ANALYSIS OF CATCHABLE TROUT FISHERIES MANAGEMENT BY COMPUTER SIMULATION

by

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Table of Contents

List of Figures

Introduction

Stocking hatchery-reared trout is a recreational fisheries management technique that has been used in the U.S.A. since the mid-1800's. Stocking catchable trout is now an important activity of most North American governmental agencies that deal with management of coldwater recreational fisheries. Catchable trout fisheries annually supply millions of anglers with an outdoor recreational experience. Public opinion has always been strongly in support of these programs and is likely to continue for the foreseeable future.

Catchable trout programs can be divided into two categories: single and multi-species stocking programs. The advantages of a single-species stocking program are that by selecting a species with a high food conversion rate, initial production costs can be kept low and the strategy to meet most management objectives is relatively simple. A potential advantage in multi-species stocking programs is that certain species may be better suited than others to particular habitat types. Inherent differences among species may give the fisheries manager greater system control than he now has in a multi-species catchable trout program. Increased initial production in multi-species programs may be offset if management objectives are better realized.

Efforts have been made to evaluate potential management strategies to obtain the greatest output from single-species catchable trout fisheries. One approach is to determine required plant size and frequency needed to provide optimal plant-to-plant survival (Butler and Borgeson 1965). Optimal survival is defined as one which is high enough to prevent an undesirable decrease in angling effort during the planting interval. Although this optimal survival is not necessarily the same for every fishery, required plant size to maintain this optimum can be calculated from estimates of mean catch per hour and catchability of stocked trout in that fishery.

In many catchable trout fisheries, agency personnel have the option to stock several species, usually brook, brown, and rainbow trout. Single-species optimization efforts are inappropriate for these fisheries because the optimal ratio of species, as well as plant size and frequency, must be considered. The manipulation of such factors as species ratio, plant size, and planting frequency within specific agency and external constraints, can be used to evaluate potential management strategies.

The first obstacle that must be faced in evaluating catchable trout fisheries management strategies is defining management objectives, or at least defining an acceptable measure of system output. Traditionally, little consideration has been given to this aspect of management (Lackey 1974). Stated objectives are usually vague and may, in some cases, be unattainable. For example, optimization of recreational benefit from catchable trout fisheries is a stated objective of many fisheries agencies. However, recreational benefit has not been quantified nor has a formalized description been widely accepted by managers. Agency personnel often accept the more immediate objectives of providing maximum percentage return of stocked fish or maximum number of recreational hours to anglers. Cost of the total stocking operation is usually included as a management constraint. These management objectives are not simultaneously reachable. Supplying anglers with the maximum number of recreational hours may not even be desirable since aesthetic values must be sacrificed. To establish a clear-cut objective, a satisfactory fishery must be defined in terms of acceptable return of stocked fish, a desired range of catch per angler hour, and an acceptable distribution of angling effort throughout the fishing season.

One approach to testing alternative management strategies in complex resource systems, such as catchable trout fisheries, is systems simulation. A system is an assemblage of components united by some form of interaction or interdependence in such a manner as to form a whole. Any real system can be looked upon from differing viewpoints, and each viewpoint gives a different perspective. A simulation of a system is an abstraction, and the degree of abstraction is a value judgment made for the purpose at hand. The key to effective modeling is to strike a proper balance between realism and abstraction (Patten 1971).

The most recent breakthrough in fisheries management methodology is the use of computers for studying the structure, and decision making processes in complex systems (Powers, Lackey, and Zuboy, 1974). If sufficient understanding of a resource system exists, managers can proceed with simulation and system modeling. This approach has been widely used in commercial fisheries, in particular the salmon fisheries (Paulik and Greenough 1966).

Much data are available concerning the interactions of system components in catchable trout fisheries. With a computer simulated catchable trout fishery, one could observe the effects of such input alternatives as: stocking different ratios of species, altering catchability coefficients, changing levels of fishing pressure, using different stocking frequencies, or a combination of these. A manager could use a simulation to develop a management strategy to meet a given objective within any constraints he chooses. The purposes of this paper are: 1) to summarize the development and structure of CATS (Catchable Trout Fishery Simulator); and 2) to illustrate development of management strategies for given objectives on hypothetical fisheries.

Simulator Development

Development of CATS was started by formally defining the system under study: a multi-species, put-and-take, catchable trout fishery. The immediate problem was to conceptually structure the fishery by relevant system components (Fig.1). Relationships between components were determined by discussions with fisheries managers, creel surveys, and a review of the literature. Observance of recurring phenomena permitted development of basic system concepts which were then programmed to form CATS.

Values for daily angling pressure in a catchable trout fishery can be constant, random, follow a predictable relationship with current fish population, or be partially predictable and partially random. A fairly constant fishing pressure can occur on a stream close to a large population center where a percentage of potential anglers will fish independent of management efforts. Random angling pressure can occur on a large lake fishery where probability of success is not appreciably increased by fishing immediately after stocking. Angling pressure often follows a predictable ratio of daily angler hours to current population of fish, i.e., $f = \alpha N$, (where f equals fishing pressure, α equals a constant, and N equals the population of fish available in the fishery). This pattern results from high fishing pressure on the day of stocking, followed by a rapid decline as trout populations are depleted. Weather and other stochastic inputs account for unpredictable variation around predicted fishing pressure generated by the ratio of angler hours to current fish population. CATS permits the user to select any of these approaches

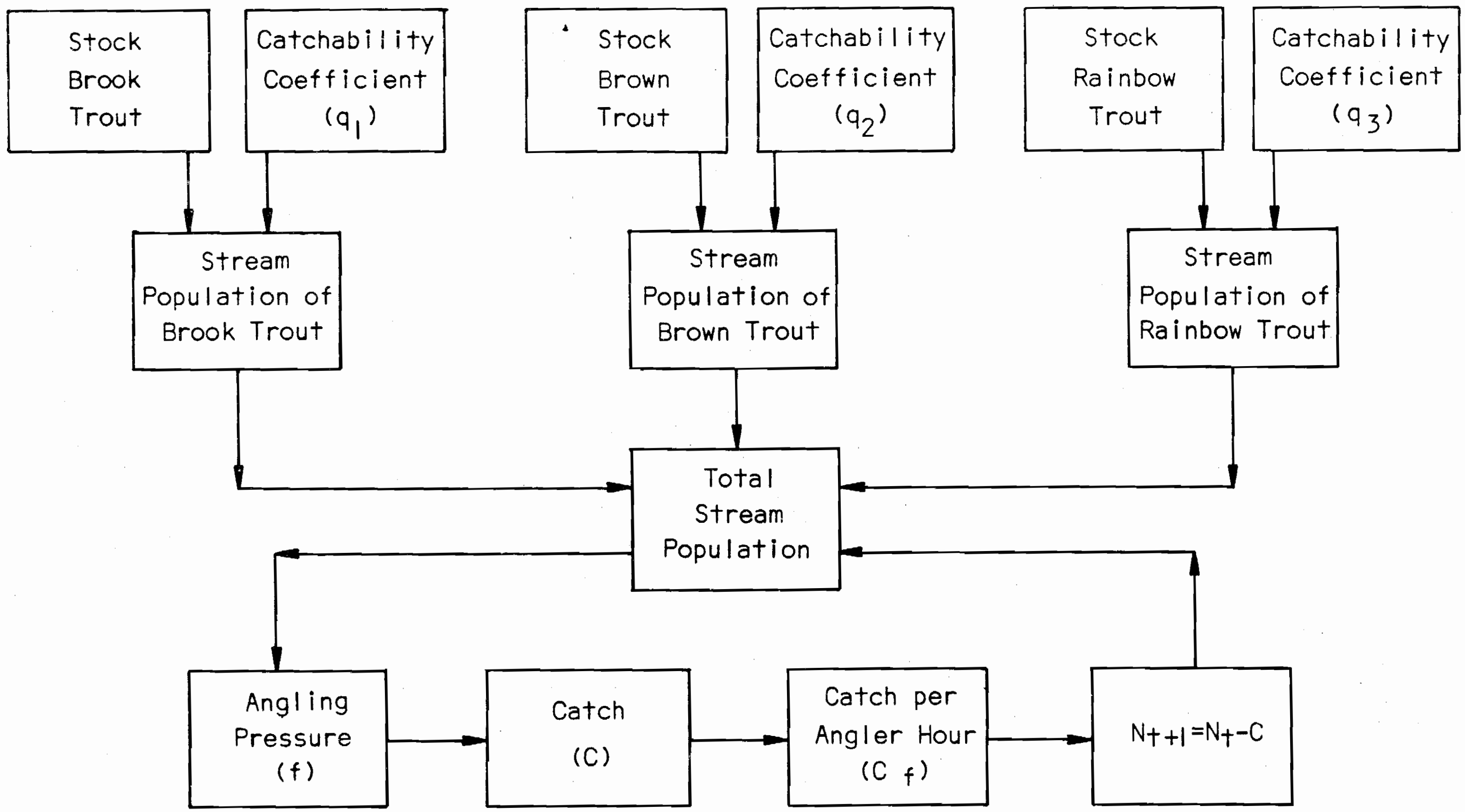

Figure 1. A simplified structure of a multi-species catchable trout fishery as simulated in CATS.

for determining daily fishing pressures.

The differences in catchability coefficients (q) of different trouts used in stocking programs can perhaps be used to advantage in management (Cooper 1959). Catchability coefficients are dependent on the environment, innate characteristics of the fish, distributional practices of the stocking agency, and the effectiveness of one unit of fishing effort. On any given water with a stable planting program, catchability of a single species is primarily dependent upon the fish's environment, because the species, its distribution, and the effectiveness of the average unit of fishing effort are nearly constant (Butler and Borgeson 1965). Relative stability of environmental conditions should result in fairly stable catchability coefficients of stocked trouts. In CATS, the user is given the option to supply any values of (q) appropriate to the situation under consideration.

Three aspects of the actual stocking process can be considered as potential management decisions: ratio of species stocked, total number of fish stocked, and stocking frequency. Annual stocking allotments for particular catchable trout waters are usually based on production (number available), demand (expected fishing pressure), and the potential of the area to support angling pressure. The user of CATS provides realistic input of the ratio of species and the total numbers to stock within these constraints.

Stocking frequency can be based on one of several options. The simplest option is to restock after some arbitrary number of days between plants. Another alternative is to stock when catch per angler hour (C/f) drops to a specified value. Although this alternative may seem reasonable, there are daily fluctuations in C/f in most fisheries that would result in restocking before it is really necessary. Perhaps the soundest principle on which to base stocking frequency is to restock after plant-to-plant survival has reached a specified level. This procedure insures that a drop in C/f is actually due to population depletion rather than natural fluctuation. CATS provides the user with each of these stocking options.

Simulator quantification was initially approached by viewing catchable trout fisheries as deterministic systems. Calculations were made as though exact or deterministic relationships between system components were known. This approach to simulation is most useful when variation in the system under consideration is largely described by the simulator. Large amounts of unexplained variation will substantially decrease the utility of deterministic models. It is often unrealistic to rely on deterministic models to help solve problems because exact values of input variables are usually not known (Kowal 1971).

