SIMULATION OF ANGLER-EXPLOITATION OF SALMON IN THE RAKAIA RIVER

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INTRODUCTION

The aim of simulation methods is to test hypotheses about the behaviour of complex natural systems by using a computer to perform a sequence of instructions which imitate the way in which we suspect that the system operates. The set of instructions represents a model of the system, translated into a computer language, and results are obtained by running the computer programme and using different starting conditions. Because digital computers operate at very high speed they can calculate very complicated interactions within a system in a very short time. This paper gives a preliminary account of some work in progress which is exploring the factors influencing the catch taken by anglers fishing for quinnat salmon in the Rakaia River. The central parts of the study concern the behaviour of the fishermen, the upstream movement of the fish and the physical characteristics of the river in so far as they affect fishing success.

The Rakaia River runs eastward from the Southern Alps for a distance of 140 km and the lower 61 km, where most of the fishing occurs, crosses the Canterbury Plains as a wide braided channel. The lower section of the river has a very even gradient (4.5 m/km) and flows in an almost straight line to the sea. Average annual discharge from the river has varied considerably from 147 to 276 cumecs (cubic metres/second). During the period from October to March, the average discharge is 249 cumecs. The highest average monthly discharge is in January and it is more than twice the discharge for July. Examination of ground-water contours along the length of the river indicates that there must be a substantial loss due to seepage in the plains section and this could be as high as 25%. The flow pattern, high discharge and its location, make the Rakaia river a very attractive source of water to generate electric power and to irrigate the surrounding farmland. The consequences of removing water and the implications for other uses of the river are not clear. As regards the fish, these may involve changes in the channel pattern and accessibility of the river from the sea, both of which have undesirable consequences for the sport fishermen. Therefore a great deal of research is required to elucidate the problem and to predict the results of varying degrees of water removal. Simulation modelling has been used as an aid to planning future research and to suggest ways in which multiple use might be possible. The initial steps reported here concern only the anglers and the salmon.

SIMULATION WORK

Adult fish migrate up the river as early as December with numbers gradually increasing through January and February and reaching a peak in March. Most of the fish are three or four years old, with small numbers of two year old and a very small number of five year old fish. The majority of fish reach the spawning ground during the month of April. Male and female fish pair up and eggs are laid in a redd excavated in the gravel. Young fish emerge after 2-3 months and may remain in the headwaters for up to a year and a further few months in the river or close to the sea, before finally entering the sea where they feed and grow very rapidly and reach the adult size. For the purposes of simulation, the life-history of salmon may be broken down into (1) upstream migration of adults, (2) spawning and hatching of young, (3) downstream migration of young fish, and (4) the oceanic phase of growth and maturation. To date, only the first two stages have been modelled.

I have attempted to interrelate the major variables affecting the number of fish which survive passage from the river mouth to the spawning grounds. These variables can be grouped into those concerning the fish (their pattern of arrival at the river mouth, the rate at which they move upstream), those concerning the fishermen (their number, distribution along the river, changes in distribution with season, the length of time to cast a line, the length of time to play and land a fish, the casting distance, bag-limit and the number of hours fished per day per man) and those concerning the river (the width of the river and its discharge).

In the simulation model the salmon run is assumed to arrive in a normally distributed way at the river mouth, so that the first fish appear at the beginning of the year and the peak occurs in mid-March (Fig. 1). Three parameters are specified to reproduce this

