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Analysis of "Quality Fishing" Regulations Through Mathematical Simulation of a Brown Trout Fishery

Richard D. Clark, Jr.

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ANALYSIS OF "QUALITY FISHING" REGULATIONS THROUGH MATHEMATICAL SIMULATION OF A BROWN TROUT FISHERY [1]

By Richard D. Clark, Jr.

Abstract

The population simulator, TROUT.DYNAMICS, was calibrated with mortality, growth, and reproduction statistics for the brown trout (*Salmo trutta*) fishery in a section of the Au Sable River, Michigan. It was then treated as a "test-tube" fishery for experimenting with different "quality fishing" regulations. A range of inverted and slot size limits was tested under a flies-only gear restriction for conditional fishing rates (*m*) of 0.20 to 0.60. The performance of these regulations was compared to typical minimum size limits, an unrestricted fishery, and a catch-and-release fishery. The potential impact of hooking mortality on the fishery was examined by simulating a wide range of hooking mortality rates for a catch-and-release regulation. Also, the effects of gear restrictions, such as fly-fishing-only or artificial-lures-only, were examined under a hypothetical scenario in which it was assumed that they would reduce fishing pressure, as well as hooking mortality. Two statistics were used as the major indices of fishery performance under the various regulations--the number of trophy-size trout (over 406 mm long) caught annually and the total annual harvest (or kill) in numbers of legal-size trout. Results showed that the catch of trophy-size fish was inversely related to the total harvest in numbers. The greatest number of trophy fish was caught under a catch-and-release fishery in which no harvest was permitted. The greatest total harvest in numbers of fish was

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obtained, but the lowest number of trophy fish was caught in an unrestricted fishery. Hooking mortality did not have a serious impact on total catch of trout until the portion of fish dying after catch and release (h) exceeded 40% and the fishing rate (m) exceeded 0.30. In contrast, the catch of trophy fish was reduced considerably by relatively small increases in hooking mortality. With respect to gear restrictions, it was found that use of fly-fishing only regulations maximized the number of trophy fish in the population, but artificials-only regulations maximized the annual catch of trophy fish from the population. The main reason for this was the assumption that the average angler had a higher catch rate with spinner type lures than with flies. Any-lure regulations maximized the total catch for the fishery. The exact numerical results of this analysis applied only to the study fishery, but the general trends in fishery statistics should apply to most stream trout fisheries and to any other fishery which conforms to major model assumptions.

The development of a new mathematical model for evaluating the effects of fishing regulations on recreational trout fisheries was reported by Clark et al. (1980). This model, of the dynamic pool type, was similar in many respects to other dynamic pool models (Beverton and Holt 1957, Ricker 1975, Walters 1969). However, the new model contained several features not available in earlier models which made it particularly useful for recreational fisheries assessments. First, it directly addressed the catch and release of fish and the hooking mortality that usually accompanies this practice. Second, it permitted direct analysis of the more unconventional size limit regulations that have been proposed for recreational fisheries, such as slot limits (harvest of fish between two specified lengths) or inverted limits (harvest of fish below a specified length). And, finally, it estimated the length frequency of the population, of the harvested catch, and of the released catch for each set of regulations.

Clark et al. (1980) used the model to compare two different minimum size limits and a slot size limit for a brown trout (*Salmo trutta*) fishery. These examples served to demonstrate the utility of the model, but they did not give much insight into the question of how a fishery might behave under the broad spectrum of different fishing rates, size limits, and gear restriction which are categorized as "quality fishing" regulations.

Favro et al. (1980) and Jensen (1981) examined some aspects of slot size limits, but they used different types of models and did not consider catch and release of trout or the effects of gear restrictions and hooking mortality. The purpose of this study was to expand the analysis of quality fishing regulations started by Clark et al. (1980) on the brown trout fishery of the Au Sable River, Michigan. The effects of a larger variety of size limits and fishing rates were predicted, and the importance of gear restrictions and hooking mortality was investigated. Implications from the analysis for trout management in general are discussed.

Methods

The brown trout fishery in the Burton's Landing to Wakeley Bridge section of the Au Sable River in Crawford County, Michigan, was used as a case study for the analysis. Clark et al. (1980) gave the biological parameters and other background information for this fishery. However, in order to help judge the applicability of the analysis to fisheries elsewhere, a few additional comments are given here.

Brown trout coexist with brook (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*) in the 14-km-long study section. They are nonmigratory, being isolated from the Great Lakes by a series of dams. The river section contains a large amount of gravel substrate which is ideal for trout spawning and, consequently, natural reproduction provides adequate recruitment to sustain the fishery. Hatchery trout have not been planted in the section since 1954. The average annual brown trout production is 100 kg per hectare which is slightly above the average for Michigan streams, while the average growth in length is below the state average (Clark et al. 1980, Gowing and Alexander 1980).

The population simulator, TROUT.DYNAMICS, was calibrated with mortality, growth, and reproduction statistics for the Au Sable brown trout population, and then it was treated as a "test-tube" fishery for experimenting with the regulations. Each regulation was simulated for a 10-year period, sufficient time for the fishery to reach a stable, equilibrium condition. It was assumed that natural mortality, growth rate, and fecundity (by size) remained constant under the range of regulations tested.

Size limits

The following regulations were simulated under a flies-only gear restriction: (1) inverted size limits of 178, 203, 229, 254, and 305 mm, where harvest of any fish below the specified length was permitted; and (2) slot size limits of 152-254 mm, 152-305 mm, 203-254 mm, 203-305 mm, 229-254 mm, and 229-305 mm, where harvest of fish between the specified lengths was permitted. Also, harvest of "trophy-size" fish greater than 406 mm was allowed under slot size limits. Fish were not vulnerable to fishing gear in any of the simulations until they reached 120 mm. Conditional fishing mortality rates (*m*) of 0.20, 0.30, 0.40, 0.50, and 0.60 were tested for each regulation.

One problem in this analysis was to find some basis for comparison of the rather unusual types of size limit regulations. Tables and graphs of theoretically derived statistics have little meaning unless they can be related and compared to some known point of reference. Therefore, reference points were developed for the study fishery. First, a series of minimum size limits was simulated. Much empirical data have been accumulated on minimum size limits for trout fisheries, so these simulations provided a series of reference points from which to judge the more unconventional size limits. Second, the extreme case of the fishery unrestricted by size limits of any kind was simulated. For this simulation it was assumed that few fishermen would harvest fish under 140 mm. Therefore, the unrestricted fishery in this analysis was equivalent to a 140-mm minimum size limit. And finally, in another extreme case, a no-kill, catch-and-release fishery was simulated. In this case, as with all the other simulations in the size limit analysis, a probability of death after hook and release (*h*) of 0.05 was used to represent fly fishing gear. Unlike the other simulations, however, hooking mortality (*mh*) in the catch-and-release fishery was the only cause of death due to fishing. These latter two extreme cases represented the upper and lower limits of the fishery with respect to the degree of exploitation imposed by fishing, and therefore, they made useful reference points.

Hooking mortality and gear restrictions

Many studies have been conducted in recent years to measure rates of hooking mortality caused by different types of terminal fishing gear, such as artificial flies or natural bait. In a review of this subject, Wydoski (1980) listed 161 references. All these studies were fairly consistent in finding that, regardless of species or conditions of the experiment, artificial flies caused the lowest hooking mortality, other artificial lures (such as spinners) caused intermediate hooking mortality, and natural bait (such as worms) caused the greatest hooking mortality. Despite these findings, quantitative population studies have failed to detect any benefit from fly-fishing-only regulations in terms of increased survival or recruitment (Shetter and Alexander 1962, Hunt 1970, and Latta 1973). Nonetheless, gear restrictions are almost always applied in conjunction with "quality" size-limit regulations.