Stochastic processes were included in CATS because the outcome of any particular strategy cannot be exactly predicted. To account for stochastic inputs such as weather, a random number generator and two random process generators were added. Even though a phenomenon may be inherently deterministic, stochastic considerations are necessary due to our ignorance (Papoulis 1965). Values for all input variables in CATS are really elements from probability distributions. To generate predictions, the user enters probability distributions instead of entering specific values for variables and constants. Generated predictions will then be probability distributions, rather than exact values (Kowal 1971). For example, a plant of one thousand rainbow trout might be found to generate one hundred angling hours of fishing pressure on the first stocking day. If predicting angling pressure were a strictly deterministic phenomenon, one would expect that in that particular fishery, a plant of one thousand trout would always produce one hundred hours of angling pressure on the day of stocking. However, this is clearly not the case in catchable trout fisheries. Angling pressure may well follow some predictable trend, but stochastic processes were incorporated into CATS to account for unexplained fluctuations in fishing pressure.

The random number generator in CATS determines the location of a particular variable on one of two probability distributions. Uniform or standard normal parameters defining these distributions are provided by the user based on his best estimates from creel survey data or any other sources. For example, a species catchability coefficient may be considered as coming from a uniform distribution with predicted extremes (end points) or a standard normal distribution with a predicted mean and standard deviation. The uniform distribution can be used when coefficients are highly variable or predictable only within certain gross bounds. The standard normal distribution can be used when coefficients are observed to be more stable.

CATS was programmed in FORTRAN IV with a main program supported by one subroutine and three function subprograms (Fig.2). Data necessary for program implementation are read from user-supplied data cards. Probability distributions generate daily values of fishing

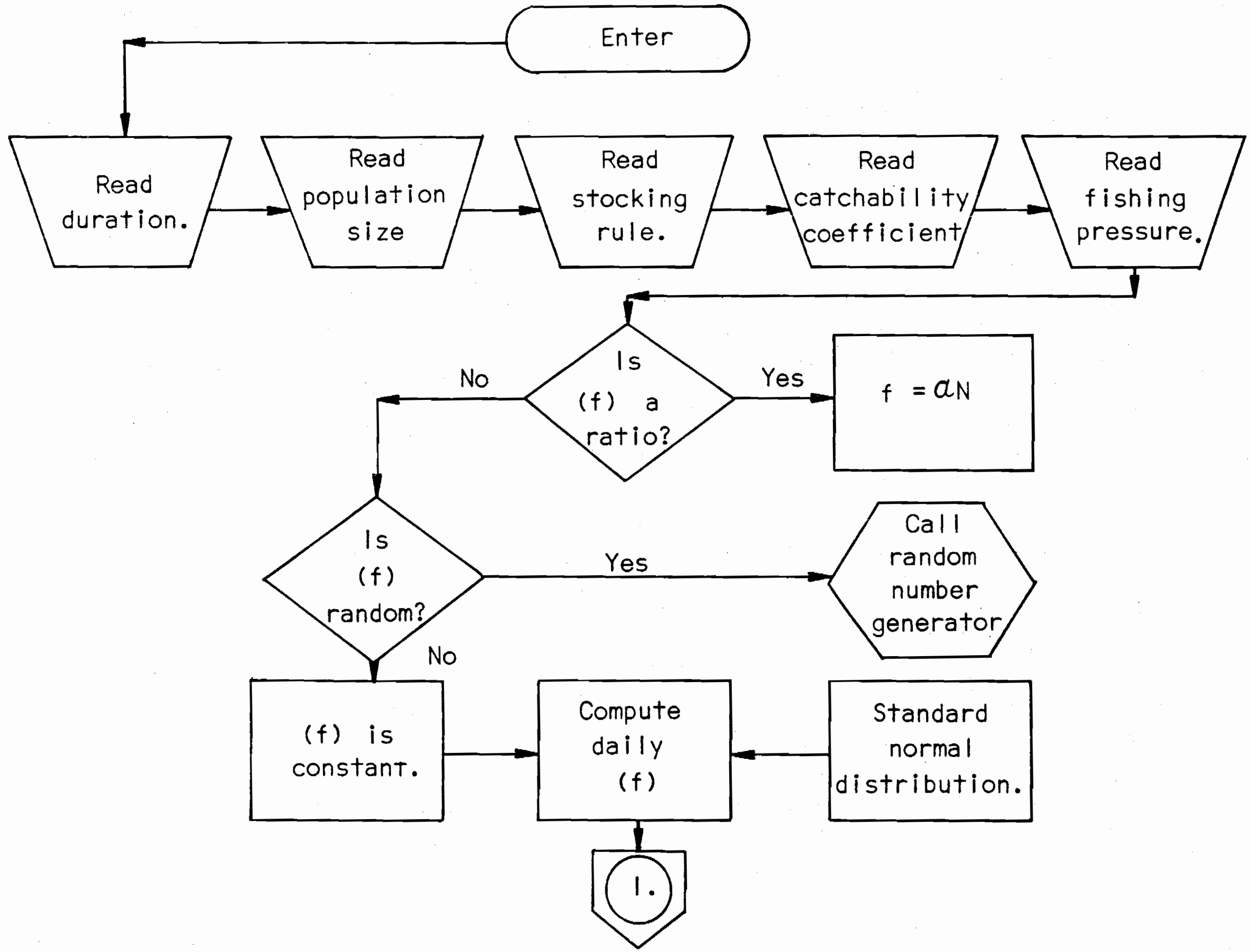

Figure 2. A flowchart discription of operations in CATS.

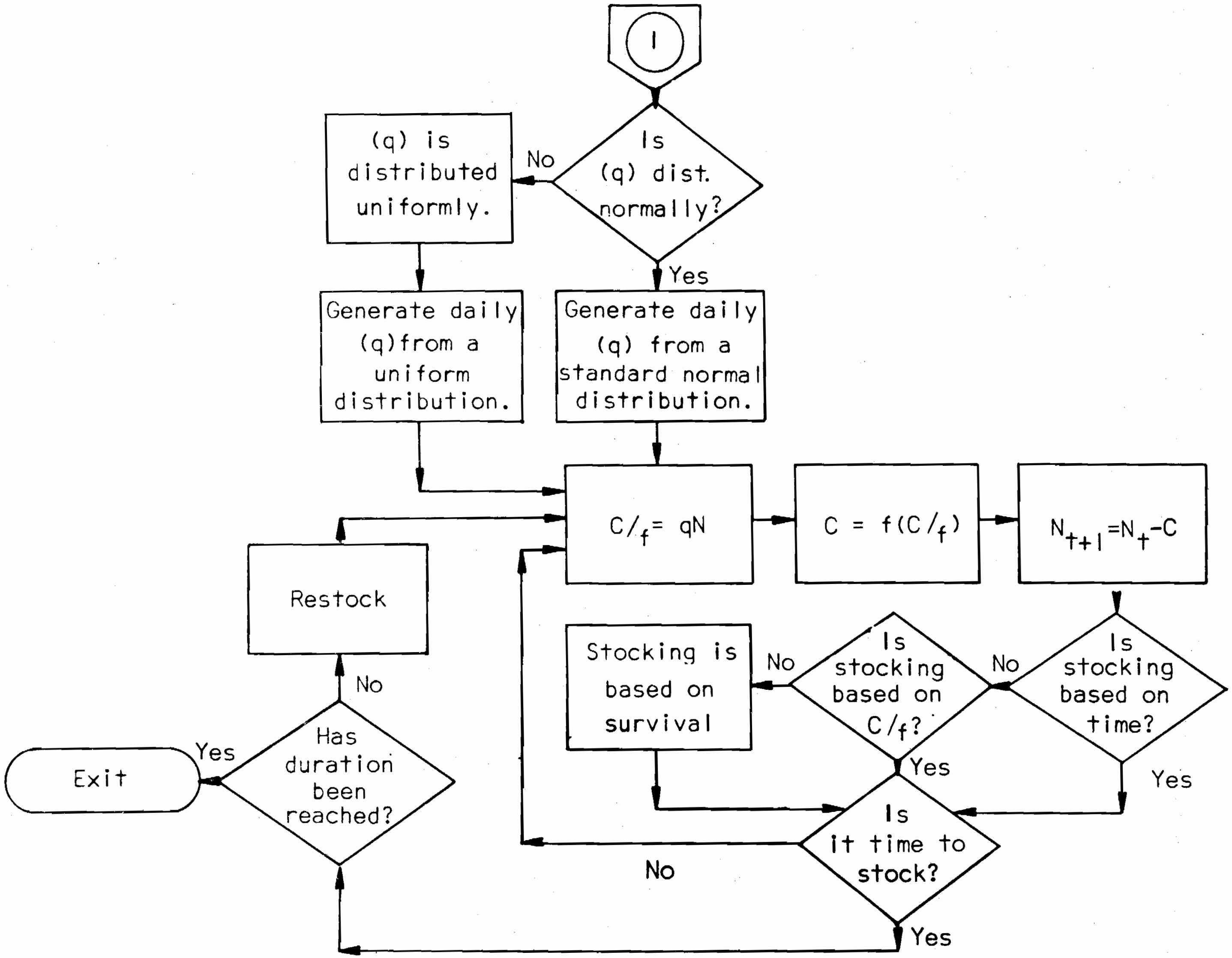

Figure 2. Continued.

pressure (f) and catchability coefficients (q). These values are used to calculate daily values of catch per angler hour (C/f) and catch (C) for each species. Species populations are then recomputed. The fishery is examined to determine whether the restocking condition, based on the stocking option selected, has been reached. If the restocking condition has not been reached, the program enters another daily iterative cycle. When the restocking condition has been met, fish are restocked. The program continues for a specified time period.

Simulator Quantification

Primary sources of validation data for CATS resulted from a one year creel survey of two catchable trout fisheries in Virginia and data from literature. One of the surveyed fisheries was a marginal trout stream located near Roanoke, Virginia. The other fishery was in Bath County, Virginia, a remote, montane region. Creel surveys were performed on these fisheries following 11 stockings which ranged from 500 to 5258 trout. A complete description of the study streams, creel survey procedures, and results are included in Lackey and Hammond (1973).

Fishing pressure was highest immediately following stocking and decreased rapidly as fish were removed. Daily fishing pressure could be reasonably well predicted by simple linear regression with current fish population (Fig.3). The r^2 values for these regressions from all stocking intervals ranged from .53 to .72. Average angling intensity on lakes and streams has been strongly correlated ($r=.87$) with the sizes of catchable trout allotments (Butler and Borgeson 1965).