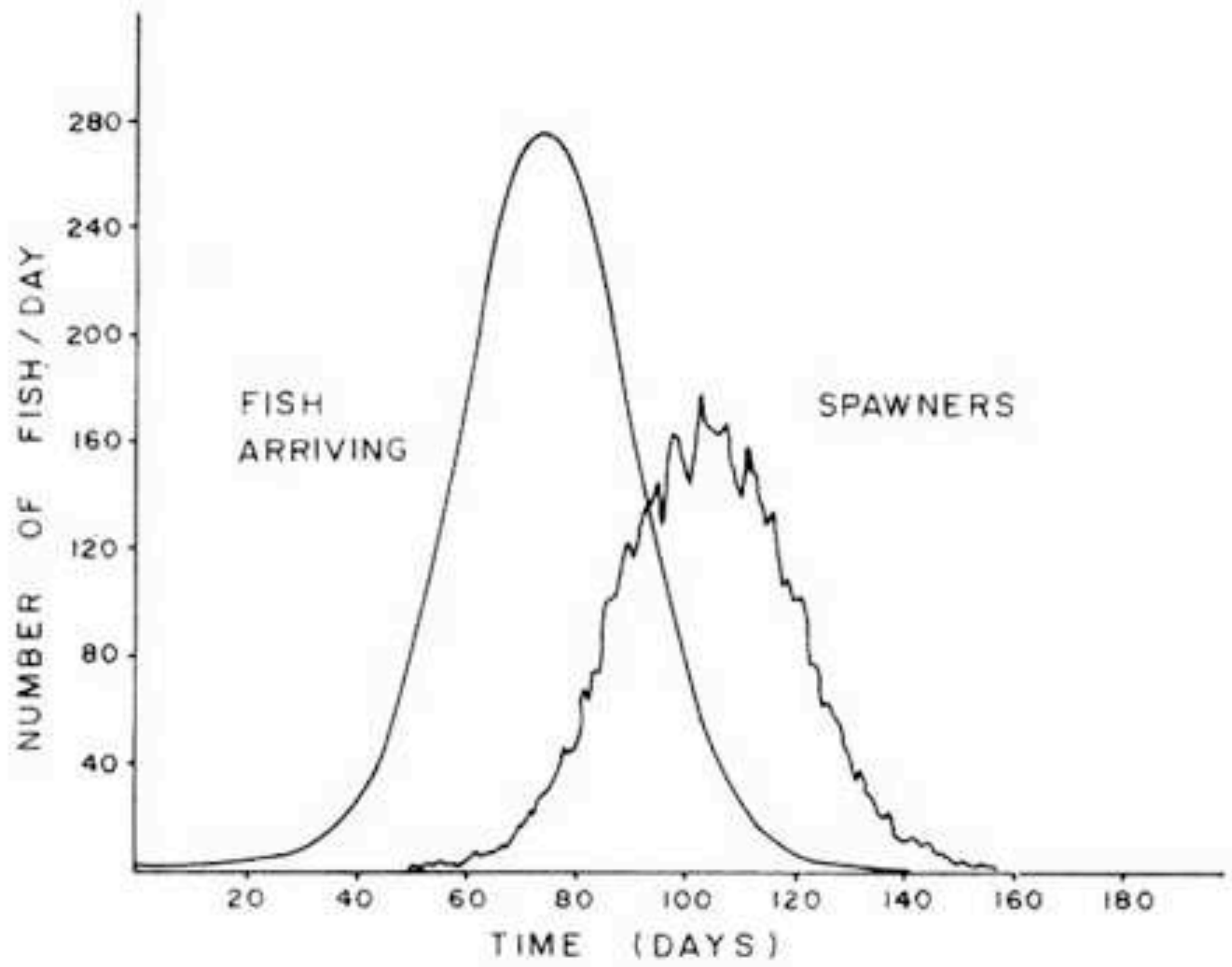

Figure 1. *Assumed pattern of arrival of adult salmon at the river mouth and the subsequent arrival of spawning fish in the headwaters after they have been exposed to the anglers (for this example, 194 fishermen). Time is measured from the beginning of the year.*

symmetrical distribution: the variance of the time of arrival, the date of peak numbers and the total run size. The area under the curve represents the total of 11 000 fish because this is the best rough estimate of the average Rakaia adult salmon population (M. Flain, pers. comm.). Run size has remained constant in all simulations so far because the whole life history has not been modelled to produce a complete population model. There is some evidence for the assumption of a normally distributed pattern of arrivals, since this corresponds to their known pattern of arrival at the Glenariffe traps where many fish spawn. It is true that this evidence is open to the objection that spawning arrival pattern may not represent the original arrival pattern because anglers may modify the original pattern and fish may not proceed directly up the river to spawn. Indeed, the arrival of spawning fish in 1971 at the Glenariffe traps was bimodal rather than unimodal (Galloway, 1972). However, the timing of peak arrival is very similar from year to year.

The rate of movement upstream is deduced from the difference in timing of the arrival peak in the headwaters, compared to the peak in angler catches at the mouth of the river, and this is about 30 days. Since the distance that the fish must swim is approximately 120 km I assume that they swim an average of 4 km per day. Therefore the river is divided into 30 segments each representing a 4 km stretch. New fish arrive at the first river segment each day, are fished, and pass on to the next segment on the following day. In this way fishing and migration up the length of the river is simulated on a daily time increment. The fishing activity of each fisherman in a section is simulated in turn. Each man is assumed to fish 4 hours each day, and his time is divided between casting and landing any fish that are hooked. Preliminary figures used for time-costs were 4 minutes per cast and 30 minutes per landed fish. Probability of fish capture is related to the number of fish present, the river-area that they occupy and the width of the river. Each cast is assumed to be of a standard length (defined as 20 m for the present simulations), in any direction, and this represents a standard chance of success related only to fish density. This is based on the assumption that the probability of encountering a fish is related to the length of the path the line traverses. If the river is less than 20 m, then the probability of capture is reduced in proportion to the casting area lost because it is assumed that a fisherman would have to use shorter casts. Each cast is reproduced by drawing a random number and inspecting it to see if it is in the right range to award the fisherman a fish. When a fish is removed the density is re-adjusted and casting continues. Success is directly

