

# Analysis of Catchable Trout Fisheries Management by Computer Simulation

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# Analysis of Catchable Trout Fisheries Management by Computer Simulation

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## 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 multispecies stocking program. The user of CATS can select alternative management strategies and functions which generate predictions of fishing pressure in a particular fishery. To evaluate the effect of each system component, CATS was exercised over a wide range of potential, although entirely hypothetical, system component alternations. 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 produced results intermediate between those 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.

Catchable trout stocking, now an important activity in many North American fisheries management agencies, annually supplies millions of anglers with an outdoor recreational experience. Public opinion has always been strongly in support of trout stocking programs and is likely to so continue in the foreseeable future.

Catchable trout stocking programs can be divided into two very general categories: single and multispecies stocking programs. Major advantages of a single-species stocking program are (1) that by selecting a species with a high food conversion rate, initial production costs can be kept low, and (2) the strategy to meet most management objectives is relatively simple. A potential advantage of a multispecies stocking program is that certain fishes may be better suited than others to particular habitat types. In a multispecies stocking program, inherent differences between species may give a manager additional control of the fishery. Increased initial production cost in multispecies programs may be offset if management objectives are better realized.

One strategy to obtain optimal output from single-species, catchable trout fisheries is to determine required plant size and frequency needed to provide optimal plant-to-plant survival (Butler and Borgeson 1965). Optimal plant-to-plant survival is defined as one which is high enough to prevent undesirable decrease in angling effort during the planting interval. Although optimal plant-to-plant survival is not necessarily the same for every fishery, the 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. Manipulation of such factors as species ratio, plant size, and planting frequency, within specific agency and external constraints, can be used to theoretically evaluate potential management strategies.

The first obstacle that must be faced in evaluating management strategies is defining management objectives, or at least defining an acceptable measure of system (fishery) output. Traditionally, relatively little consideration has been given to this aspect of fisheries management (Lackey 1974). Stated management objectives are usually vague and may, in some cases, be unattainable. For example, optimization of recreational benefit derived from catchable trout fisheries is a stated objective of many fisheries agencies, but recreational benefit has not been quantified nor has a formalized description been widely accepted by managers. Agency personnel often accept, with strong practical considerations, the more immediate objectives of providing maximum percentage return to the angler of stocked fish or the maximum number of angling hours. Cost of the total stocking operation is usually included as a management constraint, although to some degree this is a decision variable. The above two management objectives are not simultaneously reachable. Supplying anglers with the maximum number of angling hours may not even be desirable since aesthetic values may decline as angler use reaches high levels. To establish a sound objective from an analysis standpoint, 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 computer simulation. A system (fishery) is an assemblage of components united by some form of interaction or interdependence to form a whole. A computer simulation of a system is an abstraction, and the degree of abstraction is a value judgment made relative to the purpose at hand. The key to effective simulation is to strike a proper balance between realism and abstraction (Patten 1971).

By manipulating a computer-simulated catchable trout fishery, one can observe effects of such input alternatives as: (1) stocking different species ratios; (2) altering catchability coefficients; (3) changing levels of

angling pressure; (4) using different stocking frequencies; or (5) applying a combination of input alternatives. A manager could also use a computer simulator to develop a strategy to meet given objectives within specific constraints. 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 a hypothetical fishery.

#### SIMULATOR DEVELOPMENT

Development of CATS was started by systematically defining the system under study: a generalized, multispecies, put-and-take, catchable trout fishery (Fig. 1). Relationships between system components were determined by discussion with fisheries managers, review of the literature, and results from creel survey.

Daily angling pressure in a catchable trout fishery can be constant, random, follow a definite relationship with current fish populations, or be partially predictable and partially random. Fairly constant angling pressure can occur on a fishery near a large population center where potential anglers will fish largely independent of management efforts. Random angling pressure can occur on a large lake fishery where the probability of success is not appreciably increased by fishing immediately after stocking. Angling pressure can often be described as a function of the current fish population level; i.e.,  $f = \alpha N$  (where  $f$  is fishing pressure,  $\alpha$  is a constant, and  $N$  equals the population of fish available in the fishery). This relationship typically results in high angling pressure on the day of stocking, followed by a rapid decline as the trout population is depleted. Weather and other stochastic inputs account for unpredictable variation around expected angling pressure. CATS permits the user to select any of these approaches (constant, random, or a simple proportional function) for generating daily angling pressures.

