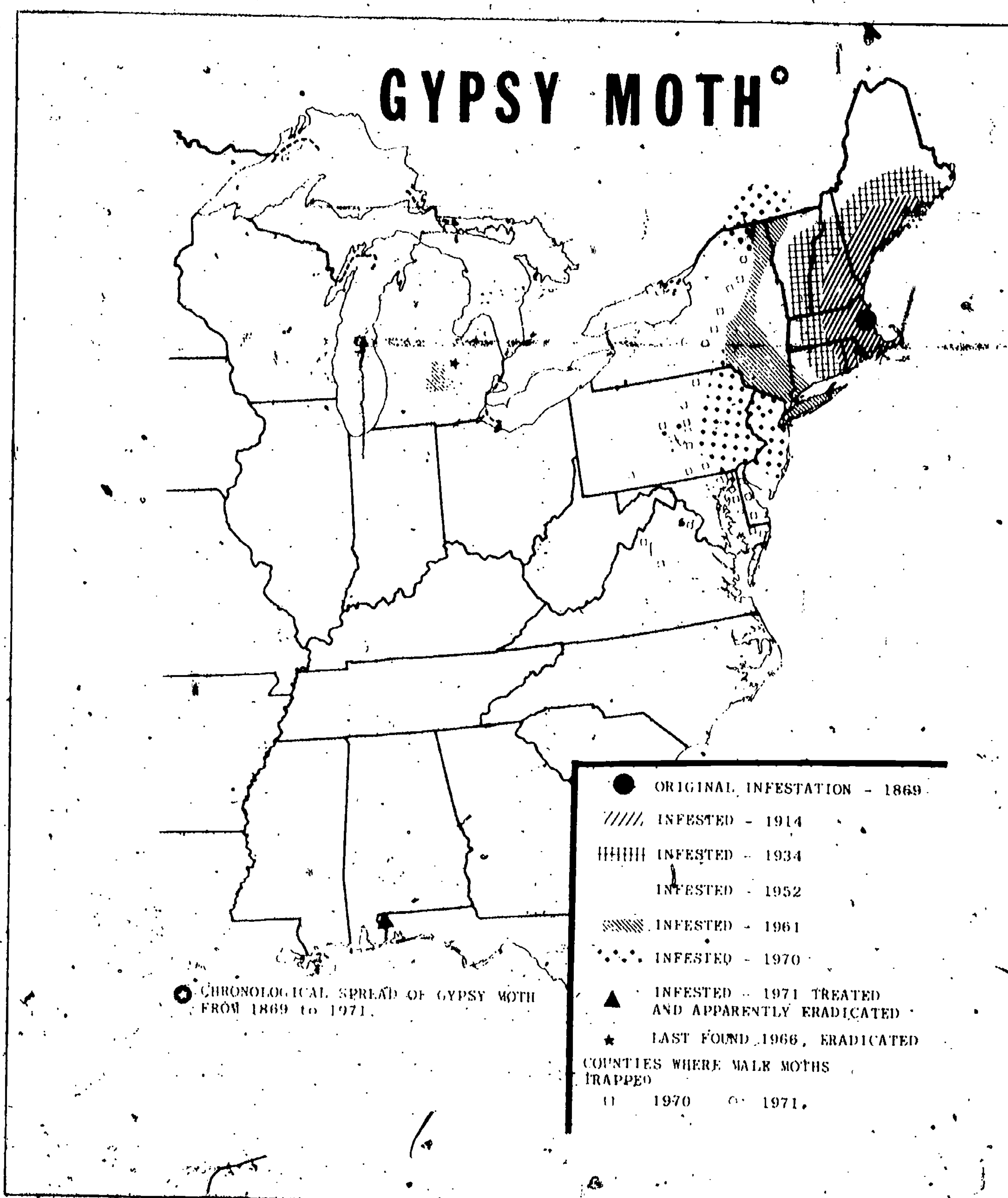
The appearance and the behavior of the males and females vary greatly. The male is brown in color, with light brown wings. The wings have wavy band markings with dark dots along the outer margin; wingspread is about 1½ inches. The female is white in color with a yellowish abdomen. She is much longer 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.