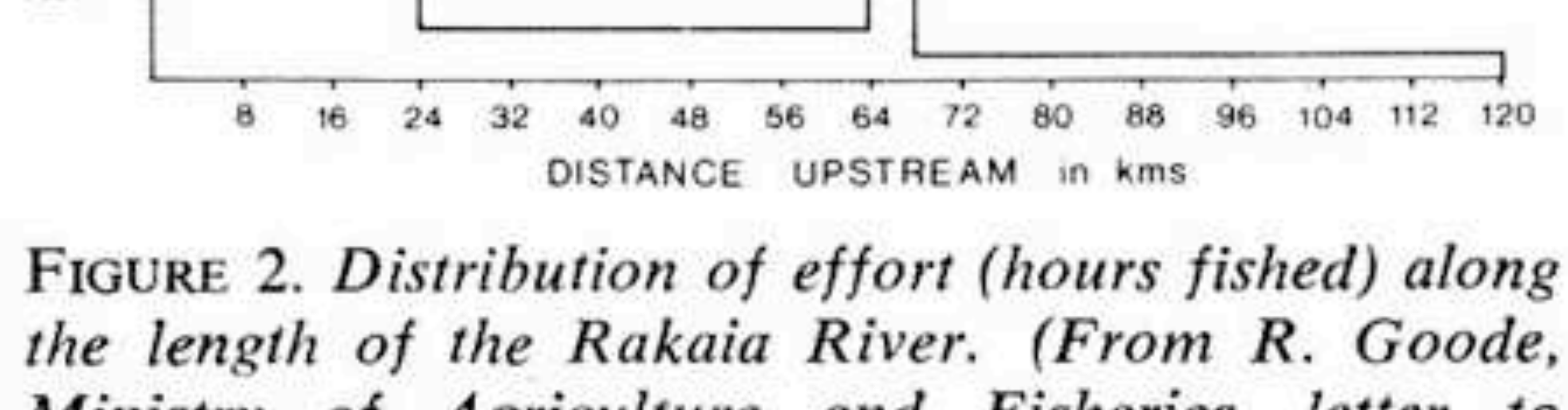

Figure 2. *Distribution of effort (hours fished) along the length of the Rakaia River. (From R. Goode, Ministry of Agriculture and Fisheries, letter to salmon anglers 5 June, 1973).*

related to numbers of fish present so that more are caught when the density is high. Comparison of the two curves in Fig. 1 illustrates this effect because many more fish are removed from the peak of the run than from the "tails". Furthermore, most of the fish are caught near the river-mouth where their density is highest.

One of the major variables is the number of fishermen present per day. In addition, the fishermen are not distributed evenly along the river, but instead they are apportioned to each 4 km segment so as to correspond to the average distribution of effort revealed by Ministry of Agriculture and Fisheries surveys (Fig. 2). Aerial surveys and questionnaires show that fishing effort is concentrated near the mouth and in the lower reaches of the river and also close to the Rakaia Gorge bridge, some 62 km upstream. Therefore in some segments the fishing pressure is very heavy, while in others it is very light. The whole river is assumed to be fished but in actual fact this may well not be true. It is known that the pattern of effort changes with the season as fishermen tend to follow the peak of the run and gradually concentrate their angling in the upper reaches of the river. Because of lack of information about precisely how this pattern changes, only an overall season average has been used.

To illustrate the behaviour of the simulation model the effects of varying some of the major factors are shown in the following figures. Fig. 3 shows what every salmon fisherman knows only too well, that most of the time they catch almost nothing and very few reach the bag-limit of four fish per day. These results are for 38 fishermen fishing for four hours per day with no constraints caused by the river being too narrow. On average it took 12.2 hours/fish to land the catch and this represents fairly good fishing. If the number of fishermen were doubled the rate would decline to 15.04 hours/fish. These results from the simulation model are very close to rates of capture observed on the river itself, which is very encouraging. If the bag-limit is altered,