The way most hooking mortality experiments are conducted produces a measurement of hooking mortality which is equivalent to the variable $\underline{h}$ in the model. That is, the proportion of fish dying after being hooked on a certain lure and released is recorded. However, in the context of a fishery, this value must be multiplied by the fishing or catch rate $\underline{m}$ to obtain the hooking mortality rate for the population. In other words, no fish in the population can die of hooking injury unless he is first caught.

Because the entire size limit analysis was conducted under a flies-only gear restriction where $\underline{h}$ was assumed to be 0.05, the question remained as to how the results would have been affected by using values of $\underline{h}$ typical of other terminal tackle such as spinning lures or worms. This question may be of little significance for regulations allowing harvest of a broad range of sizes, but may have great significance when much of the population is designated catch-and-release. A very extensive analysis would be necessary to determine how one size limit, gear restriction combination (such as a 254-mm inverted limit under flies-only) would compare with another size limit, gear restriction combination (such as a 203-mm minimum limit under any-lure). However, valuable insight into the potential effects of hooking mortality and gear restrictions can be gained by a much simpler approach.

First, the dynamics of hooking mortality can be examined by varying fishing rate (m) and the probability of death (h) under a single regulation. Obviously, the impact of hooking mortality is greatest under a no-kill, catch-and-release regulation, because all fish in the population that are vulnerable to the fishing gear are subject to catch, release, and hooking mortality. This regulation is the extreme case, so it should magnify the effects of hooking mortality in simulation results and facilitate the identification of general implications which can be extended to size limit regulations. Therefore, catch-and-release regulations were simulated for fishing rates (m) of 0.20 to 0.60 in combination with values of h from 0.05 to 1.00.

Second, the impact of gear restrictions, hooking mortality, and their consequences can be examined in a more realistic management scenario. For example, researchers have consistently found that a significant reduction in fishing pressure is one of the results of imposing gear restrictions like fly-fishing-only rules (Shetter and Alexander 1962 and 1966, Hunt 1964, Shetter 1969, and Latta 1973). Data from the North Branch of the Au Sable River, Michigan, indicate that this reduction in fishing pressure also means a reduction in fishing mortality. Fly-fishing-only regulations were compared to any-lure regulations on this stream in the 1960's by G. R. Alexander and D. S. Shetter. When their data on the fishery (Shetter 1969, Alexander 1974) were used to compute fishing mortality for the different gear types, it was found that m equaled 0.47 for brown trout under any-lure rules but only 0.29 under flies-only rules. Therefore, to best illustrate the full impact of gear restrictions on the "test-tube" brown trout fishery, simulations using values of 0.30 for m and 0.05 for h to represent flies-only regulations and 0.50 for m and 0.20 for h to represent any-lure regulations were compared. Also, an artificial-lures-only regulation was included in the comparison by assuming intermediate values for m and h of 0.40 and 0.10, respectively. Once again, a catch-and-release regulation was used in combination with these gear restrictions to magnify the impact of hooking mortality.

Somewhat higher values of h were assumed for this analysis than were found empirically by Shetter and Allison (1955 and 1958). Their values for brown trout were 0.00, 0.01, and 0.20 for artificial flies, artificial lures, and worms, respectively. The higher values seemed more appropriate for several reasons. First, a greater variety of patterns and sizes of lures is used in a public fishery than was tested by Shetter and Allison, and lure pattern, with respect to type of hook, and lure sizes, with respect to size of hook, were shown to influence the rate of hooking deaths in other experiments (Wydoski 1980). Second, Shetter and Allison observed trout for only 24 hours after being hooked, but more recent experiments indicated that delayed mortality (death after 24 hours) was significant for many species of fish (Wydoski 1980). And finally, it is possible that the average fisherman is not as careful in handling and unhooking fish as Shetter and Allison's group of experimenters, and this difference in handling might cause hooking mortality to be higher than expected in a public fishery.

Results

Among the many fishery statistics that were produced by TROUT.DYNAMICS, two were chosen as the major indices of fishery performance, the catch of trophy-size trout (over 406 mm long) and the total harvest (or kill) in numbers of trout. Both of these products from a fishery are of great interest to anglers, and consequently, trout fisheries are often managed to maximize one or the other.

In general, the results showed an inverse relationship between the two, so it is obvious that both cannot be maximized at the same time. However, varying degrees of compromise can be achieved through regulations and the simulator helps to quantify the trade-offs involved.

A few other fishery statistics from the analysis were also recorded in this report--total number of fish caught and released for each regulation, and yields in weight of the fish harvested and of the fish caught and released.

Size limits

Total annual harvest

The relationship between total number of fish harvested and annual fishing mortality rate for the study fishery was derived for minimum size limits (Fig. 1), slot size limits (Fig. 2), and inverted size limits (Fig. 3). As expected from previous work (Clark et al. 1981), total number harvested decreased as minimum size limits increased (Fig. 1). This relationship was maintained over the entire range of fishing mortality rates.

Both location and width of the harvest slot, with respect to the length frequency of the population, affected the total harvest of trout under slot size limits (Fig. 2). For example, the 152- to 254-mm regulation had the same 102-mm width as the 203- to 305-mm regulation, but the former had a total harvest which was 30 to 40% greater, depending on the fishing rate. The reason for the difference was the location of the slot within the length-frequency range of the population. For any given period in time, a larger number of fish were between 152-254 mm than between 203-305 mm because of the population size structure.

Total number of fish harvested increased if the width of the harvest slot increased, even if the location of the slot remained constant. For example, the total harvest under the 203- to 305-mm regulation was 20 to 50% greater than the 203- to 254-mm regulation. The reason was the 51-mm greater width of the former regulation.

Under inverted size limits, the total harvest increased as the maximum size limit increased in simulations with fishing mortality rates of 0.50 or less (Fig. 3). However, for the highest fishing rate of 0.60, the 305-mm inverted limit showed a decrease in harvest which was below both the 254- and the 229-mm limit.

In general, a greater number of fish was harvested from the unrestricted fishery than from any of the size limit regulations for fishing rates of 0.50 or less (Figs. 1-3). Such a result suggests that if the management objective is to maximize the number of fish harvested from a brown trout fishery, then no size limit restrictions should be imposed. This would certainly be true for the Burton-to-Wakeley section of the Au Sable River, where the data for these simulations were collected because the fishing mortality rate there was only about 0.30 for brown trout (Clark et al. 1980). This is probably true also for any brown trout fishery with adequate recruitment under a flies-only gear restriction, because fishing mortality rarely exceeds 0.50 for brown trout under such rules.

Annual catch of trophy-size trout

The relationship between the number of trophy-size fish harvested and annual fishing mortality rate was derived for minimum size limits (Fig. 4) and slot size limits (Fig. 5). Also, the catch and release of trophy-size fish versus the annual fishing mortality rate was calculated for inverted size limits (Fig. 6). In each of these relationships, trout 406 mm or larger were counted as trophy-size fish.

As expected from previous work (Clark et al. 1981), the harvest of trophy fish increased as minimum size limits increased at a given fishing rate (Fig. 4). This relationship was maintained over the entire range of fishing mortality rates. The maximum harvest of trophy fish occurred at a fishing mortality rate of 0.20 for 178- and 203-mm minimum size limits, 0.30 for 229- and 254-mm minimum limits, and 0.40 for the 305-mm minimum limit (Fig. 4). Maximum harvests were also produced for slot size limits (Fig. 5) and maximum catches for inverted size limits (Fig. 6) at various rates of fishing for each individual regulation. However, when different regulations were compared at the same rate of fishing, the general result was that the regulations restricting total harvest the most were the ones which produced the greatest catches of trophy-size fish (Figs. 1-6). The greatest number of trophy fish were caught under the extreme case of catch-and-release regulations (Fig. 6) and the smallest number were caught under the other extreme of unrestricted fishing (Figs. 4 and 5). Therefore, if the objective of management is to maximize the catch of trophy-size trout, without regard as to whether they are harvested or not, then a catch-and-release regulation should be imposed.

