tamyia flava larvae. The remainder of the content was composed chiefly of immature Diptera, Odonata and Zygoptera, Hemiptera, and fish. Seventy-five percent of the total stomach content of the 33 freshwater drum examined was comprised of *Hexagenia* naiads. Immature Coleoptera and Odonata, snails, and fish constituted the bulk of the remaining 25 percent.

The stomach analyses show that, with respect to mayflies, the nuisance species are the same as those which are important as fish food in their immature stages. With regard to caddis flies, however, the problem species *(Cheumatopsyche campyla* and *Hydropsyche orris)* are apparently not significant as food organisms in the fish examined. In this case another caddis fly, *Potamyia flava*, closely related to *H. orris* and *C. campyla* both biologically and taxonomically, has little importance as a nuisance species because it does not enter cities or residential areas in large numbers but is relatively significant as a source of food for many of the fish, especially the shovelnose sturgeon.

ACKNOWLEDGMENTS

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Some Influences of Domestication upon Three Stocks of Brook Trout (*Salvelinus fontinalis* Mitchill)

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ABSTRACT

Three stocks of brook trout—domestic, wild, and first generation removed from wild stock—were tested and observed for effects of domestication. The domestic stock had been selectively bred for 90 years, whereas the wild stock came from an isolated lake in the Adirondack Mountains. To reduce differential environmental influence to a minimum, the three lots were reared from eggs in adjacent rearing troughs at the same water temperature. After 1 year under these hatchery conditions the domestic fish were 5.2 inches in length and the wild, 3.6 inches. Throughout the rearing domestic stock were tamer and exhibited less fright than wild-stock fish. Laboratory tests showed that wild stock could stand a greater concentration of accumulated metabolites, that they could endure higher water temperature, and that domestic stock had a surface response whereby they moved to the surface of a rearing trough or a tall aquarium. Domestic fish also lacked the desire to conceal themselves. Stamina tests conducted by swimming 1,522 fish individually until exhausted in a small trough showed that the wild stock had greater stamina throughout the size range tested. Survival trials in a small stream and a pond indicated that wild fish experienced less mortality and had growth rate similar to or better than domestic fish in both habitats. After 73 days in the small stream 20 percent of the domestic and 33 percent of the wild stock survived. Domestic fish grew 0.34 inches and wild fish, 0.48 inches. Survival was 43 percent for the domestic and 65 percent for the wild after 108 days in a pond, while length increase was 2.6 inches for the domestic and 2.5 inches for the wild stock. The domestic increased more in weight. After being in a pond for nearly 4 months, the domestic stock had acquired little wariness.

INTRODUCTION

One of the first books on trout culture, *Domesticated Trout*, was written by Livingston Stone in 1873, and indeed it was a portent of impending events. To a limited extent the implications of the title were conceived by Stone for he wrote:

> The time may come when continued domestication, together with the overcoming of their [fish's] fear of man, will so modify the present action of their instincts, that, when pains are taken with domesticated trout, they will *prefer* to seek the shelter and food which they find around the homes of men to the precarious chances of a wild roaming life. This may not be probable, but I do not think it is impossible.

It is now apparent that with the existing mass culture and widespread selective breeding programs, hatchery trout cannot avoid diverging from their wild ancestors.

Influence of fish culture on trout is manifest in two ways: genetical and environmental. Selective breeding has received most attention from fish-culturists, while fisheries biologists have been more interested in the environmental effect.

Unintentional selective breeding takes place in all hatcheries. Fish that are easier to handle, that appeal to the fish-culturist as having a "nice shape," or that grow better under hatchery conditions are unconsciously favored.

Intentional breeding programs have been conducted for many years. The most common selected characteristics have been faster growth, earlier maturity, greater egg production, earlier spawning, and disease resistance. From this list it seems that evident features of selective breeding are a benefit to the fish-culturist but of unknown "value" to the fish. Many breeding programs have been eminently successful in the desired intentions. However, for self-sustaining populations, fish free from selective breeding or bred for maximum survival under natural conditions may prove more desirable.

Hatchery environment can influence fish in many ways as noted by Schuck (1948). The effect of hatchery rearing upon survival in natural waters was investigated by Needham

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and Slater (1944), Needham (1949), Eipper (1953), Wales (1954), Nielson *et al.* (1957), Smith (1957), Miller (1958), and others. In addition, the importance of hatchery environment is demonstrated by higher survival of fish which are conditioned to stream habitat prior to stocking (Schuck and Kingsbury, 1948; Miller, 1957).