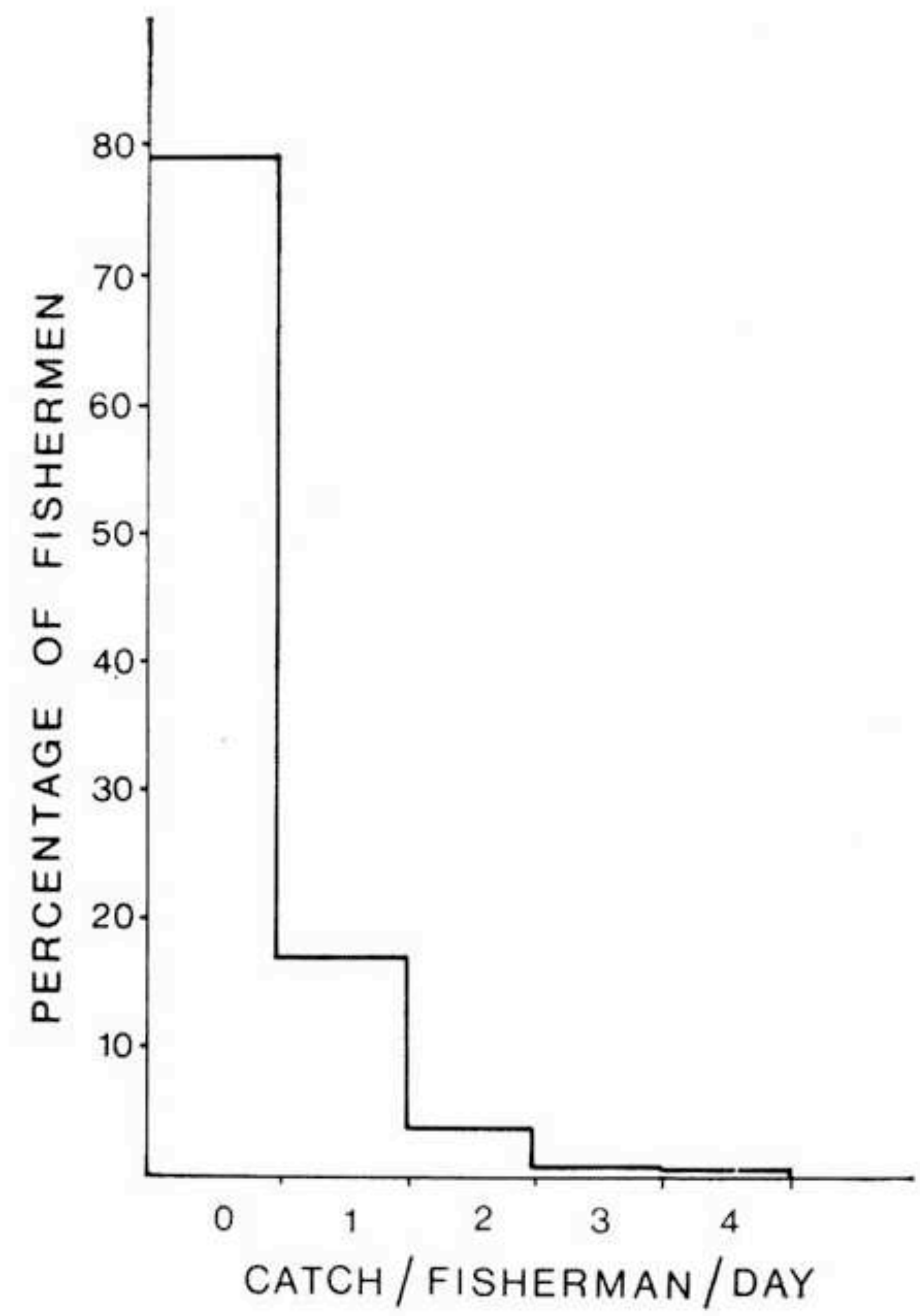

FIGURE 3. *Results of simulations: Distribution of bag-size among fishermen with 38 fishermen fishing for 4 hours/day. This catch (1350 fish) represents a catch rate of 12.2 hours/fish.*

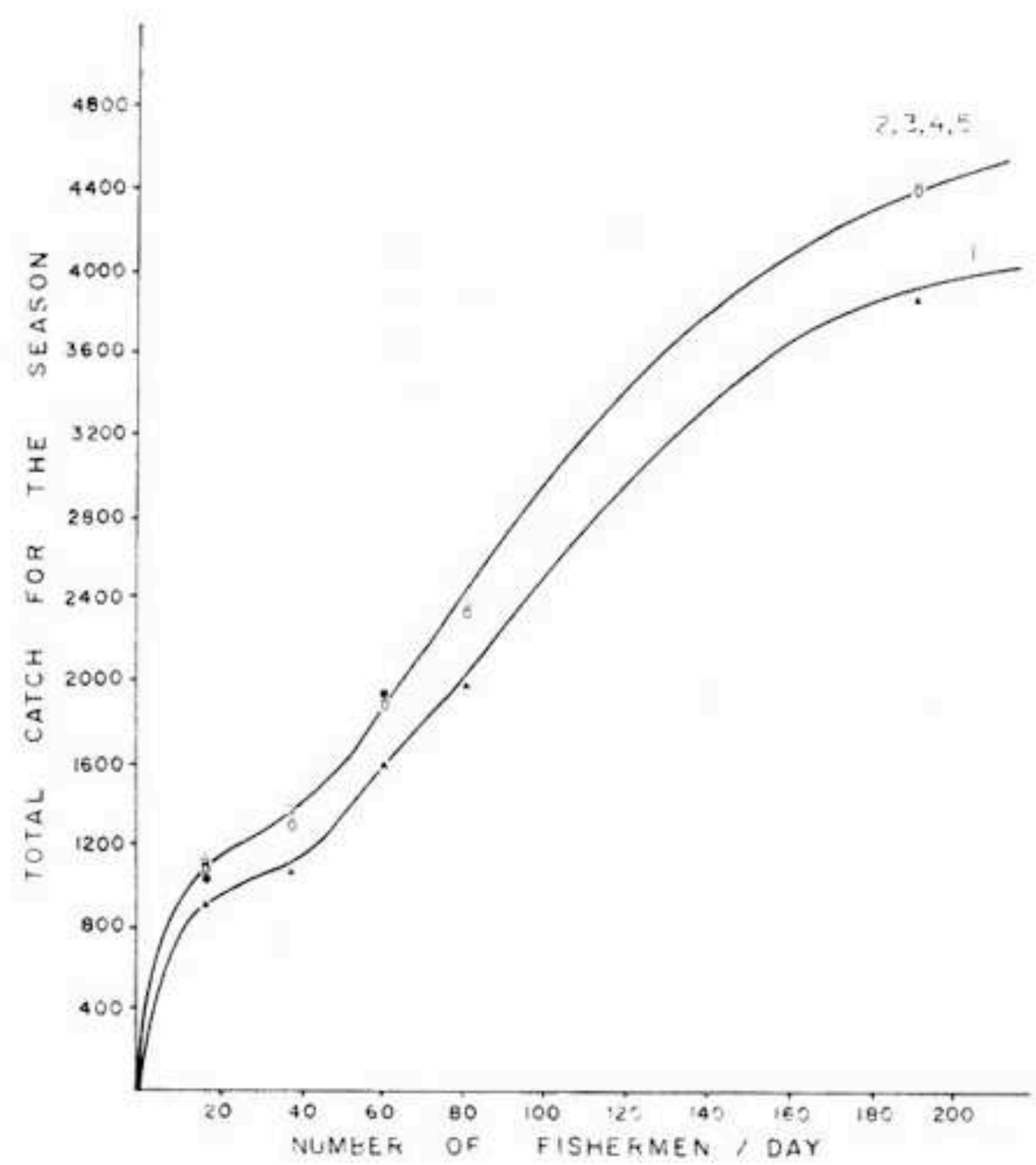

FIGURE 4. *Results of simulations: The relationship between season's catch and number of fishermen/day, illustrating the effect of altering the bag-limit from 4 to 5 or down to 1 fish per man per day. (Bag-limit = 1, ▲; 2, ■; 3, △; 4, O; 5, □.)*