An exception to this rule would be a case in which the catch-and-release regulation caused a significant decline in fishing pressure. Then the annual catch rate (m) may decrease enough to cause a decline in the annual catch of trophy fish. For example, the study fishery had an annual catch per hectare of 1.1 fish that were 406 mm or larger under a fishing rate of 0.50 and a 178-mm inverted size limit (Fig. 6). If a catch-and-release regulation was imposed on this fishery and the fishing rate dropped to below 0.40, then the annual catch of these larger fish would be 1.0 per hectare or less (Fig. 6). It is interesting to note, however, that the catch-and-release regulation produces a greater annual catch of trophy-size fish at the lowest fishing rate of 0.20 (Fig. 6) than any of the minimum size limits produce, even at higher fishing rates (Fig. 4).

Other fishery statistics

The number of fish caught and released increased as fishing rate increased for all size limit regulations (Tables 1-3). This was similar to the trend in numbers harvested at various fishing rates (Figs. 1-3). However, when regulations were compared at a single fishing rate, the number of trout caught and released from one regulation to another was inversely related to the number harvested. In general, when more fish were allocated to harvest by changing a size limit, then fewer were available for catch and release, and vice versa.

Trends in yield in weight (Tables 1-3) were qualitatively similar to trends in numbers caught (Figs. 1-3) for both harvest and catch and release of fish, except for slot size limits. The number harvested can be greater for one slot size limit than for another, while at the same time, yield is less for the former than the latter. For example, at a 0.30 fishing rate, the yield in weight of the 220 fish harvested with a 152- to 254-mm slot limit (Fig. 2) was only 17 kg (Table 2), whereas the weight of the 150 fish harvested under a 203- to 305-mm slot limit was 21 kg.

Considering all the size limit regulations tested, the one which produced the greatest yield in weight of fish harvested was the 178-mm minimum limit for fish rates of 0.40 or less, but for rates of 0.50 and 0.60 maximum weight of harvest was obtained with a 203-mm minimum limit (Tables 1-3). Maximum weight of fish caught and released was obtained with a 305-mm minimum limit at all fishing rates, except at 0.20 where the 178-mm inverted limit had a slightly higher yield.

The weight of the harvest from the unrestricted fishery was greater than any of the size limit regulations at the lowest fishing rate of 0.20 (Table 4), but it fell below the weight harvested for several of the size limit regulations at fishing rates greater than 0.30. Not surprisingly, the maximum weight of fish caught and released was obtained with catch-and-release regulations for all fishing rates tested.

Hooking mortality and gear restrictions

Obviously, as the value of $\underline{h}$ approaches unity, where every fish dies after being caught, whether released or not, differences between the effects of size limit regulations become negligible. All regulations would have the same impact on the population as the unrestricted fishery. Results of the catch-and-release simulations illustrated this point. As the value of $\underline{h}$ increased, both the total number caught (Fig. 7) and the number of trophy fish caught (Fig. 8) decreased until at $\underline{h}$ equal to 1.00, the catches under the catch-and-release regulations equaled the harvest under the unrestricted fishery (Figs. 1 and 4).

Hooking mortality had a greater impact on the catch of trophy fish (Fig. 8) than on the total catch (Fig. 7). For example, at a fishing rate of 0.60, the catch of trophy fish was reduced 39% from 1.74 to 1.07 per hectare when $\underline{h}$ increased from 0.05 to 0.20, but total catch declined only 3% from 832 to 807 per hectare. Intuitively, this result is not surprising. It is similar to saying that hooking mortality has a greater impact on fisheries with high minimum size limits than on ones with low minimum limits. Trophy fish in Figure 8 are defined in a similar way as total catch would be defined under a 406-mm minimum limit, and the total catch in Figure 7 is defined in a similar way as total catch would be defined under a 120-mm minimum limit (recall, it was assumed fish are not vulnerable to angling until they reach 120 mm in size).

Hooking mortality did not have a serious impact on total catch of trout until the portion of fish dying after catch and release exceeded 40% ($h = 0.40$) and the fishing rate exceeded 0.30 (Fig. 7). At a fishing rate of exactly 0.30, the total catch decreased only 13% from one extreme, 329 trout per hectare for h equal to 0.05, to the other extreme, 286 trout per hectare for h equal to 1.00. In contrast, even at the lowest fishing rate of 0.20 the catch of trophy fish decreased 55% from 0.49 per hectare to 0.22 per hectare over the same range of h values (Fig. 8).

When gear restrictions were considered under the hypothetical management scenario, it was no surprise to find that the most exploitative, any-lure regulations, provided the maximum total catch of 620 trout per hectare (Table 5). It was somewhat surprising, however, to find that artificials-only regulations provided the maximum catch of trophy-size fish at 1.01 per hectare. This result can easily be explained by examining the simulated data. The artificials-only restrictions reduced the number of trophy fish in the population below the level obtained under flies-only (2.85 versus 3.05 per hectare, respectively), but more of those fish were caught because of a higher catch rate (0.40 versus 0.30, respectively). The any-lure restriction reduced the number of trophy fish in the population to 2.06 per hectare which was below the point where its higher catch rate (0.50) could produce more trophy fish in the catch.

It seems unlikely that such small differences in the total catch of trophy fish could be detected in field studies. However, the individual angler is not aware of the total annual catch. He is only aware of his own catch and perhaps the catches of a limited number of other anglers. Obviously, if total catch of trophy fish remains relatively constant, as in Table 5, and fishing pressure decreases when gear restrictions are imposed, then the anglers remaining in the fishery may perceive an increase in catch per hour of trophies.

Discussion

The exact numerical results obtained in this analysis apply only to the brown trout fishery in the study section of the Au Sable River. But the ultimate purpose of the analysis was to identify general trends and principles which can be extended to other fisheries. Before making such extensions, however, it is important to note that their validity relies on the degree to which a real fishery adheres to the major modeling assumptions. The most critical assumption is that changes in fishing mortality will not cause major changes in growth or natural mortality, except in the first two years of life where natural mortality was assumed to be density dependent.

When a fishery deviates from the major assumption, as it would if growth or natural mortality was density dependent for older fish, the numbers attached to the curves in Figures 1 to 6 may change considerably. However, the qualitative nature of the trends, that is, the direction of change in the statistics from one extreme to another, is probably insensitive to fairly substantial deviations from the assumption.

For example, recruitment in the model was density dependent (Clark et al. 1980), and the density-dependent functions caused recruitment to stabilize at different levels under different regulations and fishing rates. Number of trout in age group 1 on October 1 of each year was a good index of recruitment in the simulator, because survival from birth to age 1 was controlled by density-dependent functions. Thereafter, survival was constant. The original size of the cohort at birth was related to the maturity, fecundity, and size structure of the parent stock (Clark et al. 1980). Over the range of regulations and fishing rates tested, the number of age 1 fish varied from 260 per hectare when $\underline{m}$ equaled 0.60 under a 305-mm inverted size limit to 518 per hectare when $\underline{m}$ equaled 0.40 under a 203-mm minimum limit.

If the same analysis was conducted under the assumption of constant recruitment, the numerical values in the results would have changed somewhat but the same major trends would have emerged. The main reason for this is that, while fishing clearly does have an impact on recruitment under the regulations and rates tested, the impact is not severe enough to alter the major trends in catch or yield.