Catchability coefficients were calculated for brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdneri*). Brook trout had the highest catchability followed in order by rainbow and brown trout. This relationship has been reported in many fisheries (Cooper 1959). Catchability coefficients for a species were fairly constant throughout a stocking period. Daily catchability coefficients had low variance and ranged from 5.5×10^{-4} to 14.2×10^{-4} (average 10.0×10^{-4}) for brook trout, 3.9×10^{-4} to 10.7×10^{-4} (average 7.2×10^{-4}) for rainbow trout, and 2.6×10^{-4} to 5.5×10^{-4}

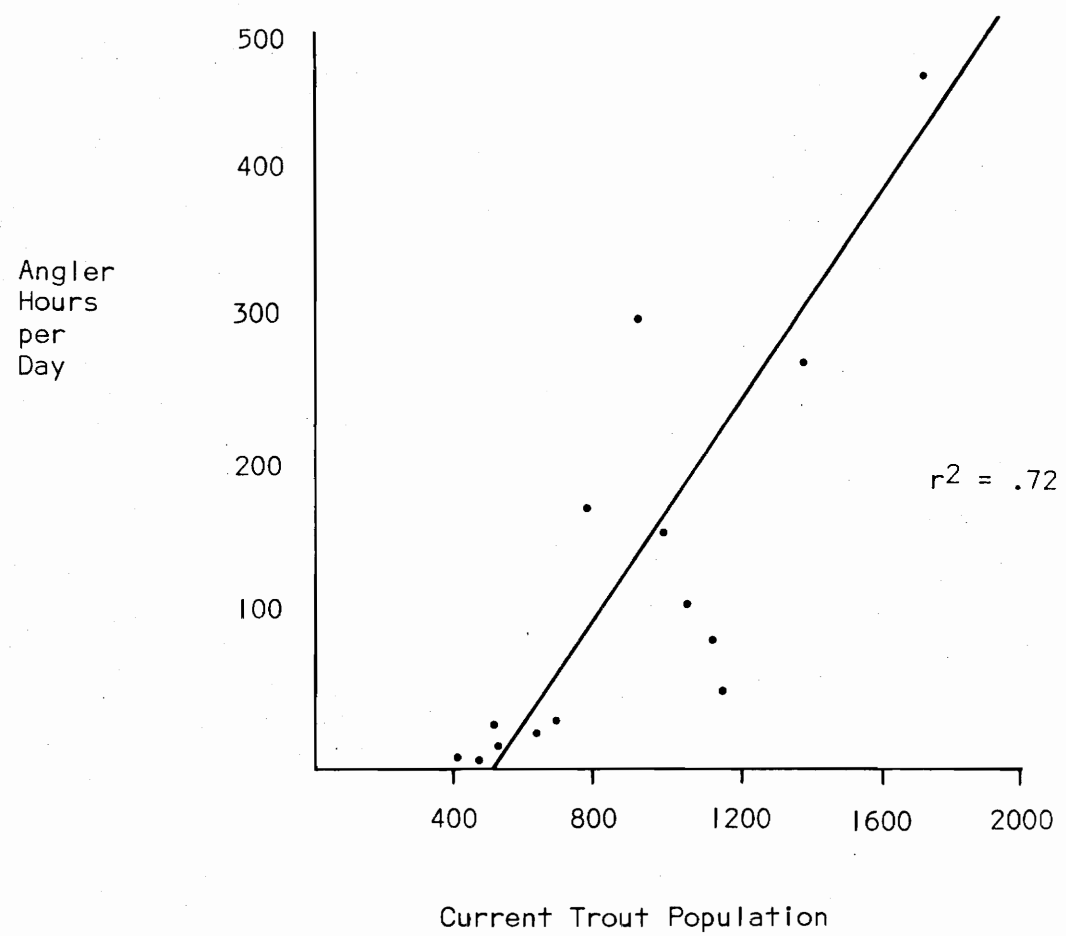

Figure 3. The relationship between daily fishing pressure and trout population during one spring stocking (May 1972) on the South Fork of The Roanoke River, Shawsville, Virginia.

(average 3.7×10^{-4}) for brown trout during a particular stocking on one fishery. There was variation in catchability coefficients from stocking to stocking on a particular fishery. In the same fishery, average catchability coefficients for brook trout ranged from 3.6×10^{-4} to 11.0×10^{-4}. This variation appeared to be primarily related to differences in water levels during the season. Ranges in catchability from 2.6×10^{-4} to 87.8×10^{-4} (average 10.71×10^{-4}) for rainbow trout stocked in study streams have been documented (Butler and Borgeson 1965). Catchability ranges tested in CATS were based on calculated means from creel surveys +100% and -50%.

Differences in stocking intervals among various fixed time increment schedules can range from daily plants on fee fishing waters, to annual plants on streams not suited for heavier stocking because of remoteness or unsuitable water temperatures. The frequency of stocking based on drops in C/f or plant-to-plant survival can be calculated for a particular fishery. The day on which the desired level of C/f or plant-to-plant survival will be reached can be closely determined based on knowledge of daily q, N, and f.

The effect of varying each system component was evaluated by exercising CATS over a wide range of potential system component alterations. User inputs are: (1) number of each species stocked; (2) desired constraints for determining stocking frequency; (3) estimates of, or a function to estimate, angler hours per day; and (4) estimates of catchability coefficients of each stocked species. There is an infinite number of combinations of these four components that could be used as data input, but only the most realistic combinations, based on field and literature data, were tested.

Simulation Results

In CATS, the main effects of altering the ratio of species stocked while stocking on a fixed time increment basis (e.g., every 30 days), were on average C/f during the stocking intervals (Fig.4) and total number of angler hours during the time interval (Fig.5). Stocking predominantly brook trout resulted in an appreciable increase in C/f and percentage return to creel. Altering the stocking ratio to favor brown trout resulted in a substantial increase in the number of angler hours provided to the fishing public. However, average C/f and percentage return to creel values were low. Because of the ranking of catchability coefficients among the three species, stocking predominantly rainbow trout reduced the effects of stocking predominantly brook or brown trout.

The main effects of altering the ratio of species stocked when stocking was performed after C/f had dropped to some arbitrary level were on length of stocking interval (Fig.6), average C/f values (Fig.7), and total angler hours provided (Fig.8). The lowest level to which C/f was allowed to drop was .25 fish per hour. Success rates lower than .25 resulted in low levels of fishing pressure. C/f directly after stocking was low when brown trout were heavily stocked, and the predetermined restocking level of C/f was reached quickly. Therefore, the number of plants necessary when the ratio of brook, rainbow, brown trouts was 1 : 2 : 3 was usually twice that of the reverse ratio. There was a substantial increase in the total angler hours provided during a given time interval when brown trout were stocked predominantly.

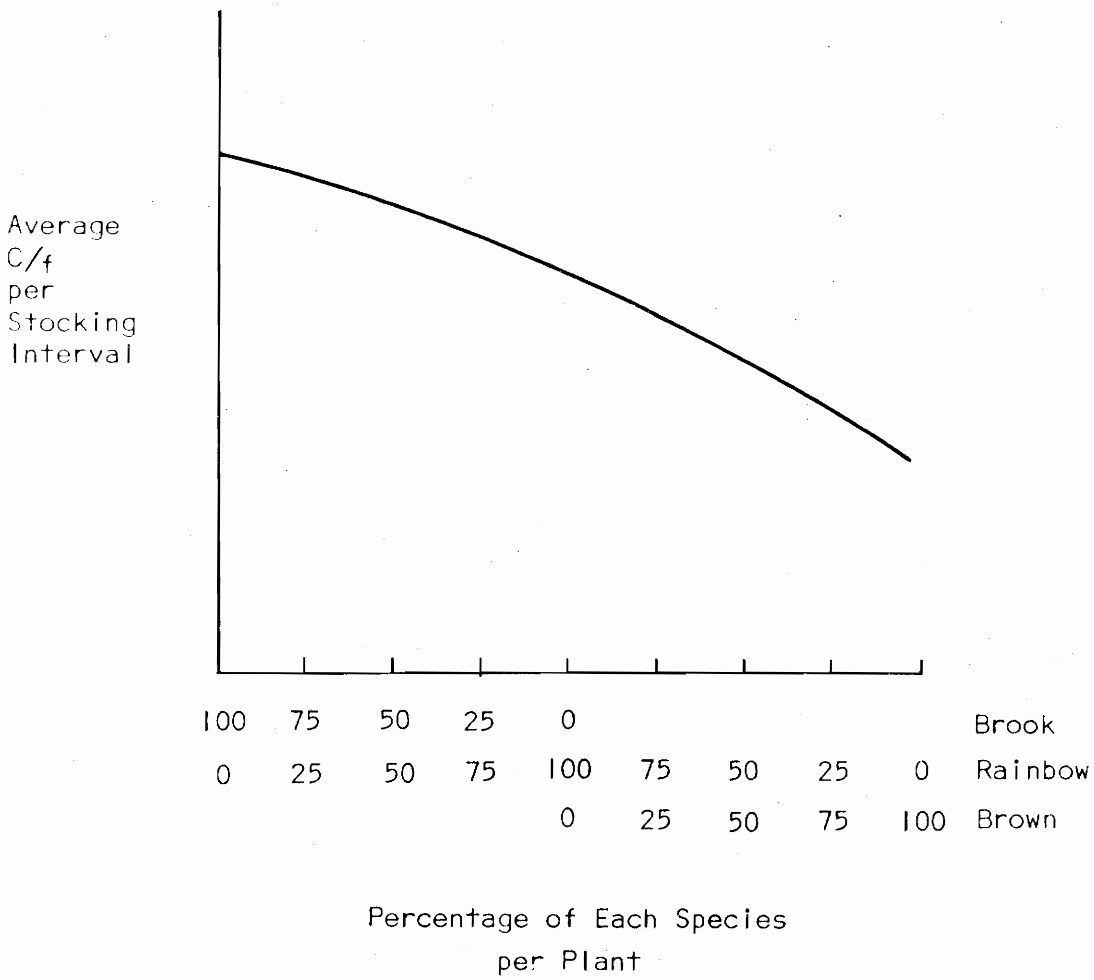

Figure 4. General relationship between average $C/_f$ per stocking interval and two-species stocking ratios when simulated stockings were performed on a fixed time increment basis.