either up or down, there is very little change in the catch until we get down to a limit of only one fish per man (Fig. 4). This substantiates the claim made by Allen (1955) and Allen and Cunningham (1957) that the bag-limit is a relatively ineffectual regulation.

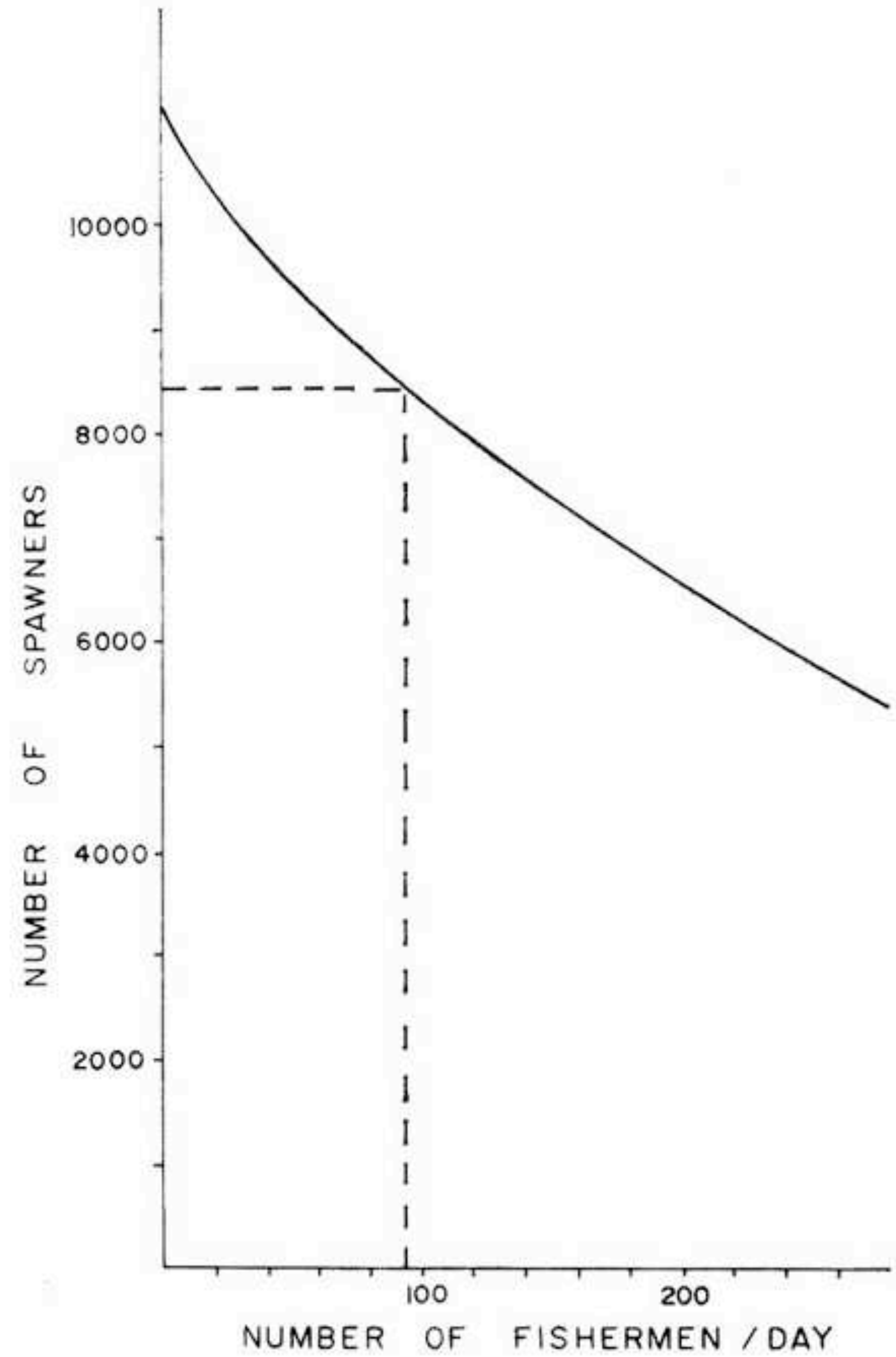

Figure 5. *Results of simulations: Relationship between escapement of spawning fish and number of fishermen. The dashed line indicates the number of anglers required to remove a catch of 2600 fish.*

When the number of fishermen is increased to high levels the catch increases but not in direct proportion because each bag becomes smaller. Nevertheless fewer spawners reach the headwaters (Fig. 5). Graynoth (1972) has estimated the annual Rakaia salmon catch at 2600 fish. The simulation model suggests that this would be taken by almost 100 fishermen angling per day for the whole season. This seems to be a reasonable number of anglers to be on the river. The object should be to regulate fishing effort so as to produce the optimum number of spawners, but unfortunately we do not know what this optimum number actually is. There seems little value in altering the bag-limit to achieve this object.