POP2 - THE LOGISTIC MODEL

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 musk-rats 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).

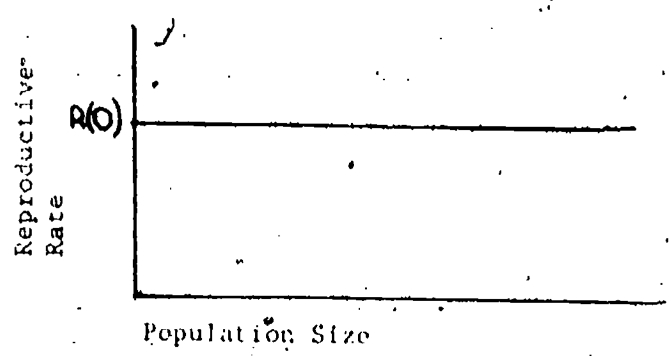


Figure 3.4.

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.

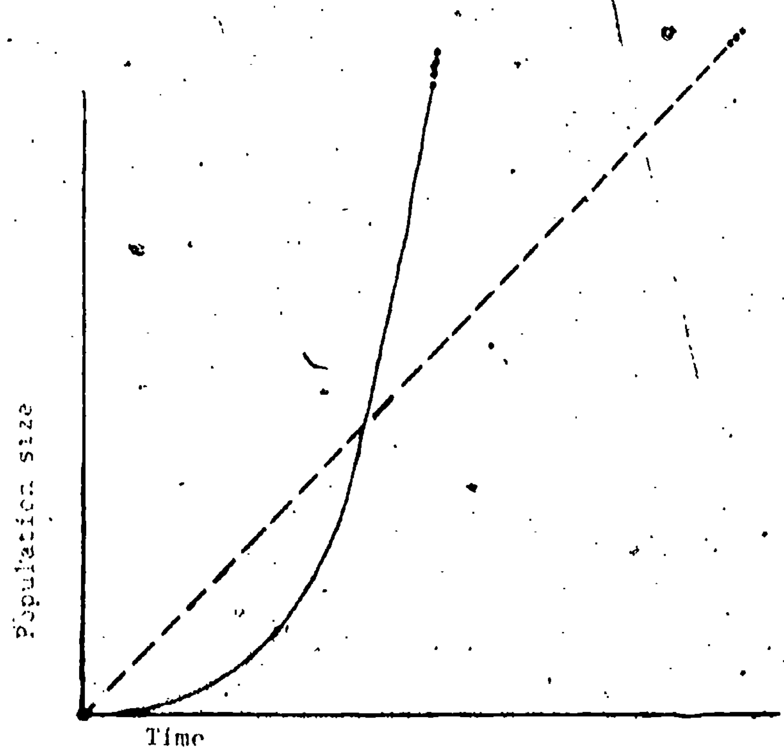


Figure 3.5. Dashed line (– – – –) indicates the arithmetic growth that Malthus predicted for food supply. The solid line (———) indicates the exponential growth expected of a population growing without limit. At the point where the lines cross, Malthus predicted that famine or some other disaster must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

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.