Differences in catchability coefficients ( $q$ ) of trouts used in stocking programs can perhaps be used to advantage in management (Cooper 1959). Catchability coefficients are dependent on the environment, innate char-

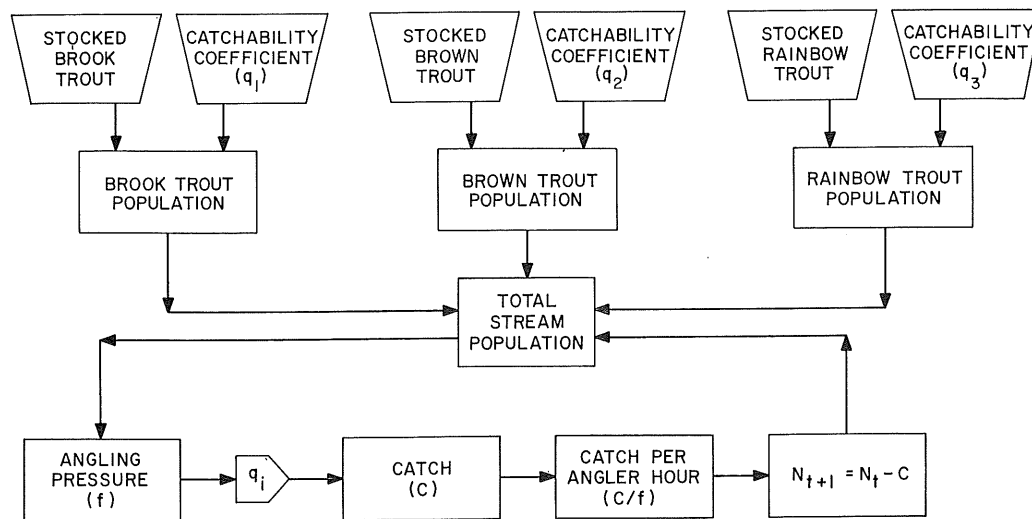


FIGURE 1.—Simplified structure of a generalized multi-species catchable trout fishery as simulated in CATS.

acteristics of the fish, distributional practices of the stocking agency, and the effectiveness of one unit of fishing effort. In any given fishery with a consistent stocking program, the catchability of a 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  $q$ .

Three aspects of the actual stocking process can be considered in CATS 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 angling pressure), and the potential of the habitat to support angling pressure. The user of CATS can provide 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 could 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 an arbitrary 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 the above stocking options.

Simulator quantification was initially approached by viewing a catchable trout fishery as a deterministic system. 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 in a catchable trout fishery cannot be exactly predicted. To account for stochastic inputs,