Density-dependent recruitment appears to be the primary means by which trout populations control their total biomass in stream environments, while changes in growth and natural mortality of adults are relatively minor (Clark et al. 1980). Therefore, most trout stream fisheries do not seriously violate the major model assumption, and it is reasonable to assume that the general trends in this analysis apply almost universally to trout streams, as well as to other types of fisheries which conform to the assumption.

The general conclusion of this study concerning quality fishing regulations on trout streams may sound rather archaic to natural resource managers--either a large number of small fish or a small number of large fish can be produced by changing regulations. More specifically, the catch of trophy size fish, either harvested or released, is inversely related to the total harvest in numbers from a fishery. This should be true for most trout stream fisheries and was illustrated by the following general trends from the study: (1) the greatest number of trophy fish were caught under a catch-and-release fishery in which no harvest was permitted; (2) the greatest total harvest in numbers of fish was obtained, but the lowest number of trophy fish were caught in an unrestricted fishery; (3) for minimum size limits, harvest of trophy fish increased and total harvest of all fish decreased when size limits were increased from 178 mm to 305 mm; (4) for slot limits, harvest of trophy fish was greatest for limits which restricted total harvest the most; and (5) for inverted size limits, catch (and release) of trophy fish decreased and total harvest of all fish increased, for fishing rates of 0.50 or less, when the maximum size limit increased from 178 mm to 305 mm.

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Table 1.--Annual yield in weight harvested and catch-and-release statistics from study fishery regulated under minimum size limits.

Fishing mortality rate (m)	Annual yield harvested (kilograms per hectare)	Illegal trout caught and released: Number per hectare	Illegal trout caught and released: Kilograms per hectare
178-mm minimum limit			
0.20	18	88	3
0.30	26	148	5
0.40	31	211	7
0.50	33	270	8
0.60	32	314	10
203-mm minimum limit			
0.20	16	128	5
0.30	24	215	9
0.40	30	315	13
0.50	35	421	17
0.60	37	526	22
229-mm minimum limit			
0.20	13	161	9
0.30	20	268	14
0.40	26	396	21
0.50	32	543	29
0.60	36	709	37
254-mm minimum limit			
0.20	9	190	13
0.30	14	312	21
0.40	19	458	31
0.50	24	633	43
0.60	29	843	56
305-mm minimum limit			
0.20	3	217	19
0.30	5	348	31
0.40	7	501	44
0.50	9	682	59
0.60	11	904	78

Table 2.--Annual yield in weight harvested and catch-and-release statistics from study fishery regulated under slot size limits.

Fishing mortality rate (m)	Annual yield harvested (kilograms per hectare)	Illegal trout caught and released	
		Number per hectare	Kilograms per hectare
152- to 254-mm slot limit			
0.20	11	78	9
0.30	17	120	12
0.40	22	157	14
0.50	24	185	14
0.60	25	197	13
152- to 305-mm slot limit			
0.20	17	50	3
0.30	24	81	4
0.40	28	109	5
0.50	29	130	5
0.60	26	137	4
203- to 254-mm slot limit			
0.20	8	161	14
0.30	12	261	22
0.40	17	377	29
0.50	21	507	37
0.60	26	646	44
203- to 305-mm slot limit			
0.20	14	134	8
0.30	21	223	13
0.40	27	325	17
0.50	32	435	22
0.60	35	544	26
229- to 254-mm slot limit			
0.20	5	194	18
0.30	7	312	28
0.40	10	451	39
0.50	13	616	52
0.60	17	814	66
229- to 305-mm slot limit			
0.20	11	167	12
0.30	17	276	18
0.40	22	405	26
0.50	28	555	35
0.60	33	725	43

Table 3.--Annual yield in weight harvested and catch-and-release statistics from study fishery regulated under inverted size limits.

Fishing mortality rate ($\underline{m}$)	Annual yield harvested (kilograms per hectare)	Illegal trout caught and released: Number per hectare	Illegal trout caught and released: Kilograms per hectare
178-mm inverted limit			
0.20	2	165	20
0.30	3	257	30
0.40	5	356	41
0.50	6	461	53
0.60	8	570	63
203-mm inverted limit			
0.20	4	126	17
0.30	7	192	25
0.40	10	256	32
0.50	13	314	37
0.60	15	357	40
229-mm inverted limit			
0.20	8	92	13
0.30	12	137	18
0.40	15	176	22
0.50	19	204	23
0.60	20	215	22
254-mm inverted limit			
0.20	11	62	9
0.30	17	91	12
0.40	21	114	13
0.50	24	128	12
0.60	23	129	10
305-mm inverted limit			
0.20	17	34	3
0.30	23	53	4
0.40	27	69	4
0.50	27	80	3
0.60	24	80	3

Table 4.--Annual yield in weight harvested and catch-and-release statistics, from study populations under an unrestricted fishery and a catch-and-release fishery.

Fishing mortality rate ($\underline{m}$)	Annual yield harvested (kilograms per hectare)	Illegal trout caught and released	
		Number per hectare	Kilograms per hectare
Unrestricted fishery			
0.20	19	59	1
0.30	26	98	1
0.40	29	135	2
0.50	29	160	2
0.60	25	164	2
Catch-and-release fishery			
0.20	0	207	23
0.30	0	329	36
0.40	0	469	51
0.50	0	633	69
0.60	0	832	90

Table 5.--Comparison of three different types of gear restrictions on the study fishery.

Regulation[a]	Simulated values of: $\underline{m}$	$\underline{h}$	Number in population[b] All fish	Fish over 406 mm	Number in catch[c] All fish	Fish over 406 mm
Flies-only	0.30	0.05	2,030	3.05	330	0.76
Artificials-only	0.40	0.10	2,050	2.85	460	1.01
Any-lure	0.50	0.20	2,210	2.06	620	0.98

[a] Gear restrictions combined with catch-and-release regulations.

[b] Equilibrium population per hectare on October 1.

[c] Annual catch per hectare.