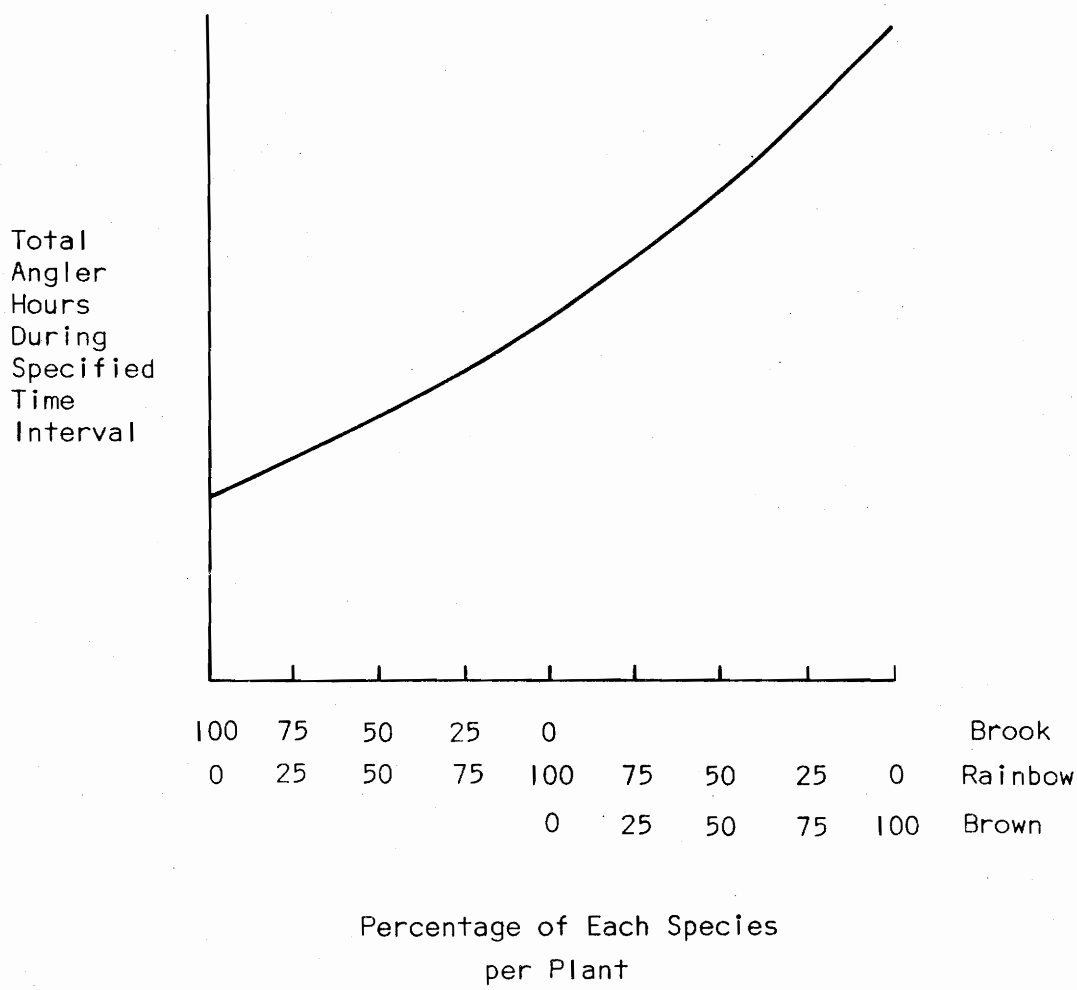

Figure 5. General relationship between fishing pressure and two-species stocking ratios when simulated stockings were performed on a fixed time increment basis.

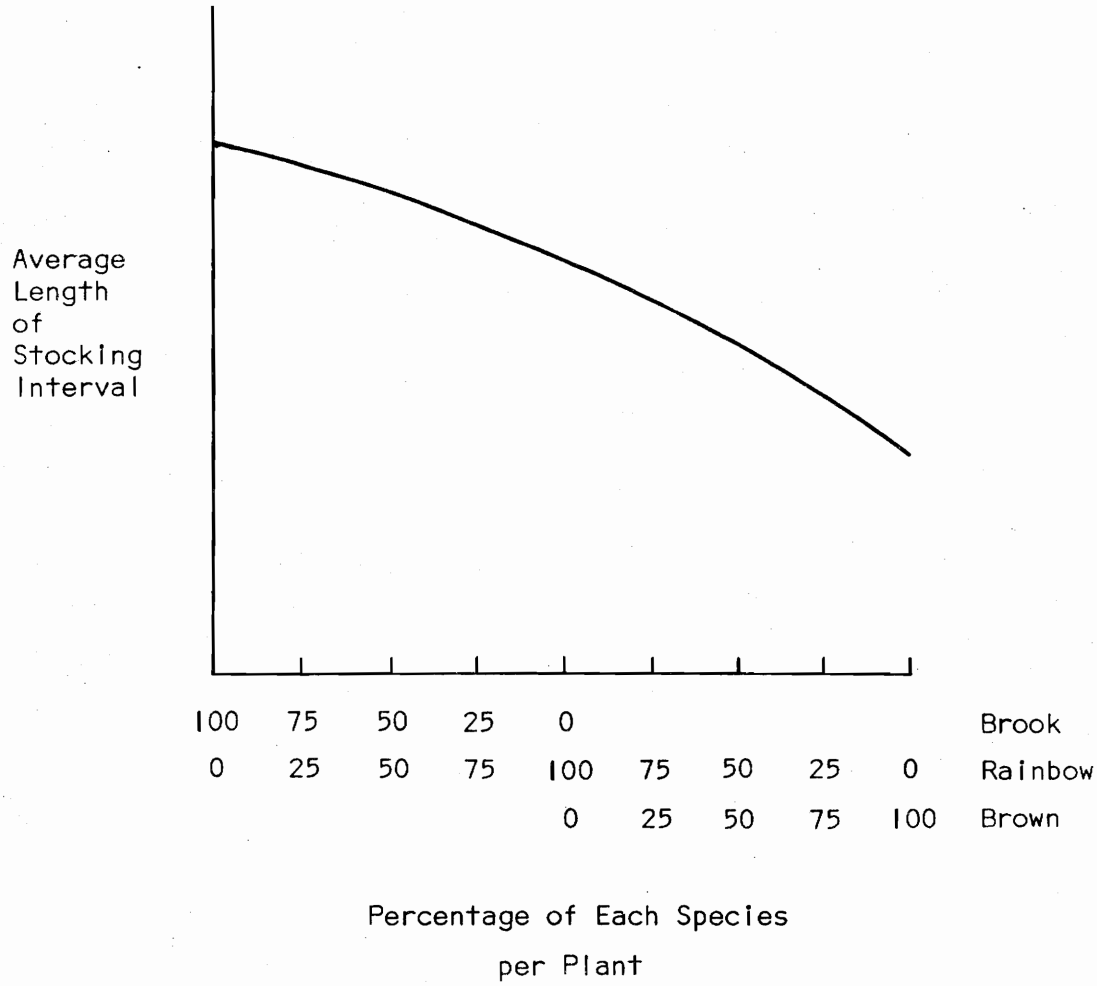

Figure 6. General relationship between stocking interval length and two-species stocking ratios when simulated stockings were performed after $C/_f$ had dropped to 0.25 fish per hour.

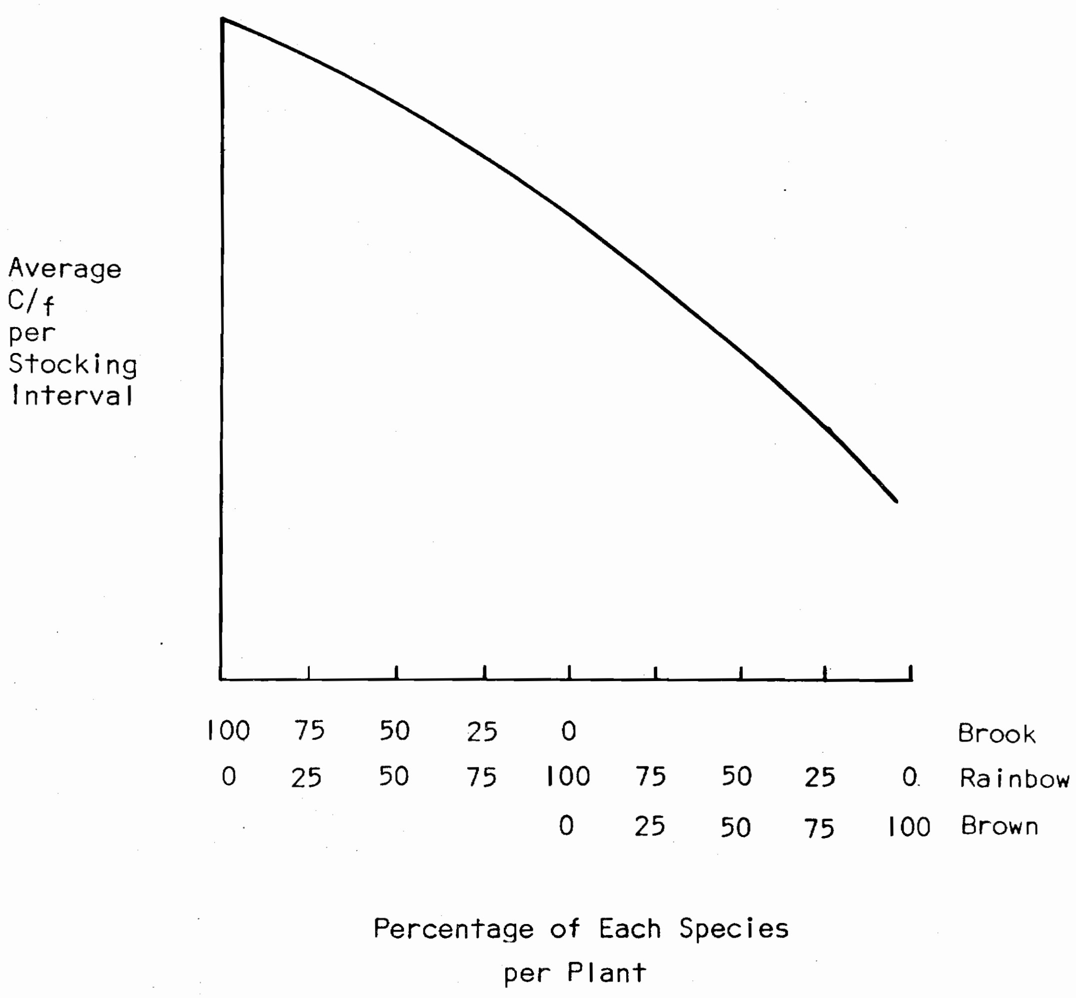

Figure 7. General relationship between average $C/_f$ per stocking interval and two-species stocking ratios when simulated stockings were performed after $C/_f$ had dropped to 0.25 fish per hour.