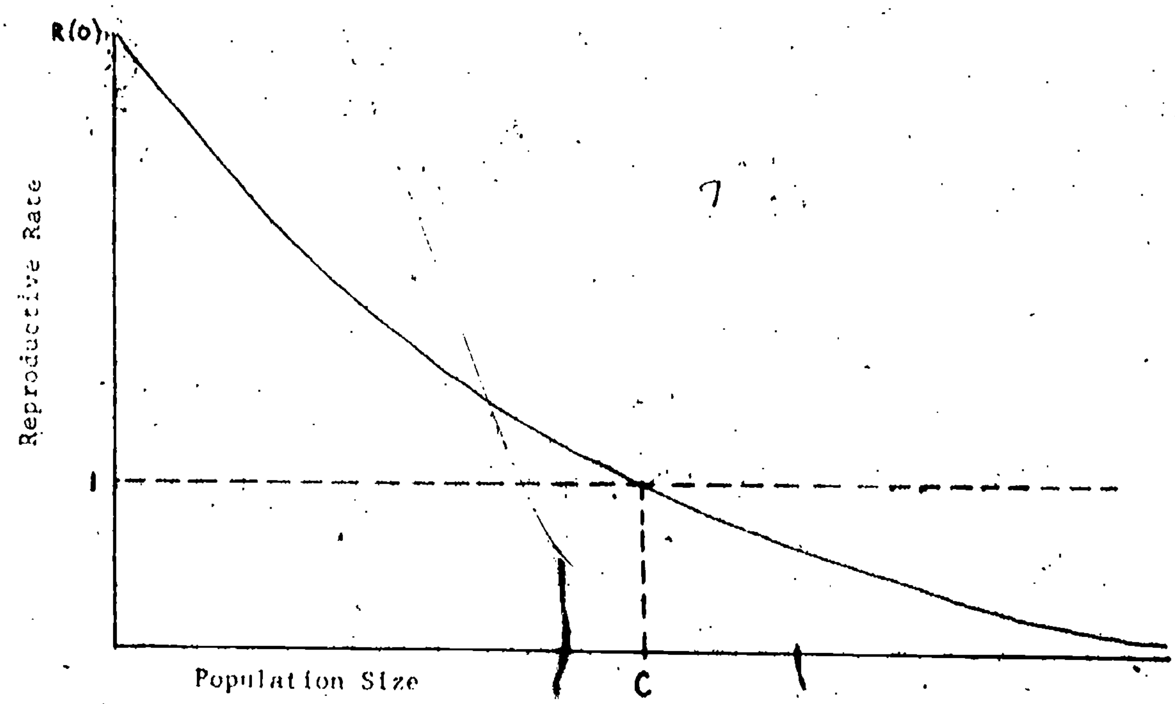


Figure 3.6. Only at the lowest populations does reproductive rate equal or near the biotic potential R(Ø). As population size increases, the actual reproductive rate drops, untul at the carrying capacity (C) the reproductive rate equals 1.

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).