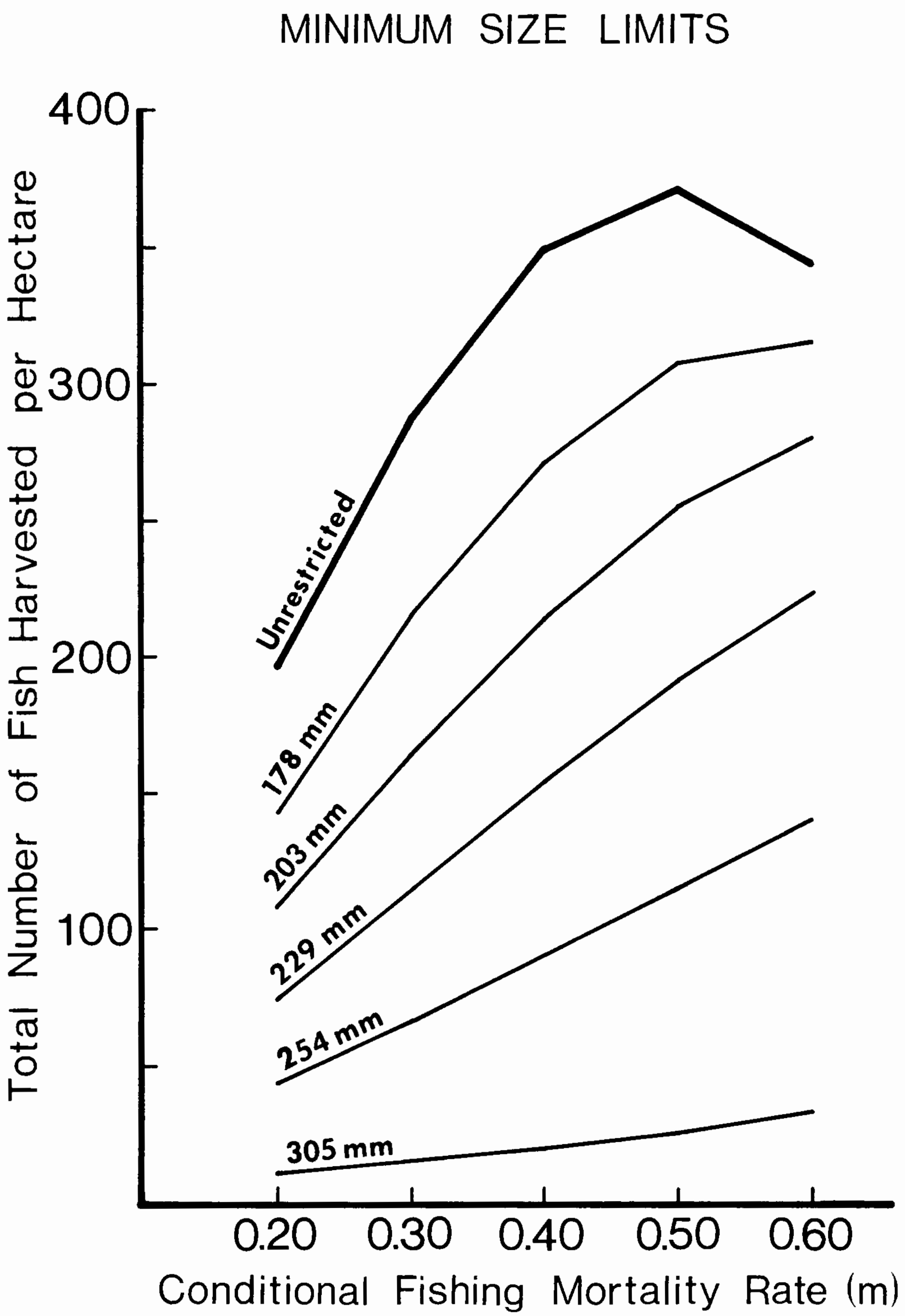

Figure 1.--The relationship between total number of fish harvested and annual fishing mortality rate for the study fishery regulated under minimum size limits. The heavy line represents the number harvested in an unrestricted fishery.

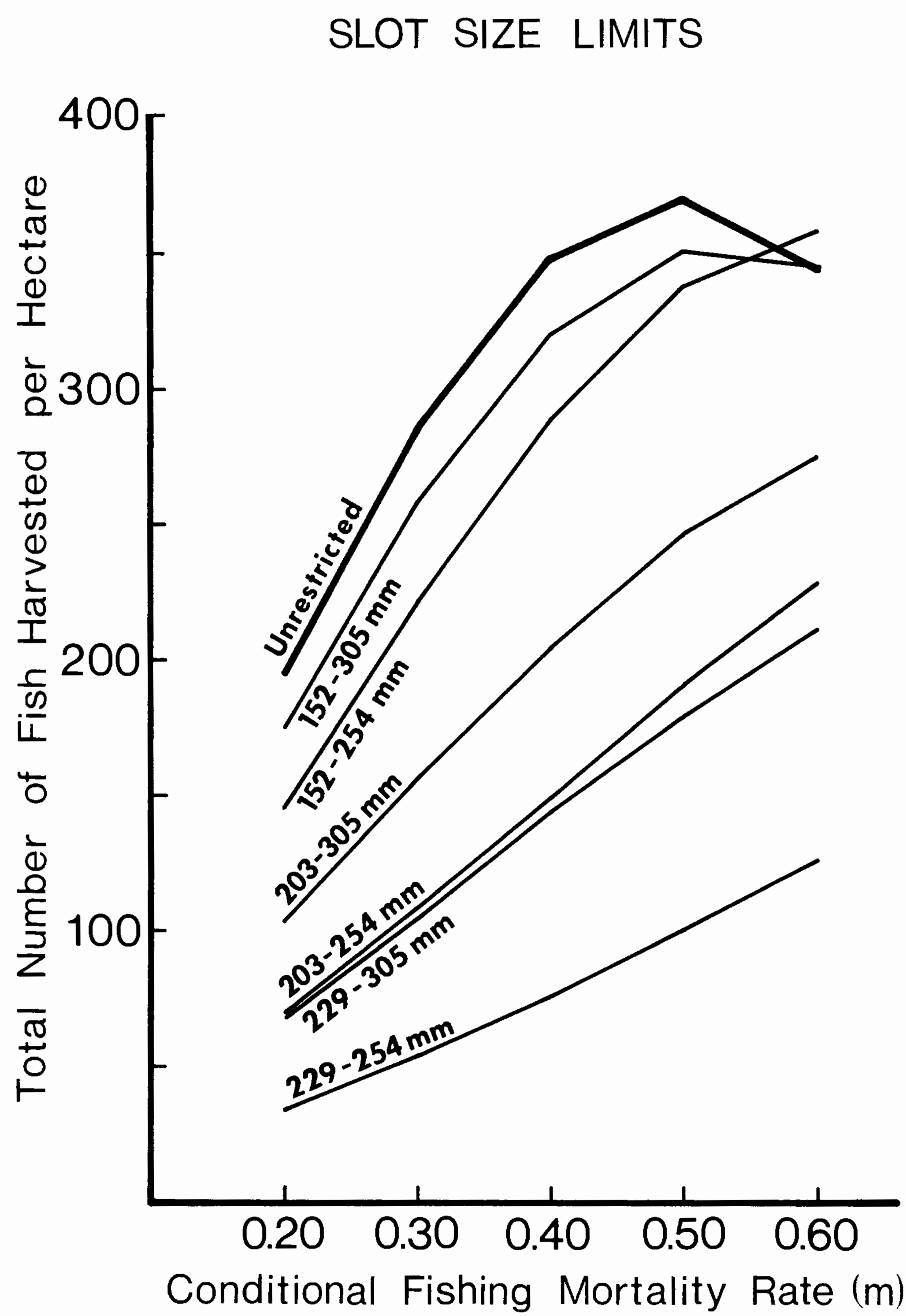

Figure 2.--The relationship between total number of fish harvested and annual fishing mortality rate for the study fishery regulated under slot size limits. The heavy line represents the number harvested in an unrestricted fishery.