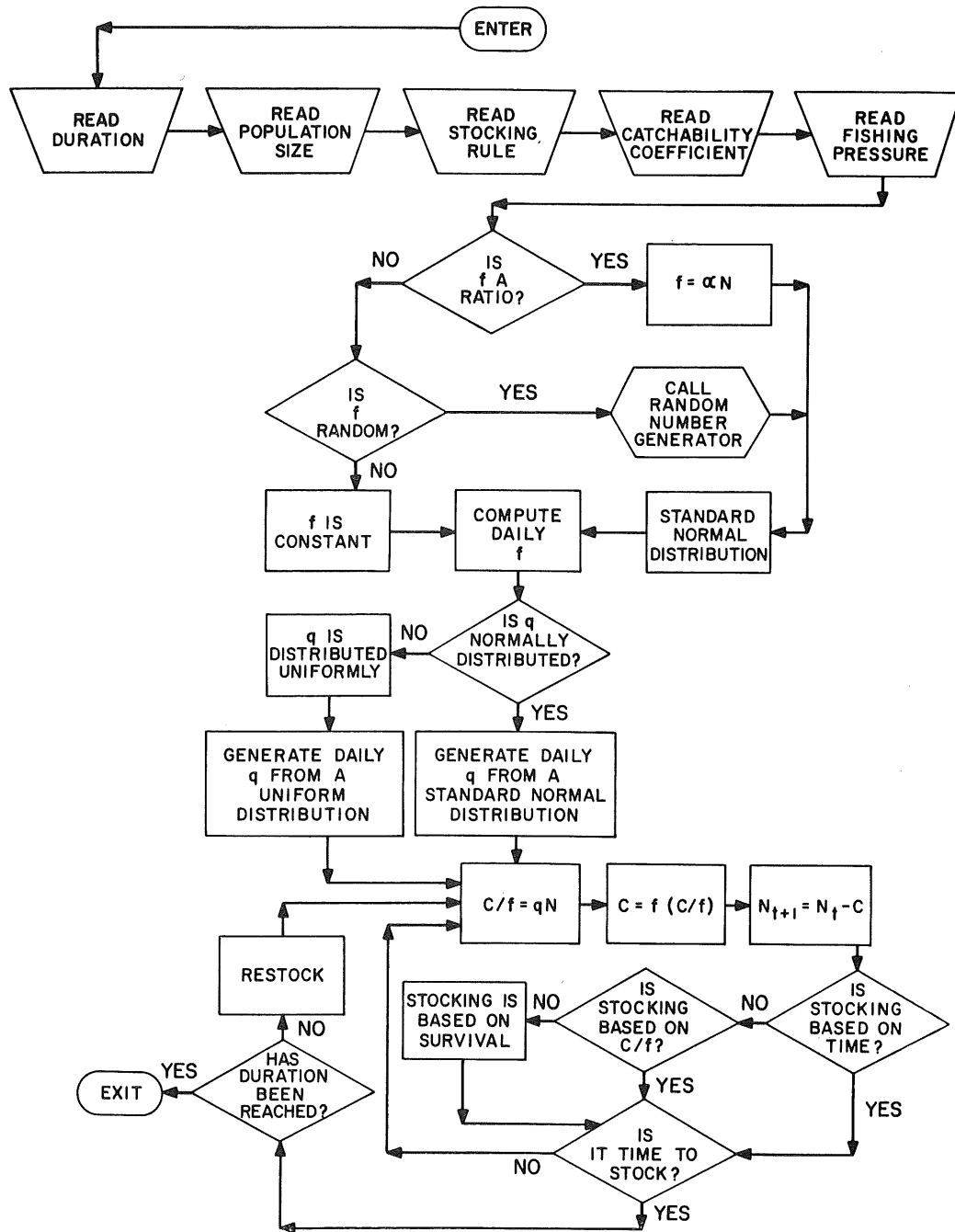


FIGURE 2.—A flow-chart description of computer operations in CATS.

such as weather, a random number generator and two random process generators were added. Values for all input variables in CATS are treated as elements from probability dis-

tributions. To generate predictions, the user enters probability distributions instead of entering specific values for variables and constants. Generated predictions will then be

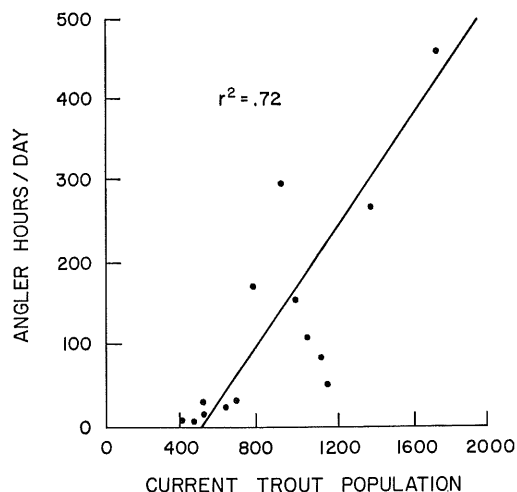


FIGURE 3.—Relationship between daily angling pressure and trout population during one stocking of 1,632 trout (May 1972) on the South Fork of the Roanoke River, Shawsville, Virginia.

probability distributions, rather than exact values (Kowal 1971).