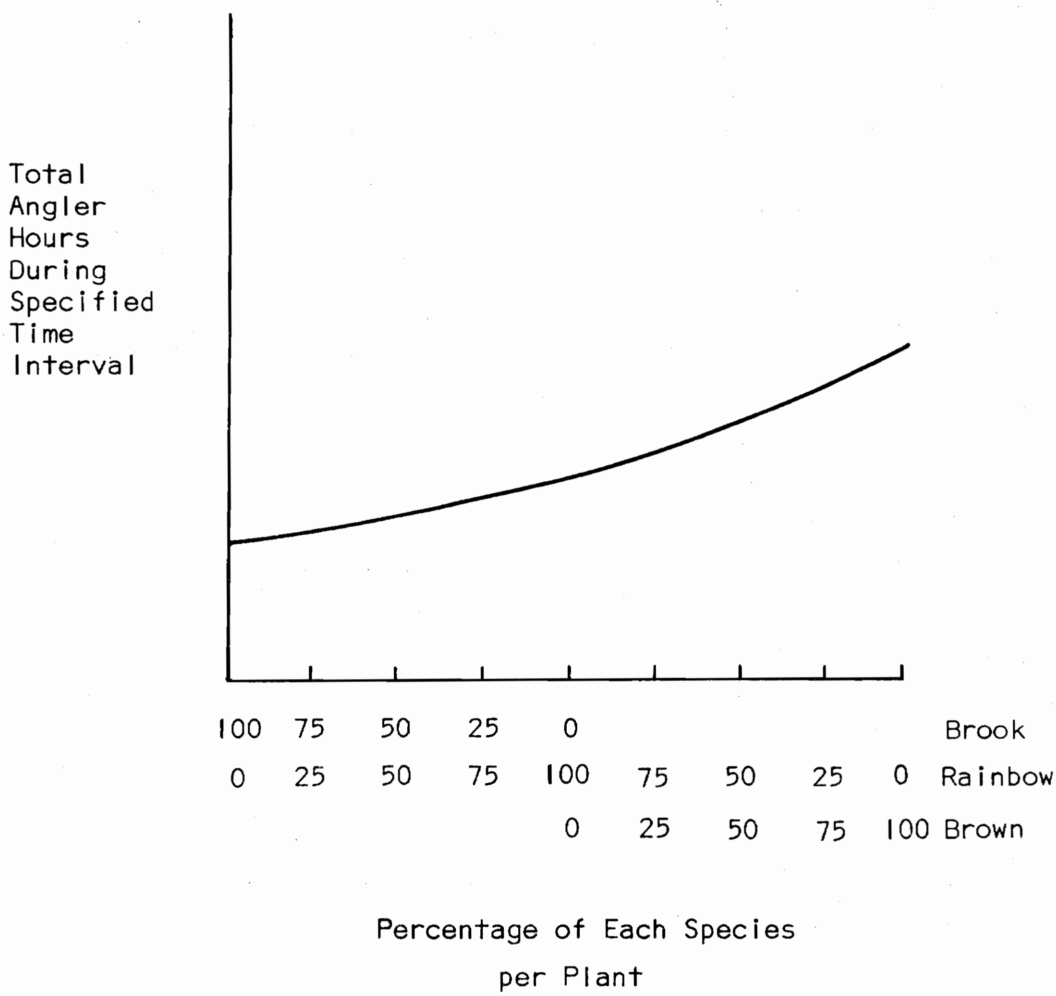

Figure 8. General relationship between fishing pressure and two-species stocking ratios when simulated stockings were performed after $C/_f$ had dropped to 0.25 fish per hour.

The third alternative for determining stocking frequency was to restock when plant-to-plant survival had reached a level below which fishing pressure would drop to an undesirably low level. In this case, greatest effects of altering stocking ratio were on average length of stocking interval (Fig.9) and average C/f (Fig.10). Frequency of plants required when the stocking ratio of brook, rainbow, and brown trout was 1 : 2 : 3, was usually half that of when the ratio was reversed. As with other alternatives, stocking an increasing proportion of brown trout lowered average C/f values and percentage return to creel. Angling pressure which occurred during two successive stocking intervals when the stocking ratio of brook, rainbow, and brown trout was 3 : 2 : 1, nearly equaled angling pressure which occurred during one stocking interval when the ratio was reversed. Therefore, total angler hours remained fairly constant regardless of stocking ratio.

Fishing pressure was considered to be constant, random, or follow a predictable relationship with current fish population with little effect on the predicted duration of the fishery. Stocking intervals equal in length could be obtained with each method. However, the level of fishing pressure used as data input had a much more sensitive effect on the predicted duration of the fishery. When daily fishing pressure was doubled, stocking intervals were reduced by approximately one half.

High variance associated with predicted mean q, had no detectable effect on the predicted duration of a fishery. Predicted mean q's were used as midpoints for the uniform distribution used to generate daily q's and the range between end points of the distribution

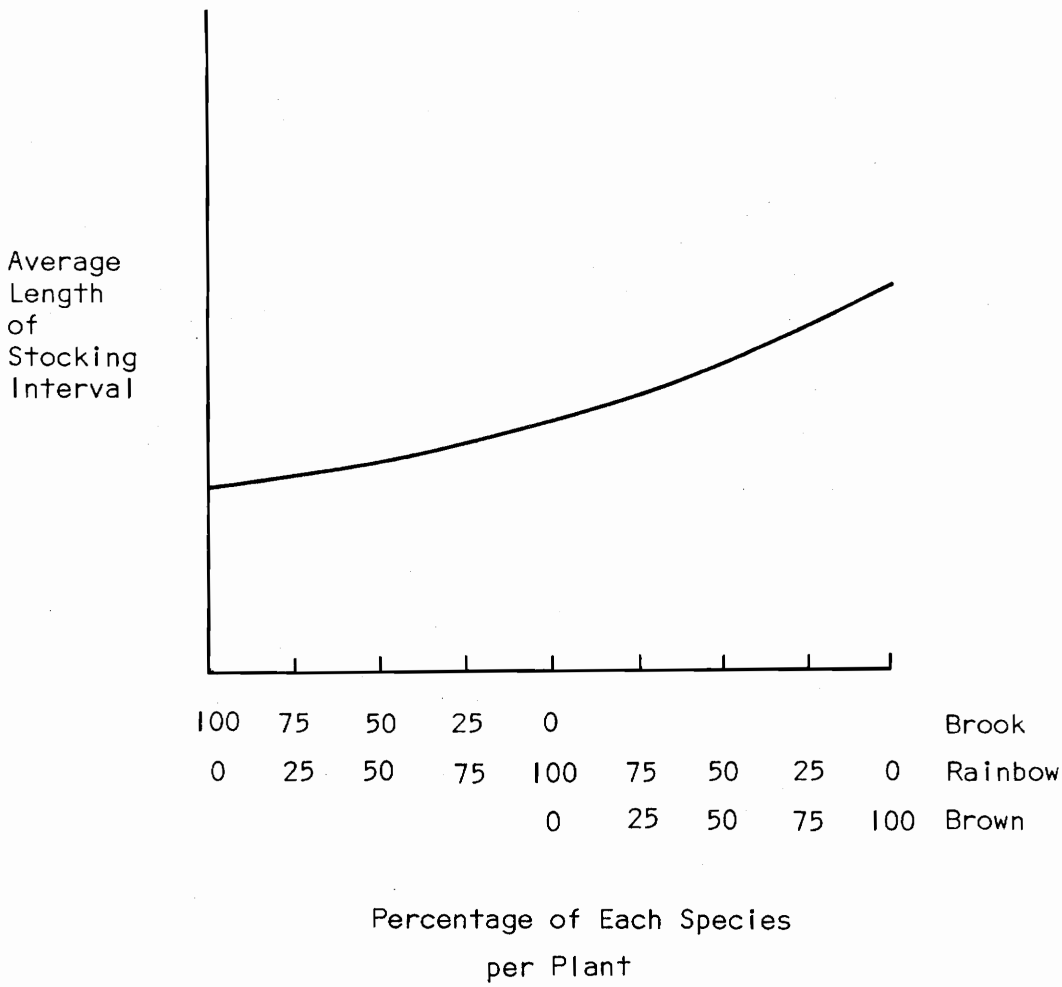

Figure 9. General relationship between stocking interval length and two- species stocking ratios when simulated stockings were performed after plant-to plant survival had dropped to 0.40.

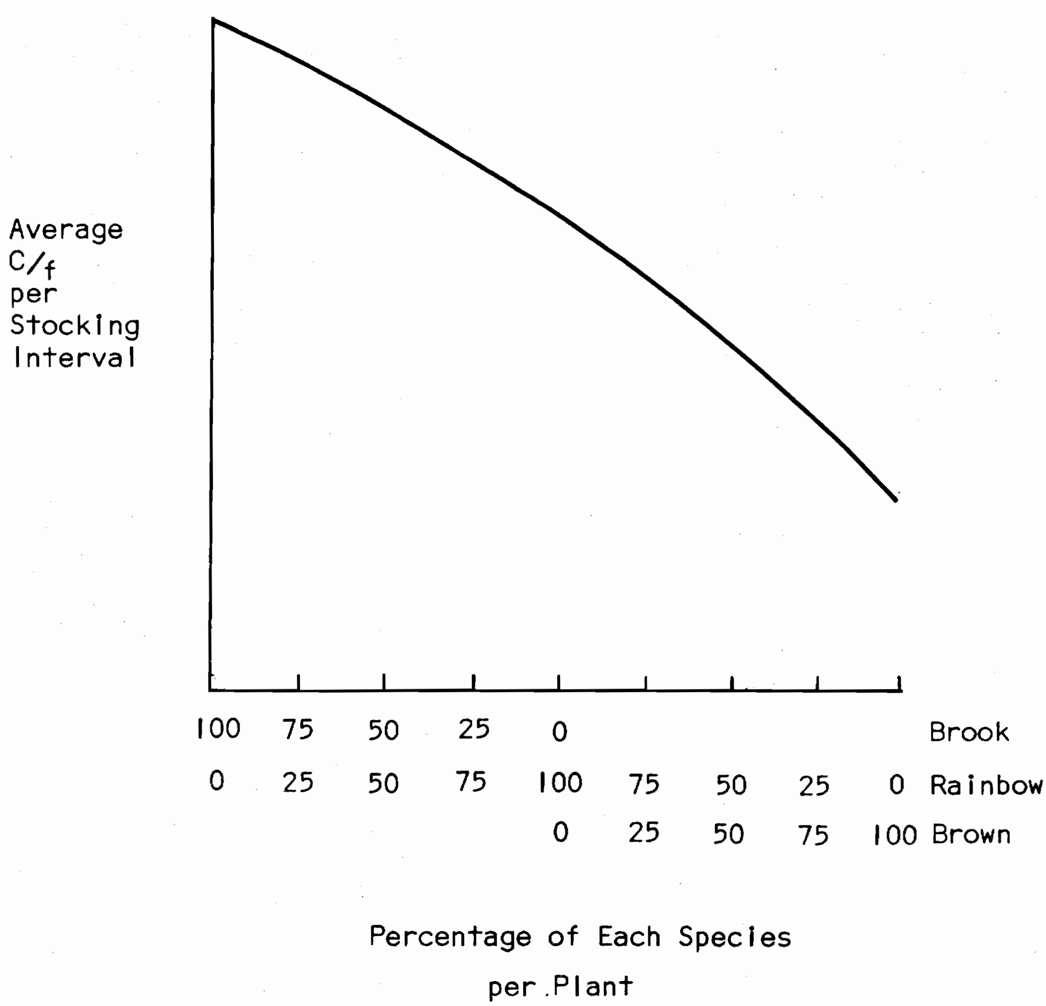

Figure 10. General relationship between average $C/_f$ per stocking interval and two-species stocking ratios when simulated stockings were performed after plant-to-plant survival had dropped to 0.40.

was quadrupled with no effect on length of stocking interval. However, when predicted mean q's were doubled throughout the simulated fishing season, stocking intervals decreased by approximately one half.

Discussion

The key premise in CATS is that definite, predictable differences in catchability coefficients exist among species of stocked trout and that these differences can be used to better meet management objectives. The user can calibrate CATS for a particular fishery, then alter the stocking ratio to gain an understanding of potential system response under different management strategies.

Estimates of expected angling pressure and catchability coefficients of each species stocked are of primary importance to the manager because of their sensitive effect on the duration of the fishery. The results of a particular management strategy may be predicted when these statistics are known or can be reasonably well predicted. Evaluation of stocking practices has usually emphasized percentage return to creel, total catch, and catch per angler hour values. Simulation results indicated these data are important only insofar as they contribute toward determining catchability coefficients and estimates of daily fishing pressure, which in turn have the greatest direct impact on the fishery.