As expressed in the preceding paragraph, the effects of the environment upon trout have been investigated but the effects of genetical changes fostered by domestication upon behavior and survival have seldom been explored. Green (1952) stocked Stillwater Pond, New York, experimentally with wild- and domestic-stock brook trout. He found higher survival the second and third year for wild stock, as well as differences in body shape, color, and wildness. Webster (1954) also found indications of different survival of wild and domestic stocks.

The objectives of the research presented in this paper are (1) to discover some of the areas in which physiology and behavior differ between a domesticated and a wild stock of fish when environmental variation is reduced to a minimum, and (2) to see if these dissimilarities influence survival in a harsh and in a mitigated natural environment. The former was determined by laboratory experiments and the latter by limited field trials.

TEST FISH

To accomplish these objectives it was necessary to acquire a domesticated stock of trout, a wild stock, and preferably a third stock as a control. Furthermore, these trout had to be reared under similar conditions in the same hatchery.

Stocks of fish

For a domestic strain a stock of brook trout was secured that had been reared in hatcheries for approximately 90 years. The selection program in early years had been to save "the best" of the 2-year-olds each year for brood stock. Later, emphasis was placed on selection for earlier spawning, and after 20 years the spawning date was advanced by 15 days. Other characteristics stressed in selection were faster growth, better shape, and disease resistance.

Honnedaga Lake, located in the southeastern Adirondack Mountains of New York State, was the source of wild fish. The following information concerning Honnedaga Lake was given by Webster (1951, 1957). The lake has a total alkalinity of less than 2 p.p.m. and a pH about 5. These conditions are unusual for a lake of about 800 acres in this region. Surface temperature rarely reaches 70° F. Brook trout are the only native fish, but several other species were temporarily established by the 1920's only to disappear later. A few lake trout *(Salvelinus namaycush)* possibly still remain as a relic population. It is likely that the peculiar environmental conditions of the lake are lethal to most introduced fish within a short time. This would be conducive to a strong inbred selection among the native trout, tending to keep the race genetically pure.

The Honnedaga brook trout are tentatively described as being slow-maturing and long-lived; 2- to 6-year-old fish are not unusual. Two- to three-pound fish are common in the spawning population.

The third lot of fish came from hatchery-stock brook trout that had spent 1 year in a lake (Long Pond near Brandon, New York) immediately previous to spawning. Originally the stock came from several commercial hatcheries in Pennsylvania and New England. This first-generation stock acted as a reference lot although it was of unknown genetic origin.

Throughout the remainder of this paper the three strains of test fish will be referred to as domestic, first generation, and wild.

Hatchery procedure

All three lots of fish were trough-reared in the Cornell University Experimental Fish Hatchery. Lots were interchanged each 2 weeks among three adjacent troughs. This reduced possible differential influences of light, accumulated waste products, and fright from human interference. Water temperature was nearly uniform among the troughs, usually within 1° and never varying more than 2° F. All fish were fed the regular diet used in the hatchery: liver when small and, as they grew larger, a mixture of 40 percent liver and 60 percent Cortland No. 6 meal. Fish used in experiments were not fed the 24 hours before a test.

All length measurements are fork lengths recorded to the nearest tenth of an inch (with

one noted exception). Weights are recorded in pounds and tenths of pounds.

Fish used in laboratory tests were given a temporary mark by clipping the dorsal or ventral lobe of the caudal fin. Ventral and pectoral fin clips are designated by V and P.

Development, growth, and mortality in hatchery

Egg diameter was 0.173 inches for the domestic, 0.165 inches for the first generation, and 0.189 inches for the wild stock. Development chronologically was similar in all three lots, with the majority of the fish hatching within a 2-week period. The domestic stock was more advanced until approximately January 1 when the other two lots were placed in warmer (50° F.) water which helped to equalize development. One possible source of differential influence was the rearing of domestic stock until the advanced-eyed stage in a different hatchery and at slightly higher water temperatures. Since it would be nearly impossible to find three widely different stocks of brook trout that spawn at the same time, temperature manipulation during early development was used to equalize the time of hatching.

Growth in length of fish of the three stocks was similar the first 80 days, after which divergence increased (Figure 1). An important factor relative to growth in the hatchery is the phlegmatic behavior of the domestic trout and the excitable nature of the wild trout. Fry of all three stocks showed little sign of fright until they were nearly an inch long and were feeding well. Then for a month (February 28 to April 3) all could be frightened easily. By April 22 the domestic and first generation fish were calmer. Throughout the remainder of the summer the wild fish were more easily frightened by human presence, a shadow, or a hand placed in the water. The domestic fish were docile and when a finger was placed in the water they often nipped it, giving the impression they were "at home" in the hatchery trough (Figure 2).