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 or any other source. For example, the catchability coefficient of a species 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 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. Spe-

cies populations are then recomputed. The fishery is examined to determine whether the restocking condition, based on the selected stocking option, 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 the 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 5,258 trout. A complete description of the study streams, creel survey procedures, and results are included in Lackey and Hammond (1973).

Creel survey results indicated angling pressure was highest immediately following stocking and decreased rapidly as fish were removed. Daily angling 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 0.53 to 0.72. Average angling intensity on streams has been strongly correlated ( $r = 0.87$ ) 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*) in the surveyed fisheries. Brook trout had the highest catchability followed in order by rainbow and brown trout. This relationship has been reported in other fisheries (Cooper 1959). Catchability coefficients for a species were fairly constant throughout a stocking period. Daily catchability coefficients had small variance and ranged from  $5.5 \times 10^{-4}$  to  $14.2 \times 10^{-4}$  (average  $10.0 \times 10^{-4}$ ) for brook trout;  $3.9 \times 10^{-4}$  to  $10.7 \times 10^{-4}$  (average  $7.2 \times 10^{-4}$ ) for rainbow trout; and  $2.6 \times 10^{-4}$  to  $5.5 \times 10^{-4}$  (av-

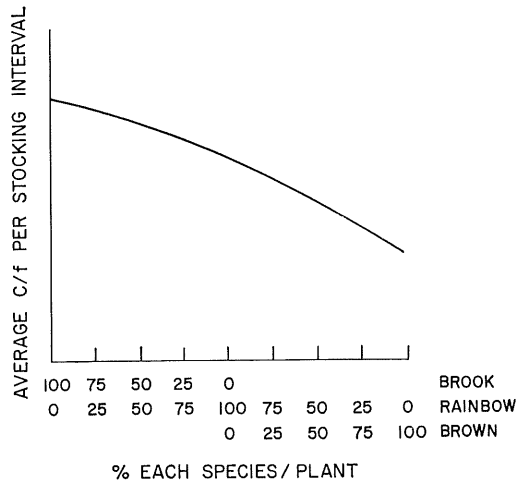


FIGURE 4.—General relationship between average  $C/f$  per stocking interval and two-species stocking ratios when simulated stockings were performed on a fixed time increment basis.

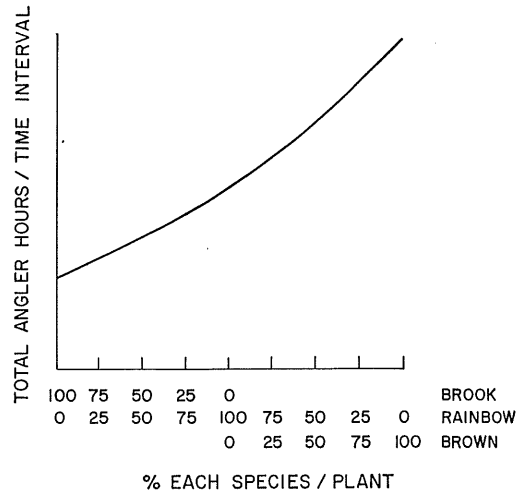


FIGURE 5.—General relationship between angling pressure and two-species stocking ratios when simulated stockings were performed on a fixed time increment basis.

erage  $3.7 \times 10^{-4}$ ) for brown trout during a particular stocking on one fishery. Average catchability coefficients for brook trout ranged from  $3.6 \times 10^{-4}$  to  $11.0 \times 10^{-4}$ . This variation appeared to be primarily related to differences in water levels during the season. Stocked rainbow trout catchability coefficients from  $2.6 \times 10^{-4}$  to  $87.8 \times 10^{-4}$  (average  $10.7 \times 10^{-4}$ ) have been documented from many fisheries (Butler and Borgeson 1965). Catchability ranges tested in CATS were based on calculated means from creel surveys  $\pm 100\%$  and  $-50\%$  to determine the effect of high variance associated with predicted mean catchability rates on the duration of the fishery.