Reducing the number of stocked fish and increasing frequency of plants has been suggested to provide a more uniform rate of return (Butler and Borgeson 1965; Ratledge and Louder 1967). CATS indicated that a reduction in plant size and an increase in planting frequency results in a more uniform harvest rate than when larger plants are made less frequently.

One strategy to increase the number of angler trips provided by a catchable trout program is to stock a species capable of withstanding heavy fishing pressure (low q) (Applegate 1963). Simulation showed an increase in total angling hours when brown trout were predominantly stocked. An increase in total angler hours can be due to an increase in length of average angler trip, an increase in total trips, or a combination of both. The latter seems to be most reasonable, indicating that stocking brown trout will increase both the length and number of angler trips.

A user of CATS or any manager, should have clear-cut, reachable management objectives in mind before he decides where, when, which species, and how many fish to plant. Progress toward improved management strategies requires the testing of alternative management strategies. For over one hundred years, basic management aspects of catchable trout stocking programs have remained virtually unchanged. McFadden (1969) warned: "Not until management is viewed as a generator of new trends rather than an answer to trends of the past will it be possible to carry out effective long-range planning." Catchable trout programs are ideal for using operations research techniques to formulate and evaluate immediate and long-range plans. These programs can be approached as systems with quantifiable component parts and operational constraints.

The options available in CATS for determining f, q, and stocking frequency are by no means all inclusive. Additional functions would add flexibility and possibly more realism. CATS could be easily expanded so that an optimal management strategy could be determined within specified budgetary and logistic constraints. Additions to CATS must be considered carefully. Although a new component may reflect reality, a poor benefit/cost ratio may prohibit use.

All input information needed to use CATS can be obtained from standard creel survey information. For many fisheries, agencies may already have the required information for program implementation. These data could easily be used to develop more efficient stocking practices as well as to evaluate current practices. The primary value of CATS is that it assists the user in making decisions concerning the selection of management strategies.