One of the consequences of removing water from the river may be to reduce the average width. Simulations suggest that this would result in a decline in the total number of fish caught (Fig. 6). However the decline is not as drastic as one might imagine because there are positive and negative consequences of width-changes to be balanced. On the one hand the fish have less river areas to occupy and must be easier to catch because they are more dense, but on the other hand the effectiveness of fishermen is reduced because they cannot cast as far. Overall there is a decline in catch, and Fig. 6 shows that this is independent of the number of fishermen (i.e. the slope of the lines are almost identical). It may well be that fishermen change their casting methods when the river becomes narrow and cast the same distance either up or downstream and theoretically, at least, maintain their catching effectiveness. If this is the case then decreasing the river width must produce a large *increase* in their catch.

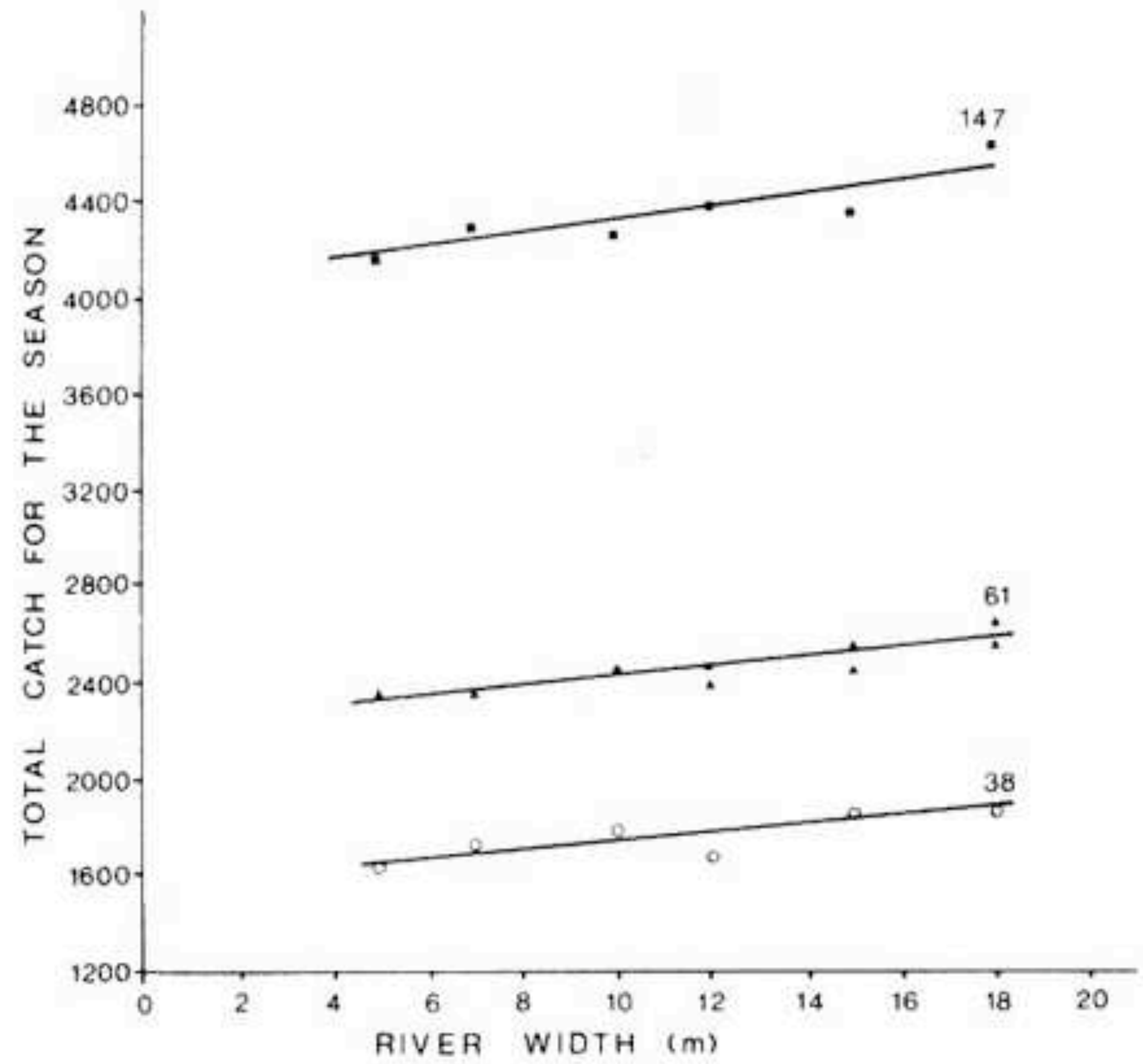

Figure 6. *Results of simulations: Showing the decline in catch with decreasing width of the river at three levels of fishing intensity, 147, 61, 38 fishermen/day.*