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

Applying CATS to a generalized hypothetical fishery showed that the main effects of altering either the ratio of species stocked or total plant size while stocking on a fixed time increment basis (e.g., every 30 days), were on average  $C/f$  during stocking intervals (Fig. 4) and total number of angler hours during the time interval (Fig. 5). Stocking predominantly brook trout resulted in an appreciably higher  $C/f$  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

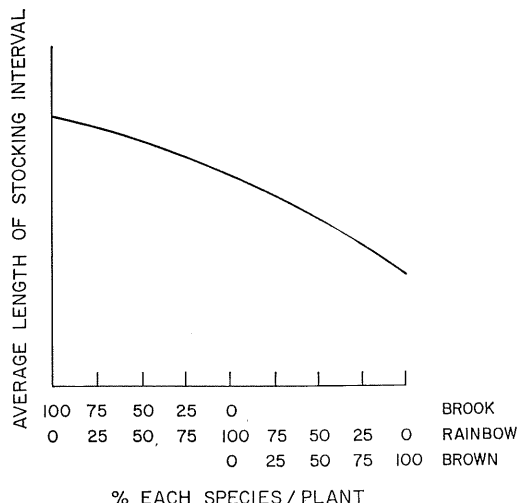


FIGURE 6.—General relationship between stocking interval length and two-species stocking ratios when simulated stockings were performed after  $C/f$  had dropped to 0.25 fish per hour.

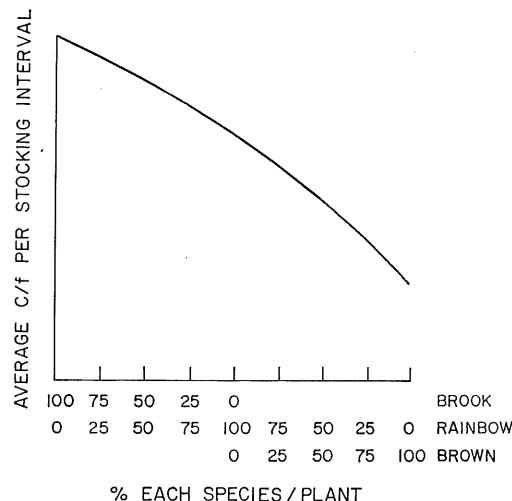


FIGURE 7.—General relationship between average  $C/f$  per stocking interval and two-species stocking ratios when simulated stockings were performed after  $C/f$  had dropped to 0.25 fish per hour.

the ranking of catchability coefficients among the three species, stocking predominantly rainbow trout gave results intermediate between the effects of stocking predominantly brook or brown trout.

The main effects of altering the ratio of species stocked in the hypothetical fishery when stocking was performed after  $C/f$  had dropped to some arbitrary level (0.25) were on length of stocking interval (Fig. 6), average  $C/f$  values (Fig. 7), and total angler hours provided (Fig. 8). Success rates lower than 0.25 resulted in low levels of angling pressure.  $C/f$  was low directly after stocking when brown trout were predominantly stocked, and the predetermined restocking level of  $C/f$  was reached quickly. Therefore, the number of plants per period of time necessary when the ratio of brook, rainbow, and brown trout 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.

The third alternative for determining stocking frequency was to restock when plant-to-plant survival had reached a level below which angling 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 per given period of time 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 one successive stocking interval when the stocking ratio of brook, rainbow, and brown trout was 3:2:1, was approximately half the angling pressure which occurred during one stocking interval when the ratio was reversed. Therefore, total angler hours remained fairly constant regardless of stocking ratio.