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Appendix

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C          MAIN PROGRAM (CATS)
C            PURPOSE - RECORD FISHERY RESPONSE FOR A MULTI-SPECIES
C                      CATCHABLE TROUT STOCKING PROGRAM AND PERFORM THE
C                      FOLLOWING FUNCTIONS:
C                      (1) READ IN DATA TO INITIALIZE RUN.
C                      (2) INITIALIZE ARRAYS AND PROGRAM VARIABLES.
C                      (3) DRIVE OTHER ROUTINES.
C                      (4) CONTROL SIMULATION LENGTH.
C
C
C            DESCRIPTION OF VARIABLES:
C
C                      POPI(4) - INITIAL POPULATIONS.
C                      STOCK(3) - NUMBER OF EACH SPECIES STOCKED PER
C                      STOCKING INTERVAL.
C                      POPN(4) - DAILY POPULATIONS.
C                      CATCH(4) - DAILY CATCH.
C                      CPH(4) - DAILY CATCH PER HOUR.
C                      N - DAY.
C                      NS - DAY COUNTER.
C                      ISF - INITIAL STOCKING FUNCTION (1,2,OR 3).
C                      TPOPN(4) - ACCUMULATOR OF DAILY POPULATIONS PER
C                      STOCKING INTERVAL.
C                      TCATCH(4) - TOTAL CATCH DURING STOCKING INTERVAL.
C                      APOPN(4) - AVERAGE OF DAILY POPULATIONS PER
C                      STOCKING INTERVAL.
C                      ACATCH(4) - AVERAGE OF DAILY CATCHES PER STOCKING
C                      INTERVAL.
C                      AVECPH(4) - WEIGHTED MEAN CATCH PER HOUR PER
C                      STOCKING INTERVAL.
C                      AVEXEP - AVERAGE ANGLER HOURS PER DAY.
C                      TXEP - TOTAL ANGLER HOURS PER STOCKING INTERVAL.
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C                IFP - FISHING PRESSURE DETERMINATOR (1,2,OR3).
C                FP - ASSOCIATED VALUE FOR IFP.
C                IC - CATCHABILITY COEFFICIENT DETERMINATOR (1 OR 2).
C                CC(3,2) - ASSOCIATED VALUES FOR IC.
C                XCC - A PARTICULAR DAILY CATCHABILITY COEFFICIENT
C                FOR ONE SPECIES.
C                NDAYS - DURATION OF FISHERY.
C                STFREQ - NUMBER OF PLANTS.
C                TSTOCK(3) - TOTAL OF EACH SPECIES STOCKED.
C                STSTOCK - TOTAL NUMBER OF FISH STOCKED.
C                SUMCAT(4) - TOTAL CATCH FOR DURATION OF FISHERY.
C                STXFP - TOTAL ANGLER HOURS FOR DURATION OF FISHERY.
C                PERCEN(4) - PERCENT OF EACH SPECIES CAUGHT.
C                ASUMCA(4) - AVERAGE CATCH PER STOCKING INTERVAL.
C                TAPOPN(4) - ACCUMULATOR OF AVERAGE DAILY
C                POPULATIONS PER STOCKING INTERVAL.
C                TACAT(4) - ACCUMULATOR OF AVERAGE DAILY CATCHES.
C                TACPH(4) - ACCUMULATOR OF WEIGHTED MEAN CATCHES
C                PER HOUR.
C                AVTNS - AVERAGE LENGTH OF STOCKING INTERVAL.
C                TNS - ACCUMULATOR FOR DETERMINING AVTNS.
C                TAXFP - ACCUMULATOR OF AVERAGE ANGLER HOURS PER
C                DAY.
C                TAVPOP(4) - AVERAGE DAILY POPULATION FOR FISHERY
C                DURATION.
C                TAVCAT(4) - AVERAGE DAILY CATCH FOR FISHERY
C                DURATION.
C                TAVCPH(4) - AVERAGE CATCH PER ANGLER HOUR FOR
C                FISHERY DURATION.
C                ASTXFP - AVERAGE ANGLER HOURS PER STOCKING
C                INTERVAL.
C                NDTG - NUMBER OF DAYS TO GO UNTILL RESTOCKING.
```

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C                  NSEED - INITIAL RANDOM NUMBER.
C
C
C       OTHER ROUTINES USED:
C
C         SUBROUTINE (PUT)
C         PURPOSE - STOCKS FISH.
C
C         FUNCTION (RAND)
C         PURPOSE - GENERATE RANDOM NUMBERS.
C
C         FUNCTION (UNFRM)
C         PURPOSE - GENERATE VALUES FROM A UNIFORM DISTRIBUTION.
C
C         FUNCTION (RNORM)
C         PURPOSE - GENERATE VALUES FROM A STANDARD NORMAL
C                   DISTRIBUTION.
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```
      COMMON POPN(4),STOCK(3),POPI(4),N,NS,ISF
      COMMON TPOPN(4),TCATCH(4),APOPN(4),ACATCH(4),AVECPH(4)
      COMMON AVEXFP,TXFP
      COMMON NDAYS
      COMMON STFREQ,TSTOCK(3),STSTOC,SUMCAT(4),STXFP,PERCEN(4),ASUMCA(4)
      COMMON TAPOPN(4),TACAT(4),TACPH(4),TNS,TAXFP,TAVPOP(4),TAVCAT(4)
      COMMON TAVCPH(4),AVTNS,TAVXFP,ASTXFP
      INTEGER STFREQ
      INTEGER TNS
      INTEGER AVTNS
      DIMENSION FP(2),CC(3,2),CATCH(4),CPH(4),IC(3),XCC(3)
      DO 11 I=1,4
   11 POPN(I)=0.0
C=========================================================================
C
C             READ IN VALUES TO INITIALIZE RUN.
C
C=========================================================================
      READ(5,500) NDAYS
      READ(5,501) STOCK
  500 FORMAT(I5,2F10.0)
  501 FORMAT(3F10.0)
      READ(5,500) ISF,SF
      NSF=SF
      READ(5,500) IFP,FP
      DO 10 ISP=1,3
   10 READ(5,500) IC(ISP),(CC(ISP,J),J=1,2)
```

```
C=======================================================================
C
C          WRITE EXPLANATION OF USER OPTIONS.
C
C=======================================================================
      WRITE(6,660)
  660 FORMAT(1H1,1X,'STOCKING RULES:')
      WRITE(6,661)
  661 FORMAT(/,6X,'1. STOCKING IS PERFORMED AT REGULAR INTERVALS.')
      WRITE(6,662)
  662 FORMAT(9X,'THE ASSOCIATED VALUE INDICATES THE NUMBER OF DAYS BETWE
     *EN PLANTS.')
      WRITE(6,663)
  663 FORMAT(/,6X,'2. STOCKING IS PERFORMED WHEN PLANT TO PLANT SURVIVAL
     * DROPS BELOW A GIVEN VALUE.')
      WRITE(6,664)
  664 FORMAT(9X,'THE ASSOCIATED VALUE INDICATES THE DESIRED PLANT TO PLA
     *NT SURVIVAL.')
      WRITE(6,665)
  665 FORMAT(/,6X,'3. STOCKING IS PERFORMED WHEN CATCH PER ANGLER HOUR D
     *ROPS BELOW A GIVEN VALUE.')
      WRITE(6,666)
  666 FORMAT(9X,'THE ASSOCIATED VALUE INDICATES THE LOWEST CATCH PER ANG
     *LER HOUR ACCEPTABLE BEFORE RESTOCKING BECOMES NECESSARY.')
      WRITE(6,667)
  667 FORMAT(//,1X,'FISHING PRESSURE DETERMINATION:')
      WRITE(6,668)
  668 FORMAT(/,6X,'1. FISHING PRESSURE IS BASED ON THE CURRENT POPULATIO
     *N OF FISH.')
```

```
      WRITE(6,669)
  669 FORMAT(9X,'THE ASSOCIATED VALUES ARE THE RATIO USED TO PREDICT THE
     * EXPECTED MEAN VALUE OF ANGLER HOURS BASED ON THE CURRENT',/,9X,'P
     *OPULATION OF FISH,AND THE STANDARD DEVIATION FROM THAT MEAN.')
      WRITE(6,670)
  670 FORMAT(/,6X,'2. FISHING PRESSURE IS CONSTANT.')
      WRITE(6,671)
  671 FORMAT(9X,'THE ASSOCIATED VALUE INDICATES THE NUMBER OF ANGLER HOU
     *RS EXPENDED PER DAY.')
      WRITE(6,672)
  672 FORMAT(/,6X,'3. FISHING PRESSURE IS RANDOM.')
      WRITE(6,673)
  673 FORMAT(9X,'THE ASSOCIATED VALUES INDICATE THE MEAN AND STANDARD DE
     *VIATION FROM A STANDARD NORMAL DISTRIBUTION OF FISHING PRESSURE.')
      WRITE(6,674)
  674 FORMAT(//,1X,'CATCHABILITY COEFFICIENT DETERMINATION RULES:')
      WRITE(6,675)
  675 FORMAT(//,6X,'1. DAILY CATCHABILITY COEFFICIENTS ARE SELECTED FROM
     * A STANDARD NORMAL DISTRIBUTION.',/,9X,'THE ASSOCIATED VALUES ARE
     *THE EXPECTED MEAN AND STANDARD DEVIATION FROM THAT DISTRIBUTION.')
      WRITE(6,676)
  676 FORMAT(/,6X,'2. DAILY CATCHABILITY COEFFICIENTS ARE SELECTED FROM
     *A UNIFORM DISTRIBUTION.',/,9X,'THE ASSOCIATED VALUES ARE THE EXPEC
     *TED END POINTS OF THE DISTRIBUTION.')
C=======================================================================
C
C           PRINT OUT DATA INPUT.
C
C=======================================================================
      WRITE(6,677) NDAYS
  677 FORMAT(1H1,1X,'DAYS =',I5)
```

```
      WRITE(6,678) STOCK
  678 FORMAT(//1X,'FISH STOCKED:',3X,'BROOK TROUT -',1X,F5.0,5X,'BROWN T
     *ROUT -',1X,F5.0,5X,'RAINBOW TROUT -',F5.0)
      WRITE(6,679) ISF,SF
  679 FORMAT(//1X,'STOCKING RULE:',I3,5X,'ASSOCIATED VALUE:',F10.4)
      WRITE(6,680) IFP,FP
  680 FORMAT(//,1X,'FISHING PRESSURE DETERMINATION:',I3,5X,'ASSOCIATED V
     *ALUES:',2F20.4)
      WRITE(6,681)
  681 FORMAT(////1X,'CATCHABILITY COEFFICIENT DETERMINATION FOR EACH SPE
     *CIES:')
      WRITE(6,682)
  682 FORMAT(//,3X,'SPECIES',5X,'RULE',6X,'ASSOCIATED      VALUES')
      WRITE(6,683) IC(1),(CC(1,J),J=1,2)
  683 FORMAT(//,1X,'BROOK TROUT',5X,I1,5X,F10.5,4X,F10.5)
      WRITE(6,684) IC(2),(CC(2,J),J=1,2)
  684 FORMAT (//,1X,'BROWN TROUT',5X,I1,5X,F10.5,4X,F10.5)
      WRITE(6,685) IC(3),(CC(3,J),J=1,2)
  685 FORMAT(//1X,'RAINBOW TROUT',3X,I1,5X,F10.5,4X,F10.5,///)
C=====================================================================
C
C               INITIALIZE RANDOM NUMBER GENERATOR.
C
C=====================================================================
C
      NSEED=3984521
```

```
C=====================================================================
C
C           INITIALIZE MASTER PROGRAM VARIABLES.
C
C=====================================================================
      N=0
      STFREQ=0
      DO 13 I=1,4
      TAPOPN(I)=0
      TACAT(I)=0
      TACPH(I)=0
   13 SUMCAT(I)=0
      TAXFP=0
      STXFP=0
      TNS=0
      DO 14 ISP=1,3
   14 TSTOCK(ISP)=0
C=====================================================================
C
C           CALL SUBROUTINE (PUT) TO STOCK FISH.
C
C=====================================================================
      CALL PUT
      DO 15 I=1,4
   15 POPI(I)=POPN(I)
      CPH(4)=0
      MDTG=NDAYS
```

```
C=======================================================================
C
C          THE FOLLOWING STATEMENT ENABLES THE SIMULATOR TO CONTINUE
C          PAST THE SPECIFIED FISHERY DURATION TO COMPLETE THE FINAL
C          STOCKING INTERVAL WHEN STOCKING IS PERFORMED ON A FIXED TIME
C          INCREMENT BASIS.
C
C=======================================================================
      IF(ISF.EQ.1)NDTG=NDAYS+NSF-MOD(NDAYS,NSF)
      N=0
  999 CONTINUE
      N=N+1
      NS=NS+1
C=======================================================================
C
C          GENERATE DAILY FISHING PRESSURE.
C
C=======================================================================
      IF (IFP-2) 50,51,52
   50 RXFP=FP(1)*POPN(4)
      XFP=RNORM(RXFP,FP(2),NSEED)
      GO TO 53
   51 XFP=FP(1)
      GO TO 53
   52 XFP=RNORM(FP(1),FP(2),NSEED)
```

```
C=========================================================================
C
C          THIS DO LOOP GENERATES DAILY CATCHABILITY COEFFICIENTS,
C          CATCHES,AND CATCH PER HOUR VALUES.
C
C=========================================================================
   53 DO 60 ISP=1,3
      IF (IC(ISP) .EQ. 1) XCC(ISP)=RNORM(CC(ISP,1),CC(ISP,2),NSEED)
      IF (IC(ISP) .EQ. 2) XCC(ISP)=UNFRM(CC(ISP,1),CC(ISP,2),NSEED)
      CPH(ISP)=XCC(ISP)*POPN(ISP)
   60 CATCH(ISP)=XFP*CPH(ISP)
C=========================================================================
C
C          CALCULATE DAILY TOTALS OF POPULATION,CATCH,AND CATCH PER
C          HOUR.
C
C=========================================================================
      POPN(4)=POPN(1)+POPN(2)+POPN(3)
      CATCH(4)=CATCH(1)+CATCH(2)+CATCH(3)
      CPH(4)=CPH(1)+CPH(2)+CPH(3)
C=========================================================================
C
C          PRINT DAILY VALUES OF POPULATION,CATCH,CATCH PER HOUR,AND
C          FISHING PRESSURE FOR EACH SPECIES PLUS TOTAL.
C
C=========================================================================
      WRITE(6,600) N,(POPN(I),CATCH(I),CPH(I),I=1,4),XFP
  600 FORMAT(1X,I5,F9.0,F8.0,F7.2,F11.0,F8.0,F7.2,F11.0,F8.0,F7.2,F11.0,
     *F8.0,F7.2,F15.2)
```

```
C=====================================================================
C
C           RECOMPUTE POPULATION.
C
C=====================================================================
      DO 61 I=1,4
   61 POPN(I)=POPN(I)-CATCH(I)
      DO 70 I=1,4
      TPOPN(I)=TPOPN(I)+POPN(I)
   70 TCATCH(I)=TCATCH(I)+CATCH(I)
      DO 80 I=1,4
      APOPN(I)=TPOPN(I)/NS
   80 ACATCH(I)=TCATCH(I)/NS
      TXFP=TXFP+XFP
      AVEXFP=TXFP/NS
      DO 90 I=1,4
   90 AVECPH(I)=TCATCH(I)/TXFP
C=====================================================================
C
C           IF STOCKING TIME HAS BEEN REACHED,CALL SUBROUTINE (PUT)
C           WHICH STOCKS FISH.
C
C=====================================================================
      IF (ISF .EQ. 1 .AND. NS .EQ. NSF) CALL PUT
      IF (ISF .EQ. 2 .AND. POPN(4)/POPI(4) .LE. SF) CALL PUT
      IF (ISF .EQ. 3 .AND. CPH(4) .LE. SF) CALL PUT
```

```
C=====================================================================
C
C          THE FOLLOWING STATEMENTS ENABLE THE SIMULATOR TO CONTINUE
C          PAST THE SPECIFIED FISHERY DURATION TO COMPLETE THE FINAL
C          STOCKING INTERVAL WHEN STOCKING IS BASED ON CATCH PER HOUR
C          OR PLANT TO PLANT SURVIVAL.
C
C=====================================================================
      IF(N.GE.NDAYS.AND.ISF.EQ.2.AND.POPN(4)/POPI(4).GT.SF)NDTG=NDTG+1
      IF(N.GE.NDAYS.AND.ISF.EQ.3.AND.CPH(4).GT.SF)NDTG=NDTG+1
      IF(N.LT.NDTG)GO TO 999
C=====================================================================
C
C          THIS DO LOOP CALCULATES PERCENTAGE RETURN OF EACH SPECIES.
C
C=====================================================================
      DO 93 I=1,3
      IF (TSTOCK(I).EQ.0.0) PERCEN(I)=0.0
      IF (TSTOCK(I).EQ.0.0) GO TO 93
      PERCEN(I)=(SUMCAT(I)/TSTOCK(I))*100
   93 CONTINUE
      PERCEN(4)=(SUMCAT(4)/STSTOC)*100
      DO 91 I=1,4
      TAVPOP(I)=TAPOPN(I)/STFREQ
      TAVCAT(I)=TACAT(I)/STFREQ
      TAVCPH(I)=TACPH(I)/STFREQ
   91 ASUMCA(I)=SUMCAT(I)/STFREQ
      TAVXFP=TAXFP/STFREQ
      ASTXFP=STXFP/STFREQ
      AVTNS=TNS/STFREQ
```

```
C=======================================================================
C
C           PRINT SUMMARY OF ALL STOCKING INTERVALS.
C
C=======================================================================
      WRITE(6,700)
  700 FORMAT(////,61X,'SUMMARY',//)
      WRITE(6,701) STFREQ
  701 FORMAT(10X,'TOTAL NUMBER OF PLANTS',47X,I2,/)
      WRITE(6,702) N
  702 FORMAT(10X,'TOTAL DURATION IN DAYS',45X,I4,/)
      WRITE(6,703) AVTNS
  703 FORMAT(10X,'AVERAGE LENGTH OF STOCKING INTERVAL',33X,I3,/)
      WRITE(6,704) TAVXFP
  704 FORMAT(10X,'AVERAGE ANGLER HOURS PER DAY',39X,F7.2,/)
      WRITE(6,705) ASTXFP
  705 FORMAT(10X,'AVERAGE ANGLER HOURS PER STOCKING INTERVAL',24X,F8.2,/
     *)
      WRITE(6,706) STXFP
  706 FORMAT(10X,'TOTAL ANGLER HOURS',47X,F9.2,////)
```

```
      WRITE(6,707)
  707 FORMAT(42X,'BROOK TROUT',7X,'BROWN TROUT',7X,'RAINBOW TROUT',9X,'T
     *OTAL',//)
      WRITE(6,708) TSTOCK,STSTOC
  708 FORMAT(10X,'TOTAL STOCKED',21X,F7.0,11X,F7.0,11X,F7.0,12X,F7.0,/)
      WRITE(6,709) SUMCAT
  709 FORMAT(10X,'TOTAL CATCH',24X,F6.0,12X,F6.0,12X,F6.0,12X,F7.0,/)
      WRITE(6,710) PERCEN
  710 FORMAT(10X,'PERCENT CAUGHT',23X,F4.0,14X,F4.0,14X,F4.0,15X,F4.0,/)
      WRITE(6,711) TAVPOP
  711 FORMAT(10X,'AVERAGE DAILY POPULATION',12X,F5.0,13X,F5.0,13X,F5.0,1
     *4X,F5.0,/)
      WRITE(6,712) TAVCAT
  712 FORMAT(10X,'AVERAGE DAILY CATCH',17X,F5.0,13X,F5.0,13X,F5.0,14X,F5
     *.0,/)
      WRITE(6,713) TAVCPH
  713 FORMAT(10X,'AVERAGE CATCH PER ANGLER HOUR',8X,F4.2,14X,F4.2,14X,F4
     *.2,15X,F4.2,/)
      STOP
      END
```

```
C=====================================================================
C
C          THIS SUBROUTINE INITIALLY STOCKS AND RESTOCKS FISH.
C
C=====================================================================
      SUBROUTINE PUT
      COMMON POPN(4),STOCK(3),POPI(4),N,NS,ISF
      COMMON TPOPN(4),TCATCH(4),APOPN(4),ACATCH(4),AVECPH(4)
      COMMON AVEXFP,TXFP
      COMMON NDAYS
      COMMON STFREQ,TSTOCK(3),STSTOC,SUMCAT(4),STXFP,PERCEN(4),ASUMCA(4)
      COMMON TAPOPN(4),TACAT(4),TACPH(4),TNS,TAXFP,TAVPOP(4),TAVCAT(4)
      COMMON TAVCPH(4),AVTNS,TAVXFP,ASTXFP
      INTEGER STFREQ
      INTEGER TNS
      INTEGER AVTNS
      IF(N.GE.NDAYS) GO TO 699
C=====================================================================
C
C          THIS DO LOOP READJUSTS POPULATION.
C
C=====================================================================
      DO 10 ISP=1,3
      IF (N .GT. 0) STOCK(ISP)=POPI(ISP)-POPN(ISP)
      POPN(ISP)=POPN(ISP)+STOCK(ISP)
   10 POPN(4)=POPN(4)+STOCK(ISP)
  699 CONTINUE
      DO 92 ISP=1,3
      TSTOCK(ISP)=TSTOCK(ISP)+STOCK(ISP)
   92 STSTOC=TSTOCK(1)+TSTOCK(2)+TSTOCK(3)
      IF (N.EQ.0) GO TO 696
      TNS=TNS+NS
```

```
C=========================================================================
C
C          PRINT TOTALS AND AVERAGES FOR EACH STOCKING INTERVAL.
C
C=========================================================================
      WRITE (6,601)
  601 FORMAT(//,27X,'BROOK TROUT',5X,'BROWN TROUT',5X,'RAINBOW TROUT',5X
     *,'TOTAL')
      WRITE (6,602)(APCPN(I),I=1,4)
  602 FORMAT(1X,'AVE. DAILY POPULATION',5X,F8.0,6X,F8.0,9X,F8.0,6X,F8.0)
      WRITE (6,603)(ACATCH(I),I=1,4)
  603 FORMAT(1X,'AVE. DAILY CATCH',10X,F8.0,8X,F8.0,9X,F8.0,6X,F8.0)
      WRITE(6,604)(TCATCH(I),I=1,4)
  604 FORMAT(1X,'TOTAL CATCH',15X,F8.0,8X,F8.0,9X,F8.0,6X,F8.0)
      WRITE(6,605)(AVECPH(I),I=1,4)
  605 FORMAT(1X,'WEIGHTED MEAN  C/H',8X,F10.2,6X,F10.2,7X,F10.2,4X,F10.2
     *)
      WRITE(6,606) AVEXFP
  606 FORMAT(///,1X,'AVE. ANGLER HRS. PER DAY -',F10.2)
      WRITE (6,607) TXFP
  607 FORMAT(1X,'TOTAL ANGLER HOURS -',6X,F10.2,////)
      WRITE(6,608)
  608 FORMAT(1X,132(1H_))
      DO 95 I=1,4
      TAPOPN(I)=TAPOPN(I)+APCPN(I)
      TACAT(I)=TACAT(I)+ACATCH(I)
      TACPH(I)=TACPH(I)+AVECPH(I)
   95 SUMCAT(I)=SUMCAT(I)+TCATCH(I)
      TAXFP=TAXFP+AVEXFP
      STXFP=STXFP+TXFP
      IF(N.GT.NDAYS) RETURN
```

```
696 WRITE(6,600) N
600 FORMAT(/////,1X,'STOCKING PERFORMED ON DAY',I5,/)
    NS=0
    STFREQ=STFREQ+1
    WRITE(6,697)
697 FORMAT(//,15X,'BROOK TROUT',15X,'BROWN TROUT',14X,'RAINBOW TROUT',
   *16X,'TOTAL')
    WRITE(6,698)
698 FORMAT(/,4X,4(6X,'POPN.    CATCH     C/H'),6X,'ANGLER HRS.',/)
    DO 40 I=1,4
    TPOPN(I)=0
 40 TCATCH(I)=0
    TXFP=0
    RETURN
    END
```

```
C
C         THIS FUNCTION GENERATES RANDOM NUMBERS.
C
      FUNCTION RAND(IX)
      IX=IX*65539
      IF (IX) 5,6,6
    5 IX=IX+2147483647+1
    6 YFL=IX
      RAND=YFL*.4656613E-9
      RETURN
      END
```

```
C
C         THIS FUNCTION GENERATES VALUES FROM A UNIFORM DISTRIBUTION
C         WITH SPECIFIED PARAMETERS.
C
      FUNCTION UNFRM(A,B,NSEED)
      UNFRM=A+(B-A)*RAND(NSEED)
      RETURN
      END
```

```
C
C         THIS FUNCTION GENERATES VALUES FROM A STANDARD NORMAL
C         DISTRIBUTION WITH SPECIFIED PARAMETERS.
C
      FUNCTION RNORM(XBAR,SD,NSEED)
      XLIM=3.0*SD
      XMIN=XBAR-XLIM
      XMAX=XBAR+XLIM
      RA=RAND(NSEED)
      RB=RAND(NSEED)
      V=(-2.0*ALOG(RA))**0.5*COS(6.283*RB)
      RNORM=V*SD+XBAR
      IF (RNORM .LT. XMIN) RNORM=XMIN
      IF (RNORM .GT. XMAX) RNORM=XMAX
      IF(RNORM.LT.0.0)RNORM=RNORM**2
      RETURN
      END
```

```
C=======================================================================
C
C          EXPLANATION OF USER OPTIONS
C
C=======================================================================
C
C        STOCKING RULES:
C
C
C            1. STOCKING IS PERFORMED AT REGULAR INTERVALS.
C               THE ASSOCIATED VALUE INDICATES THE NUMBER OF DAYS
C               BETWEEN PLANTS.
C
C            2. STOCKING IS PERFORMED WHEN PLANT TO PLANT SURVIVAL
C               DROPS BELOW A GIVEN VALUE.
C               THE ASSOCIATED VALUE INDICATES THE DESIRED PLANT TO
C               PLANT SURVIVAL.
C
C            3. STOCKING IS PERFORMED WHEN CATCH PER ANGLER HOUR
C               DROPS BELOW A GIVEN VALUE.
C               THE ASSOCIATED VALUE INDICATES THE LOWEST CATCH PER
C               ANGLER HOUR ACCEPTABLE BEFORE RESTOCKING BECOMES
C               NECESSARY.
```

```
C         FISHING PRESSURE DETERMINATION:
C
C              1. FISHING PRESSURE IS BASED ON THE CURRENT POPULATION
C                 OF FISH.
C                 THE ASSOCIATED VALUES ARE THE RATIO USED TO PREDICT
C                 THE EXPECTED MEAN VALUE OF ANGLER HOURS BASED ON THE
C                 CURRENTPOPULATION OF FISH,AND THE STANDARD DEVIATION
C                 FROM THAT MEAN.
C
C              2. FISHING PRESSURE IS CONSTANT.
C                 THE ASSOCIATED VALUE INDICATES THE NUMBER OF ANGLER
C                 HOURS EXPENDED PER DAY.
C
C              3. FISHING PRESSURE IS RANDOM.
C                 THE ASSOCIATED VALUES INDICATE THE MEAN AND STANDARD
C                 DEVIATION FROM A STANDARD NORMAL DISTRIBUTION OF
C                 FISHING PRESSURE.
```

```
C          CATCHABILITY COEFFICIENT DETERMINATION RULES:
C
C
C             1. DAILY CATCHABILITY COEFFICIENTS ARE SELECTED FROM A
C                STANDARD NORMAL DISTRIBUTION.
C                THE ASSOCIATED VALUESARE THE EXPECTED MEAN AND
C                STANDARD DEVIATION FROM THAT DISTRIBUTION.
C
C             2. DAILY CATCHABILITY COEFFICIENTS ARE SELECTED FROM A
C                UNIFORM DISTRIBUTION.
C                THE ASSOCIATED VALUES ARE THE EXPECTED END POINTS OF
C                THE DISTRIBUTION.
```

```
      DATA CARDS:
C
C
C
C     CARD 1 - DURATION OF FISHERY IN DAYS (INTEGER)  COLUMN 1-5
C
C
C     CARD 2 - NUMBER OF BROOK TROUT STOCKED (REAL)  COLUMN 1-10
C              NUMBER OF BROWN TROUT STOCKED (REAL)  COLUMN 11-20
C              NUMBER OF RAINBOW TROUT STOCKED (REAL)  COLUMN 21-30
C
C
C     CARD 3 - STOCKING RULE (INTEGER 1,2,OR 3)  COLUMN 1-5
C              ASSOCIATED VALUE (REAL)  COLUMN 6-15
C
C
C     CARD 4 - FISHING PRESSURE DETERMINATOR (INTEGER 1,2,OR 3)
C              COLUMN 1-5
C              ASSOCIATED VALUES (REAL)  COLUMN 6-15,16-25
C
C
C     CARDS 5,6,AND 7 - (ONE FOR EACH SPECIES)
C              CATCHABILITY COEFFICIENT DETERMINATOR (INTEGER 1 OR 2)
C              ASSOCIATED VALUES (REAL)  COLUMN 6-15,16-25
C              COLUMN 1-5
```