Condition factors from measurements taken on November 15, when the domestic fish were 5.19 inches and the wild 3.65 inches, were 54.05 for the former and 38.58 for the latter. Casual inspection clearly showed that the wild trout were slimmer.

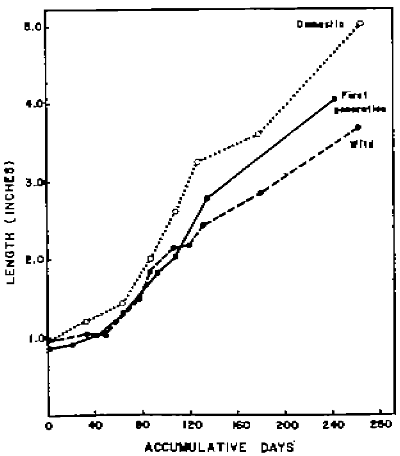

FIGURE 1.—Growth of three stocks of brook trout in Cornell University Experimental Fish Hatchery.

FIGURE 2.—Domestic fish (above) were not frightened by placing a hand in the trough; wild fish (below) show avoiding reaction.

Mortality was heavy in all three lots. From egg take to approximately 1 year, it was 93 percent for the domestic, 62 percent for the first generation, and 64 percent for the wild. The poor quality of the Cornell University Hatchery water supply attributed to much of this high mortality. Early mortality may be important because of the possible selection to which the remaining individuals have been subjected. A population which has suffered heavy mortality may be composed of hardier individuals than a population that has experienced low mortality. Wales (1954) discussed Pacific salmon as having 90 percent mortality in wild populations, but pampered hatchery fish as having a much lower death rate until stocked after which an equalization mortality occurred. In the present situation selective early mortality would tend to favor fish of the domestic stock for they had a higher rate than either the other two.

LABORATORY EXPERIMENTS

Effects of metabolites

Five trials were conducted to determine the comparative mortality caused by high metabolite concentration. Test containers were a series of 1,000-milliliter beakers nearly submerged in running water. Each beaker was aerated by oxygen. An equal number of fish from each lot was put in the same beaker. Fish length was 1.7 inches in Trials I to III and 2.9 inches in Trials IV and V. When approximately 50 percent of the fish in a beaker had died, all fish were removed and counted. Two to three hours were required to reach this mortality level.

The data from these trials (Table 1) indicate a wide difference in the ability of fish of the three lots to withstand accumulated metabolic wastes. Approximately 51 percent of the domestic, 50 percent of the first generation, and 20 percent of the wild fish died.

The obvious factor to which this differential susceptibility might be attributed is general hardiness or well-being of the fish. The relationship between head size and efficiency of elimination of body waste was not realized at the time the tests were conducted. Later, several papers stimulated further investigation. Graham (1956), while working on fresh-water alewives *(Alosa pseudoharengus)*, suggested that since osmotic exchange takes place through the gills and oral membranes the large-headed individuals have an advantage in osmotic regulation. Keys (1931) found that large-headed killifish *(Fundulus parvipinnis)* could withstand adverse conditions such as decreased salinity or oxygen deficiency better than small-headed individuals. A small head is characteristic of many faster-growing fish (Martin, 1949; Tester, 1937).

Although the fish tested could not be measured, two other groups were available: yearlings from the same lots and fingerlings similar in length to the test fish of a later year class from the same two stocks. Fifteen domestic fingerlings and yearling fish from the two lots were 1.6 and 6.3 inches in mean length; 15 wild fingerlings and yearling fish were 1.7 and 4.0 inches in mean length. The following six measurements were taken:

- Fork length—tip of snout to caudal fork.
- Body width—at widest part of body.
- Body depth—at deepest part of body.
- Head length—tip of snout to posterior margin of opercular membrane.
- Head width—distance between normally appressed preopercles.
- Head depth—distance on a vertical line immediately posterior to the eye.

All measurements were made with calipers to the nearest tenth of a millimeter.

TABLE 1.—*The mortality of three groups of confined brook trout in response to accumulated metabolic wastes*

Trial number	Water temperature (degrees F.)	Stock of fish					
		Domestic[1]		First generation		Wild	
		Number	Mortality	Number	Mortality	Number	Mortality
I	52	20	11	—	—	20	4
II	51	40	18	40	22	40	7
III	52	20	10	20	8	20	3
IV	58	7	4	—	—	7	3
V	56	7	5	—	—	7	2
Total		94	48	60	30	94	19
Percentage		—	51	—	50	—	20

[1]Chi-square (domestic and wild) = 12.56, P < 0.01.