A second simulation model, which will ultimately be linked to the first, deals with spawning and the production of young fish. Adults which survive the fishery and reach the headwaters (see Fig. 1), select spawning sites and lay their eggs. A finite number of sites (each with equal production potential) is assumed and each fish randomly selects a site. Utilisation of available sites is distributed in a random-normal manner so that some areas are heavily used and disturbed by the fish while others are only used infrequently. The degree of spread of utilisation by spawning fish is unknown and so a broad range of possibilities has been explored (Fig. 7). When

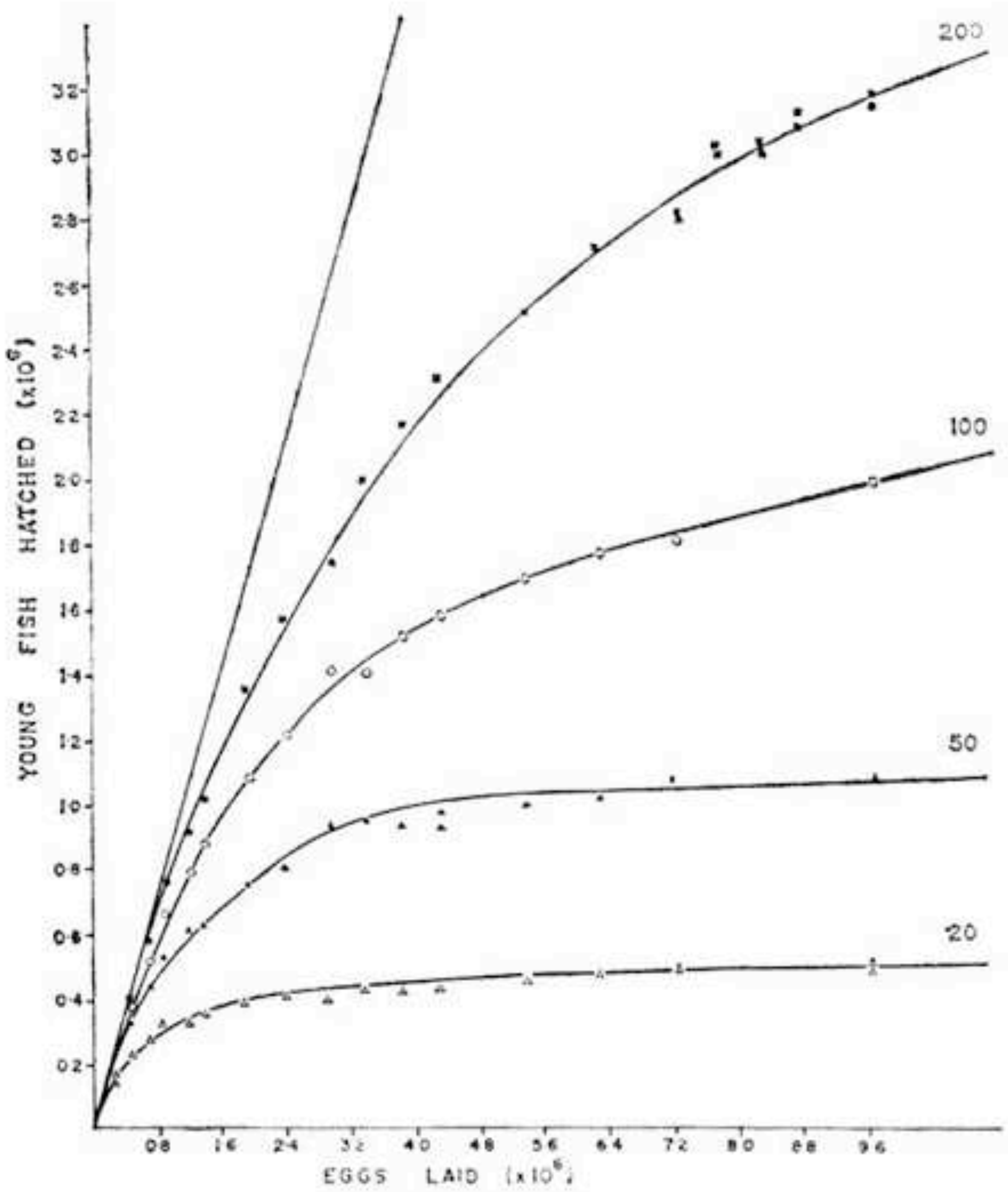

FIGURE 7. *Results of simulations: Showing the relationship between production of young fish and numbers of eggs laid with different degrees of utilisation of available spawning area (20, 50, 100 200 represent the variance in distribution of spawning among suitable redd-sites).*

utilisation is very restricted, large numbers of eggs are destroyed by superimposition of eggs laid by successive fish and the production potential for the whole spawning area is far from realised. A small number of adult fish produce just as many offspring as does a large number. As more of the spawning sites are used more young are produced per adult. Superimposition was initially suspected to also be influenced by the pattern of arrival of the females but this can be shown to be of little importance. Multiple use of spawning sites is not feasible because development of eggs in the gravel occupies a length of time much greater than the period over which adult fish arrive on the spawning ground. Limitations on the availability of spawning and nursery areas are probably the key to the possible enhancement of the size of the Rakaia river salmon run (Flain, 1972; Eggleston, 1972) and there is some evidence from the Glenariffe trap that superimposition or some other density dependent process results in significant reduction in the number of redds completed at high adult densities (Fig. 8).