Angling pressure was considered to be constant, random, or predictably related to current fish population; the choice had little effect on the duration of the fishery. Stocking intervals equal in length could be obtained with each method. However, the level of angling pressure used as data input had a much more sensitive effect on the predicted duration of the fishery. When daily angling pres-



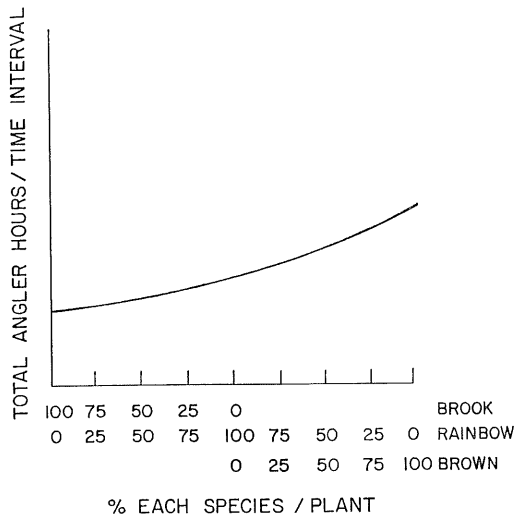


FIGURE 8.—General relationship between angling pressure and two-species stocking ratios when simulated stockings were performed after C/f had dropped to 0.25 fish per hour.

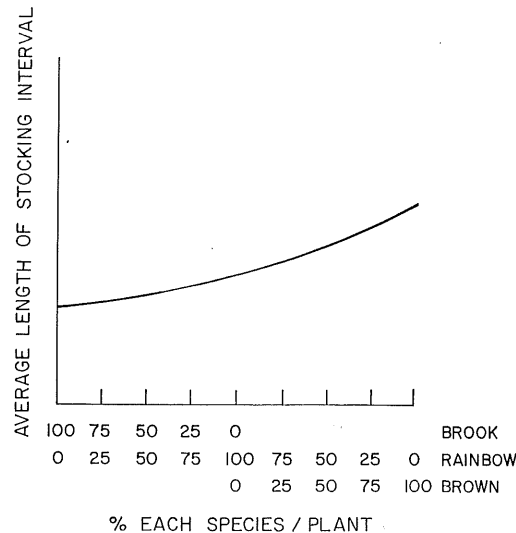


FIGURE 9.—General relationship between stocking interval length and two-species stocking ratios when simulated stockings were performed after plant-to-plant survival had dropped to 0.40.

sure 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 was quadrupled with no effect on length of stocking interval. However, when predicted mean  $q$ 's were doubled throughout the simulated angling 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 or modify CATS for a particular fishery, then alter the stocking ratio to gain an understanding of potential system response under different management strategies. Our results are based on analysis of a hypothetical fishery using realistic input data, but our conclusions should be applied to other catchable trout fisheries with caution.

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. 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 angling pressure, which in turn have the greatest direct impact on the fishery.

Reducing the number of stocked fish and increasing frequency of plants have been suggested to provide a more uniform rate of return (Butler and Borgeson 1965; Ratledge and Louder 1967). CATS, for species and data shown, indicated that a reduction in plant size and an increase in planting frequency result 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 angling pressure (low  $q$ ) (Applegate 1963). Simulation showed an in-

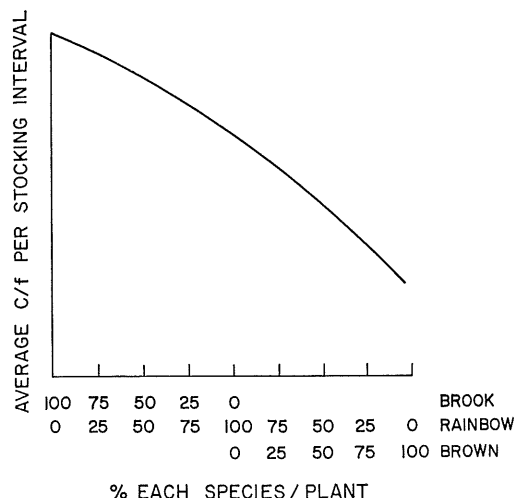


FIGURE 10.—General relationship between average C/f per stocking interval and two-species stocking ratios when simulated stockings were performed after plant-to-plant survival had dropped to 0.40.

crease 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.

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 100 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.

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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