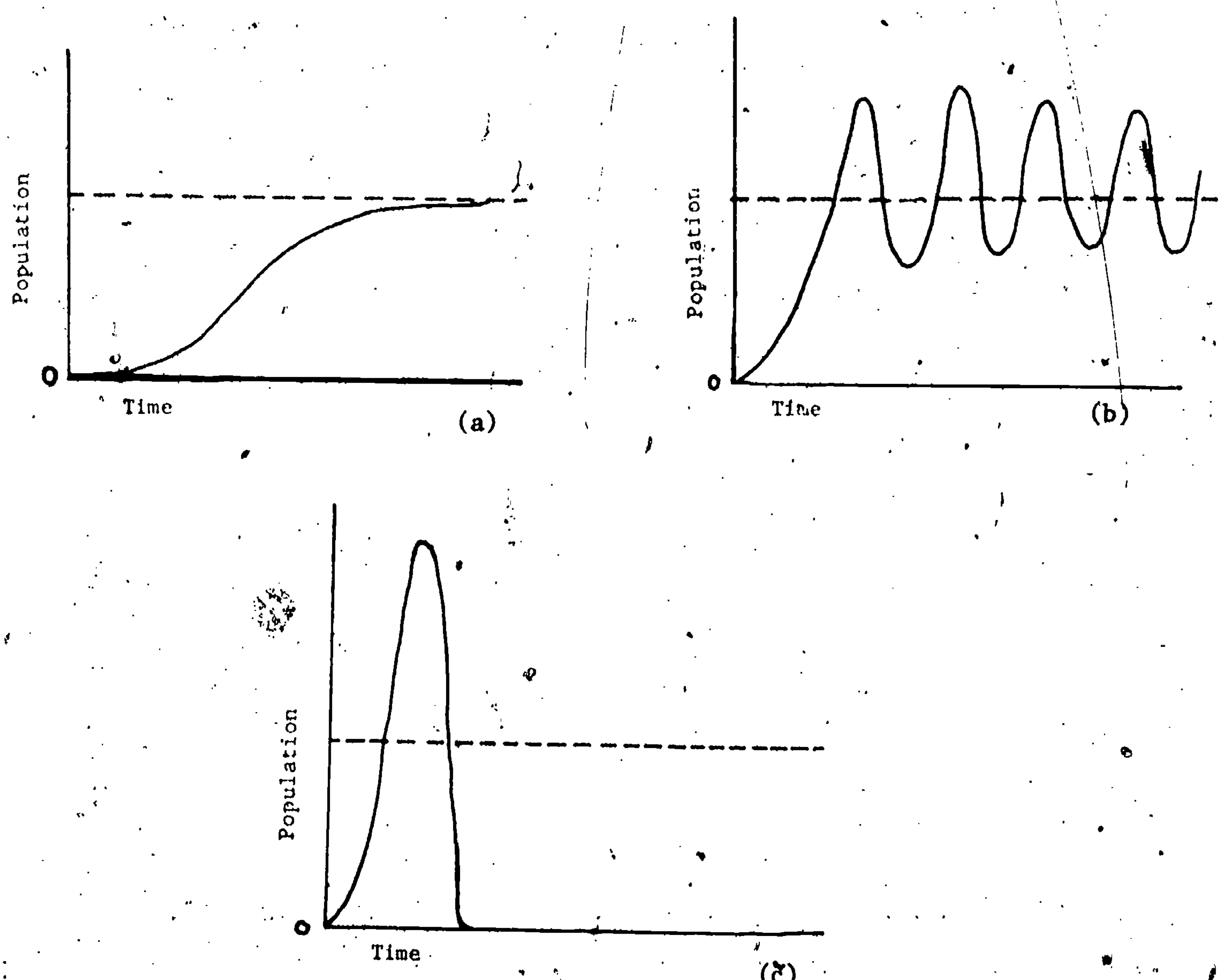


Figure 3.7. See text for details. Dotted lines (– – – –) indicate carrying capacity.

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.