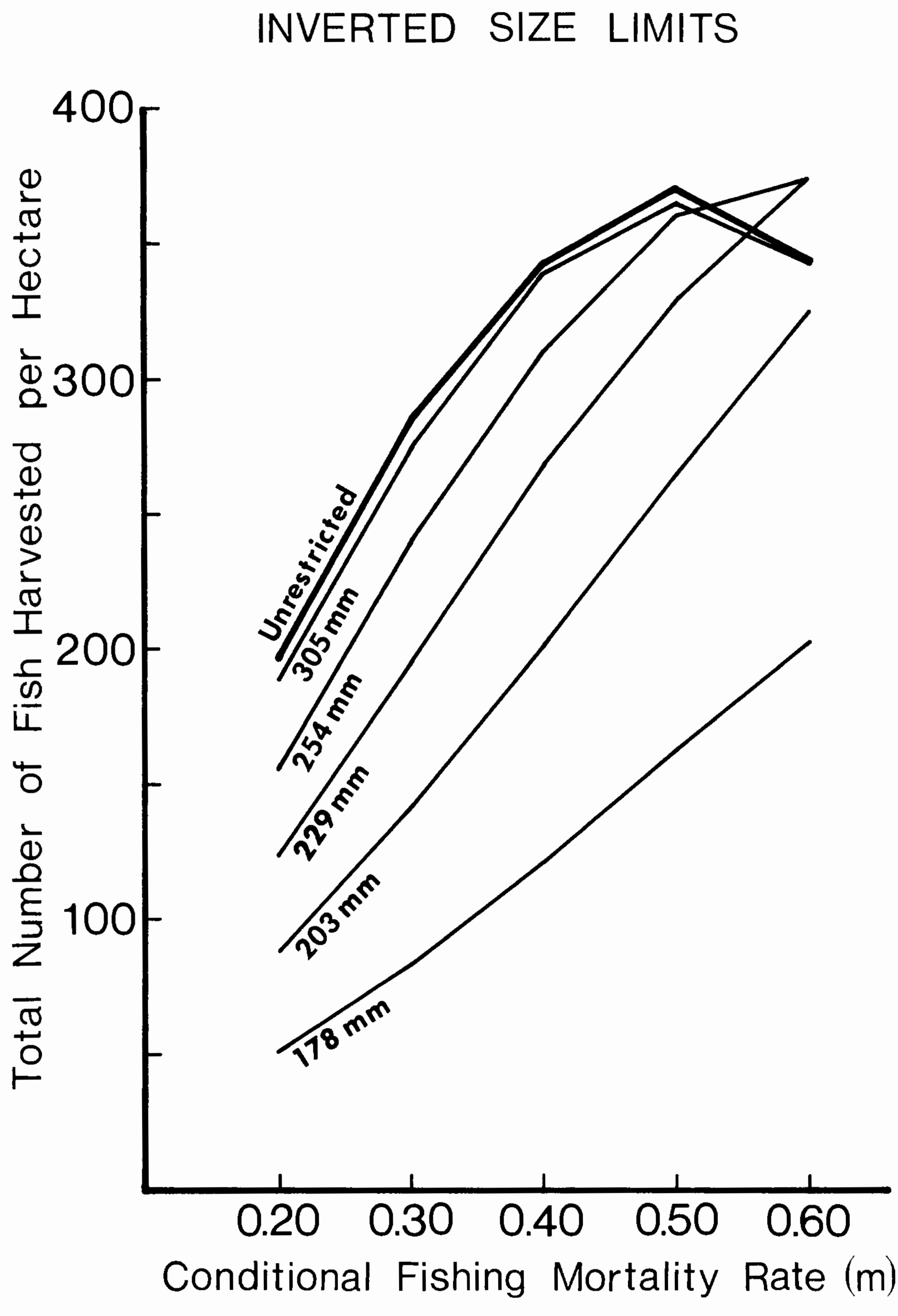

Figure 3.--The relationship between total number of fish harvested and annual fishing mortality rate for the study fishery regulated under inverted size limits. The heavy line represents the number harvested in an unrestricted fishery.

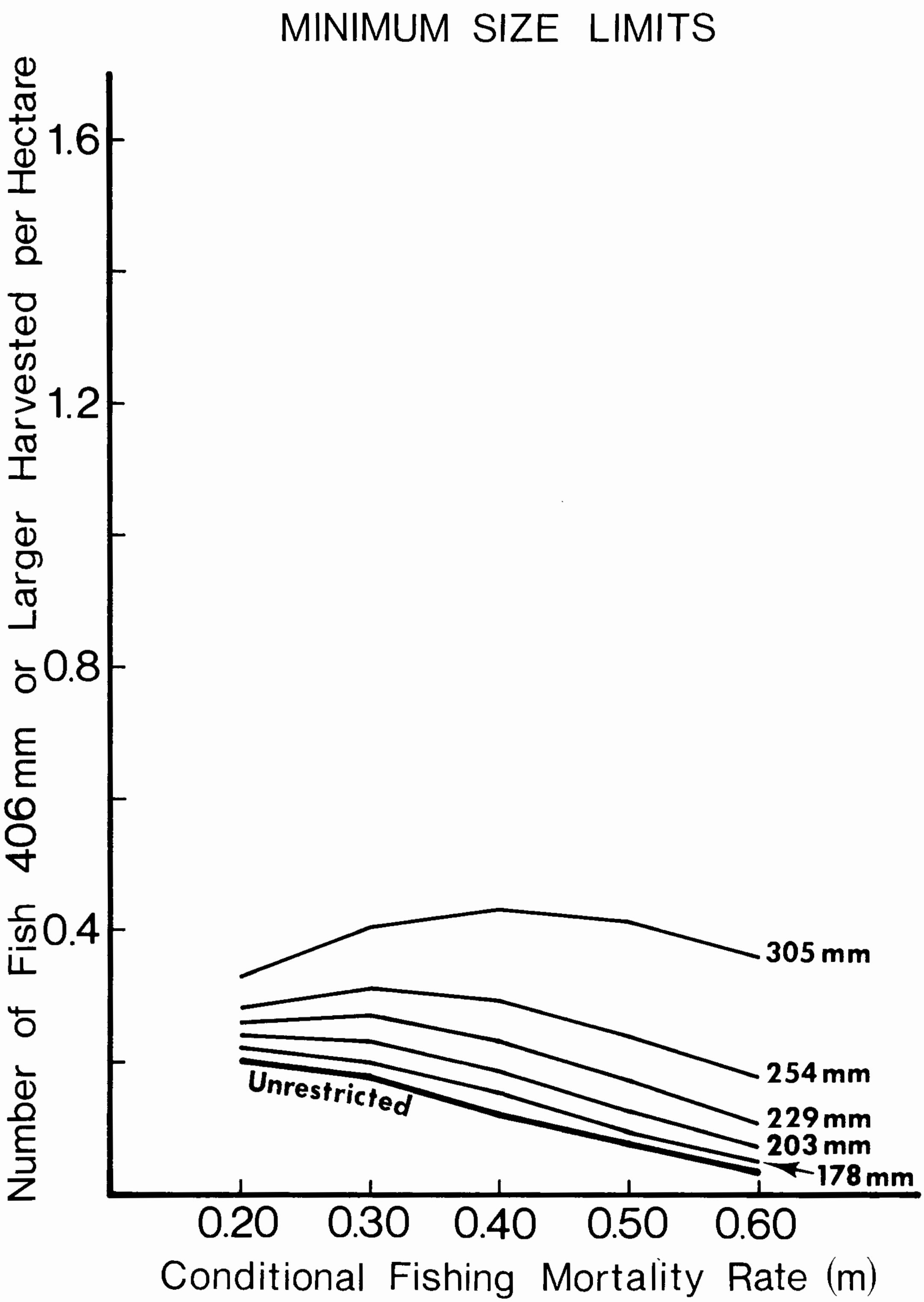

Figure 4.--The relationship between number of trophy-size fish harvested and annual fishing mortality rate for the study fishery regulated under minimum size limits. The heavy line represents the number of trophy-size fish harvested in an unrestricted fishery.