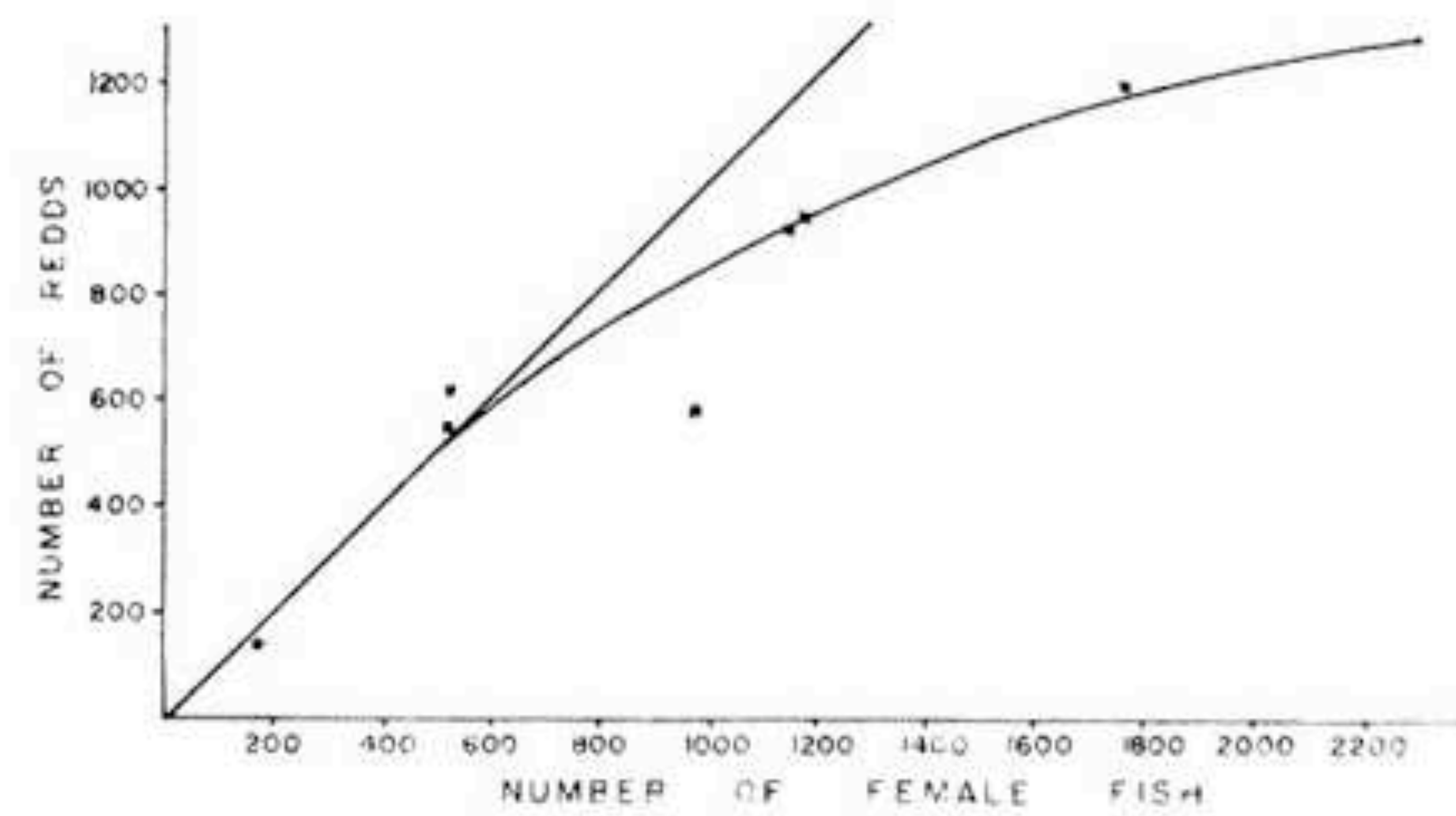

FIGURE 8. *Observed relationship between the number of redds produced and number of female spawning fish. (Data from Wing, 1972.)*

FUTURE WORK ON SALMON

As a result of the simulation work a number of critical areas can be identified and future work should try to answer some of the following questions:

1. What is the true pattern of arrivals of fish at the mouth of the river? Capturing, tagging and releasing salmon at sea during the season would provide a tremendous amount of information and (as noted by Eggleston 1972) allow estimation of the size of the whole run and rates of movement upstream. From this we could get a better idea of the degree of exposure of fish to the fishermen.

2. Do fish migrate a unit distance/hour (as assumed), or is migration a function of certain times during the day? How would such movement concentrations affect fisherman success?

3. What are some more accurate estimates of the way fishermen apportion their time? What other details of their behaviour could be incorporated into the model to improve its realism?

4. What is the precise distribution of fishermen along the length of the river and how does it change with the season? The existing information on this point is too imprecise for use in the simulation model.

5. What is the extent of suitable spawning areas in the Rakaia headwaters and how can they be improved and expanded? Flain (1972) has made some suggestions about protection from floods, which should prove very valuable.

The employment of a simulation model that can be used to guide research and which can evolve as new evidence comes to light, would be an invaluable tool. As more data becomes available it could be "plugged in" to a simulation model that could become the basis for future management of the salmon population. At the same time, a management model could become an essential part of the river system analysis envisaged by Huber (1975), to resolve conflicts in the use of the Rakaia water resource.

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