Vita

Dennis Edward Hammond was born on May 20th, 1944. He received his B.S. from S.U.N.Y. Brockport in 1966. After four years and three months of active duty in the United States Marine Corps, he became a research assistant at Virginia Polytechnic Institute and State University where he received his M.S. in 1974.

Dennis E. Hammond

ANALYSIS OF CATCHABLE TROUT FISHERIES

MANAGEMENT BY COMPUTER SIMULATION

by

Dennis Edward Hammond

(ABSTRACT)

Although strategies to meet most management objectives are relatively clearcut in single-species catchable trout programs, strategies become much more complex when two or more species are involved. A difficult problem that must be faced in evaluating catchable trout fisheries management strategies is defining management objectives. One approach to testing alternative management strategies in complex resource systems, such as catchable trout fisheries, is systems simulation. A computer-implemented catchable trout fishery simulator (CATS) was developed to evaluate fishery response under various management strategies in a multi-species stocking program. The user of CATS can select alternative management strategies and functions which generate predictions of fishing pressure on a particular fishery. To evaluate the effect of each system component, CATS was exercised over a wide range of potential system component alterations. Predominant stocking of brook trout appreciably increased average catch per angler hour and percentage return to creel. Altering the stocking ratio to favor brown trout substantially increased the number of angler hours. Stocking predominantly rainbow trout reduced the effects caused by stocking predominantly brook or brown trout. Estimates of expected angling pressure and catchability coefficients of each species stocked

are of primary importance because of their considerable effect on other system components. A user must have a sound objective before deciding where, when, which species, and how many fish to plant. The primary utility of CATS is to enable the user to evaluate management strategies prior to implementation.