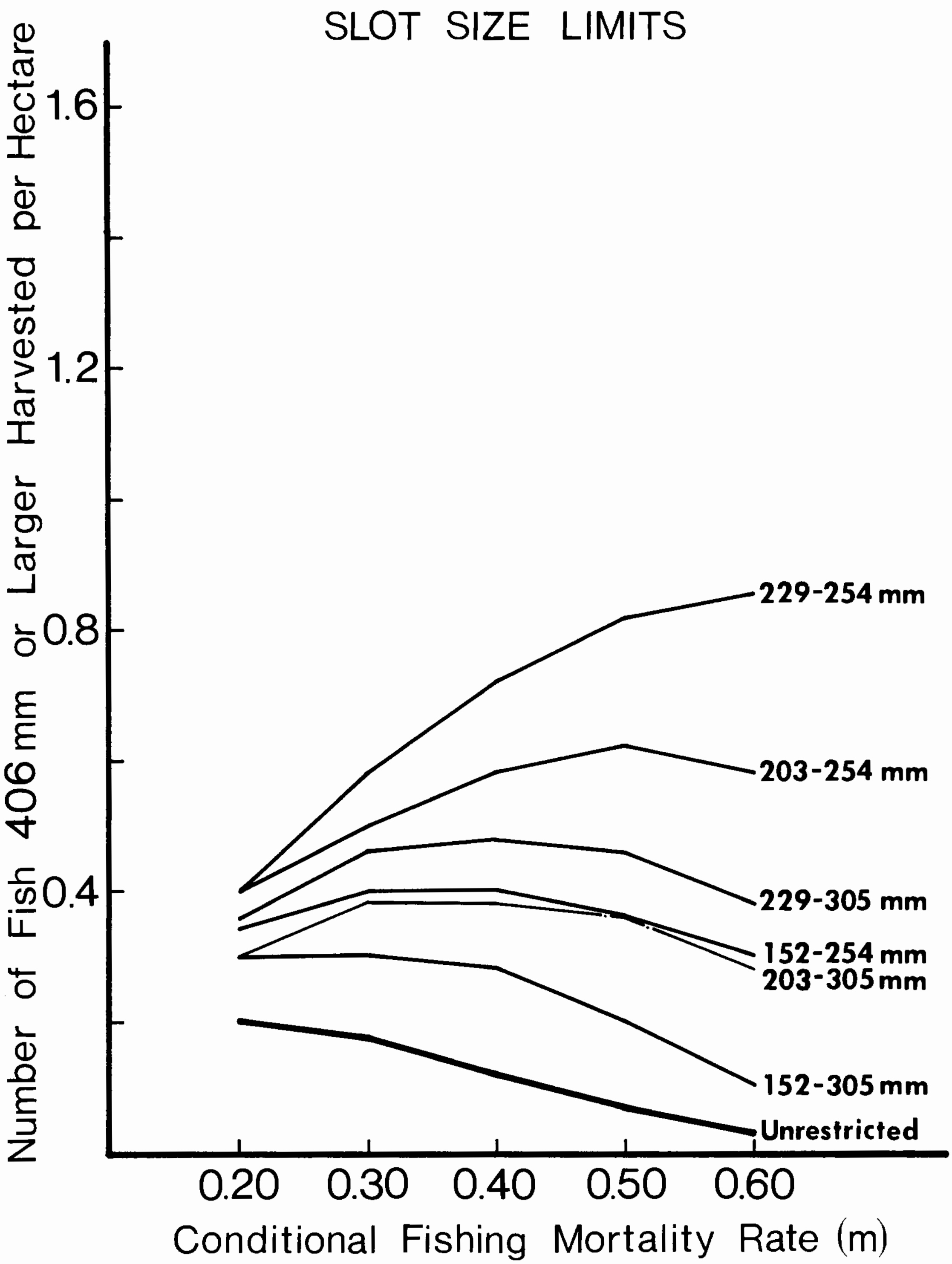

Figure 5.--The relationship between number of trophy-size fish harvested and annual fishing mortality rate for the study fishery regulated under slot size limits. The heavy line represents the number of trophy-size fish harvested in an unrestricted fishery.

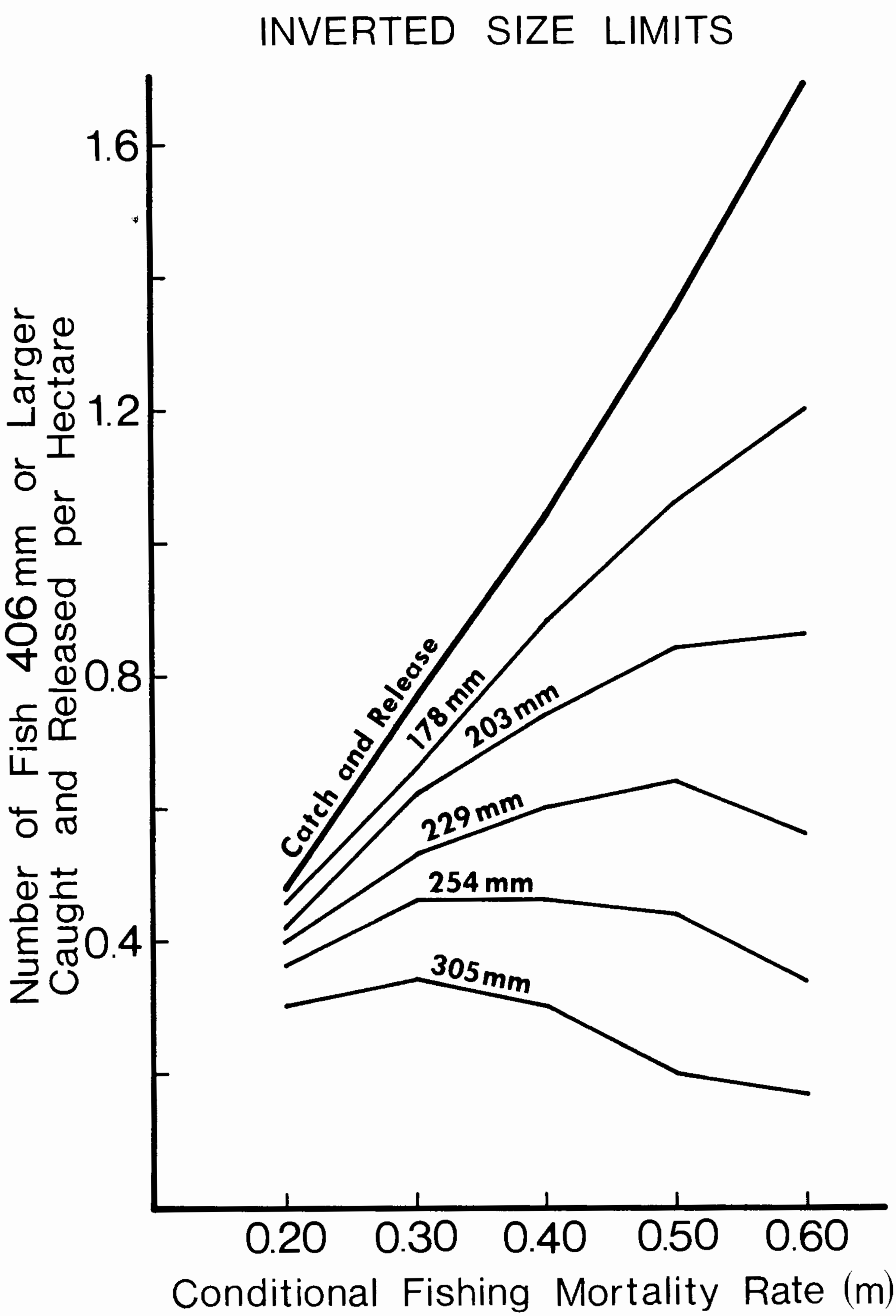

Figure 6.--The relationship between number of trophy-size fish caught and released and annual fishing mortality rate for the study fishery regulated under inverted size limits. The heavy line represents the number caught and released under flies-only, catch-and-release regulations.