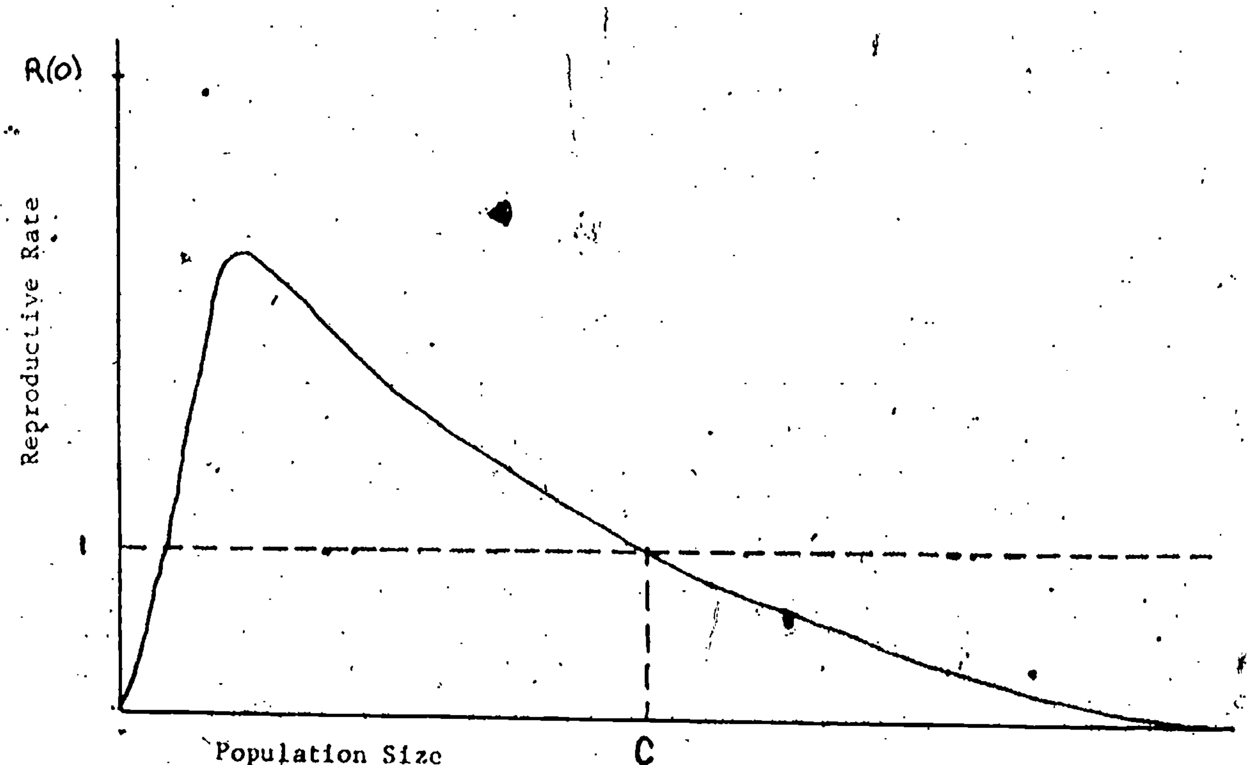


Figure 3.8. At both high and low populations, the reproductive rate is suppressed. (Carrying capacity indicated by C.)

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:

For POP1   R = RØ

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

For POP2   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.

For POP3   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:

For POP1   P = RØ * P

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

For POP3   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
```

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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.

---

*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(∅) = 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(∅) include P(∅)=2, for a projection of the future population starting off with 2 individuals (1 male and 1 female, of course); or P(∅)=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

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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 [illegible]tion 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 (3 b), 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
.	.	.
.	.	.
.	.	.

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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. Using POP2 - Investigation of the role of carrying capacity in determining reproductive rate in the POP2 model.

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:

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

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

Selected Student Text Materials

BIOLOGICAL SCIENCE: AN INQUIRY INTO LIFE
BSCS (Yellow) 2nd Edition
Harcourt, Brace and World, New York (1968).

Ch.38, pp.734-755: A look at the consequences of human population growth.

Ch.31, pp.568-570: Exponential growth model relative to evolution.

BIOLOGICAL SCIENCE: MOLECULES TO MAN
BSCS (Blue) Revised Edition
Houghton Mifflin Company, Boston (1968).

Ch.27, pp.679-697: Covers almost all the concepts essential to POP series models.

BIOLOGICAL SCIENCE: PATTERNS AND PROCESSES
BSCS Revised Edition
Holt, Rinehart and Winston, New York (1970).

p.36: Explosive exponential growth.

pp.55-60: Population graphing exercise.

BIOLOGY: AN INQUIRY INTO THE NATURE OF LIFE
Weinberg, Stanley
Allyn and Bacon, Boston (1971).

pp.543-545: Logistic model development.

pp.527-530: Human population explosion.

NOTE: Most texts have appropriate background materials in the sections indexed under populations.

College Texts

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PRINCIPLES OF ANIMAL ECOLOGY
W. B. Saunders Publishing Co., Philadelphia (1971).

Especially Section III: Populations, pp.263-419.

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THE DISTRIBUTION AND ABUNDANCE OF ANIMALS
University of Chicago Press, Chicago (1954).

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THE STRUGGLE FOR EXISTENCE
Hafner Publishing Co., New York (1969).

Keeton, William
BIOLOGICAL SCIENCE, 2nd Edition
W. W. Norton and Co., New York (1972).

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Odum, Eugene
FUNDAMENTALS OF ECOLOGY, 3rd Edition
W. B. Saunders Publishing Co., Philadelphia (1971).

pp.106-138: Limiting factors

pp.162-228: Populations

Slobodkin, Lawrence
GROWTH AND REGULATION OF ANIMAL POPULATIONS
Holt, Rinehart and Winston, New York (1961).

Periodicals and U. S. Government Publications

HERE COMES THE GYPSY MOTH by Jean George

Reader's Digest, March 1972 (p.49)

condensed from *The Conservationist* (Feb.- Mar.'72 issue)

GYPSY MOTH CONTROL BY THE SEX ATTRACTANT PHEROMONE

M. Beroga and E. F. Knipling

Science, Vol.177, No.4043, p.19 (1971)

THE GYPSY MOTH

Program Aid 910
United States Department of Agriculture (1970)
Washington, D. C.

THE GYPSY MOTH FACT SHEET

Research Service
United States Department of Agriculture (1970)

NOTE: There have been many articles on defoliation in local papers throughout the infested areas.