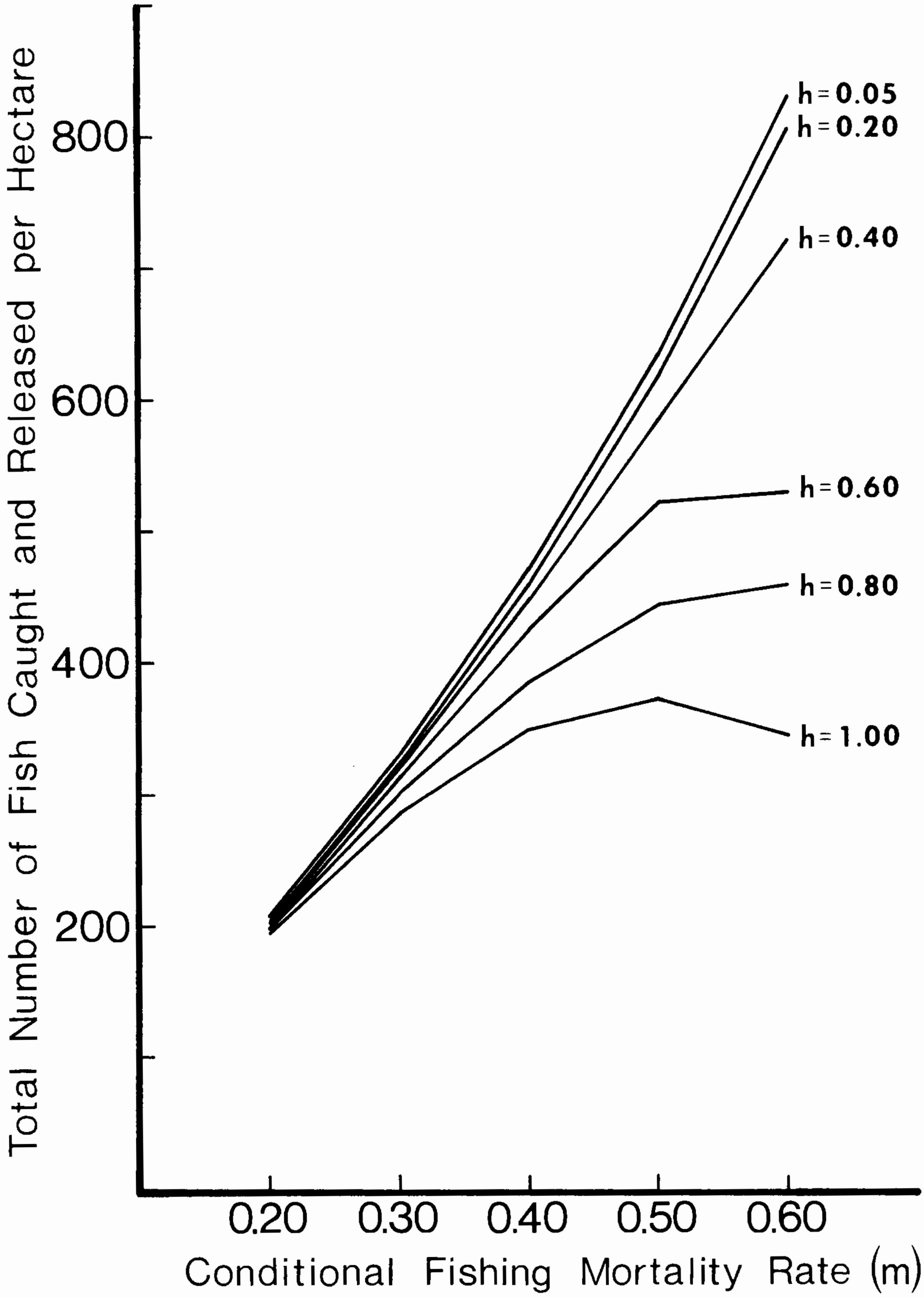

Figure 7.--The relationship between total catch and annual fishing mortality rate for catch-and-release regulations with different rates of hooking mortality. The value *h* is the probability a fish dies after being caught and released. Hooking mortality rate equals *mh* .

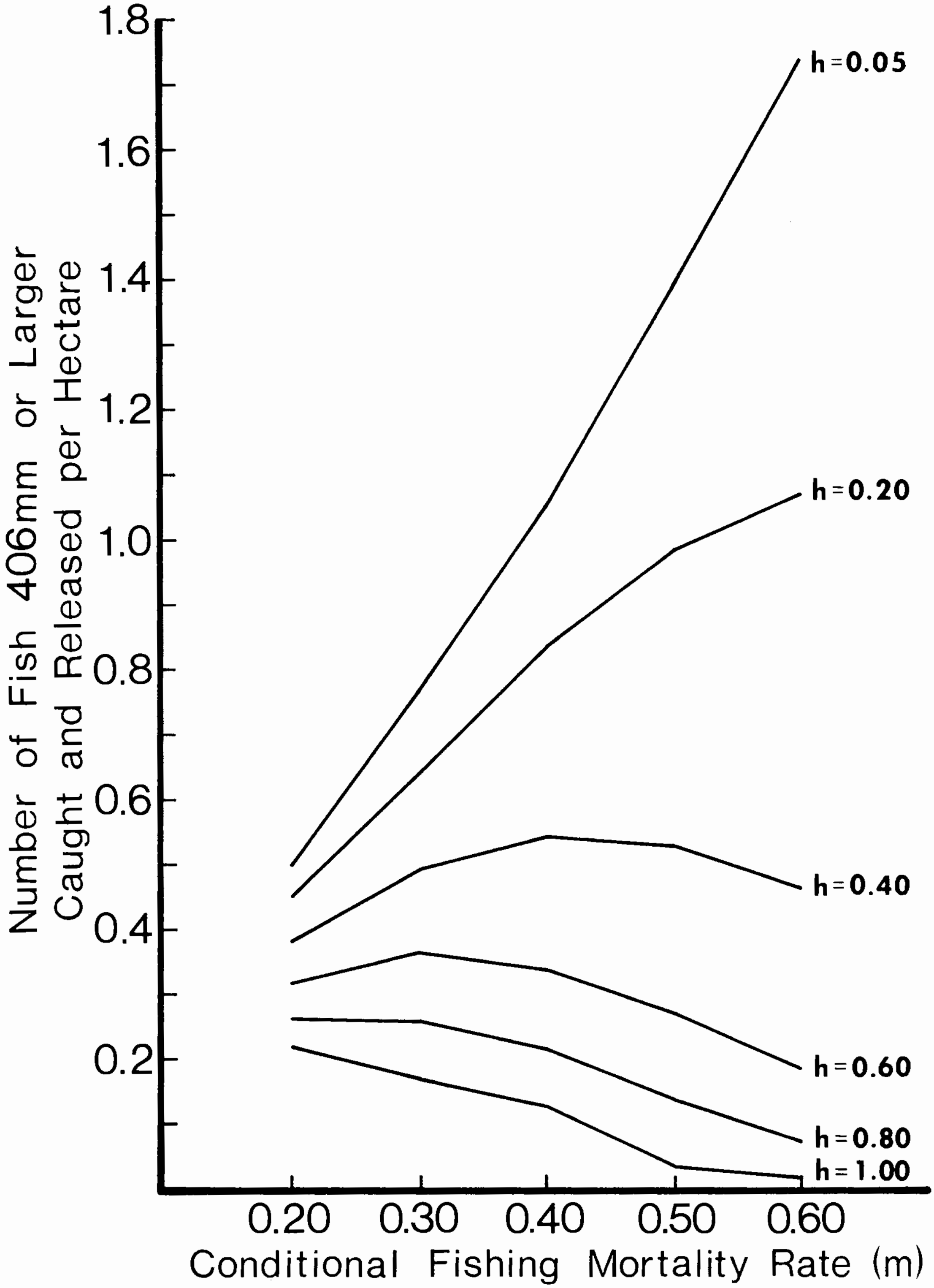

Figure 8.--The relationship between number of trophy-size fish caught and released and annual fishing mortality rate for catch-and-release regulations with different rates of hooking mortality. The value h is the probability a fish dies after being caught and released. Hooking mortality rate equals mh .

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Report approved by W. C. Latta

Typed by M. S. McClure