TABLE 2.—*Maximum temperature tolerance of three lots of brook trout when temperature was raised to maximum (80° F.) in 5 hours*

Trial number	Water temperature (degrees F.)	Stock of fish					
		Domestic[1]		First generation		Wild	
		Number	Mortality	Number	Mortality	Number	Mortality
I	62	10	10	10	6	10	0
II	64	20	10	20	4	20	4
III	60	20	15	20	11	20	4
IV	58	15	10	15	6	15	8
Total		65	45	65	27	65	16
Percentage		—	69	—	42	—	25

[1]Chi-square (domestic and wild) = 15.76, P < 0.01.

The three body measurements for each fish were added and the same was done to the head measurements. To compute a head-to-body ratio the sum of the three head measurements was divided into the sum of the three body measurements. The mean head-to-body ratios were:

	Domestic	Wild
Fingerlings	2.661 ± 0.060	2.589 ± 0.031
Yearlings	2.880 ± 0.139	2.676 ± 0.090

Both of these groups have a head-to-body size ratio that is different at the .05 level as measured by a rank-sum test. This agrees with the above references in that the faster-growing individuals in these two stocks of brook trout had smaller heads. Thus, the wild stock had a greater area over which to regulate osmotic balance.

High temperature tolerance

Extreme temperatures have been reported (Huntsman, 1942, 1946; Gunter, 1947) as the cause of fish mortality in natural situations. Ultimate lethal temperatures become important when marginal waters are utilized for trout. This is especially true if high water temperatures restrict over-summer survival. When some brook trout required 7 days to die at 79.7 to 83.3° F., Embody (1921) thought that perhaps all strains of brook trout might not be able to stand these high water temperatures.

Temporarily-marked test fish, 1.9 inches long, were placed in a 20-gallon glass aquarium. Water temperature was raised to 80° F. (the chosen maximum temperature) in 5 hours by running a stream of temperature-controlled water into the aquarium. As soon as motility was completely lost, a fish was considered dead. The intent was to terminate the test at 50 percent mortality, but due to periodic checks it was not always possible to stop the test at the prescribed time so a greater mortality occurred in some instances. Table 2 shows that the wild stock had less mortality than either of the others.

Domestic brook trout reared on a hatchery diet have a higher fat content than wild brook trout from natural waters. Not only is the fat content higher but it is more saturated (Phillips *et al.*, 1955). To continue the relation of fat to lethal temperatures one step further, resistance to temperature extremes may be changed by feeding different fats to goldfish (Hoar and Cottle, 1952). This was true even though the fish appeared to be in excellent condition. As will be shown later in this paper, wild fish utilize a hatchery diet differently than domestic fish; the amount and type of fat present could be one factor that reduces the temperature tolerance of domestic trout.

Surface response

A noticeable difference during the rearing was that fish of the wild stock had a tendency to remain near the bottom of their trough while domestic fish were spread vertically throughout the water. This was true even when the groups were undisturbed.

To investigate this surface response the following test was used. Test fish were placed in a tall glass tank measuring 36 by 6 by 4 inches: water was homothermous and light was of even intensity. During some tests a glass plate covered the open top of the tank, but in other tests it was removed. Reactions of the fish were the same either way (Figure 3). Fish used in Trials I to V were 1.6 inches long; those in Trials VI and VII, 2.8 inches. Five marked fish from each lot (a total of 15) were placed in the tank and a count of the top five was taken every 10 minutes until the end of the test. In two tests only the wild and domestic fish were used. All three stocks were used in the other five. In each of the seven trials more domestic fish were counted near the surface than wild ones (Table 3). Twice as many domestic (50 percent) as wild (26 percent) were counted in the top five fish. First-generation fish behaved much like the domestic.

The main hydrostatic organ is the air bladder which equalizes density of the fish with that of the environment. In many bottom-dwelling forms the air bladder is reduced, and in intertidal species, often absent; it is best developed in limnetic or pelagic forms (Jones, 1957). Jones also attributed the

FIGURE 3.—Surface response of two lots of brook trout in a tall aquarium. Domestic fish are near top; wild fish near bottom.

TABLE 3.—*A summary of the surface response of three lots of brook trout in a tall aquarium*

Item	Stock of fish		
	Domestic[2]	First generation	Wild
Number of fish per trial	5	5	5
Number of trials	7	4	7
Total observations	35	28	35
Total possible observations[1]	175	140	175
Total fish in top 5 counts	88	51	45
Percentage of fish in top 5	50	36	26

[1]Number of fish per trial × total observations.
[2]Chi-square (domestic and wild) = 14.36, $P < 0.01$.

movement of gas in and out of the air bladder to stimuli caused by exteroceptors. Could domestic trout that have spent many generations in shallow raceways and rearing ponds have been selectively adapted to this low-pressure artificial environment, or could the exteroceptors through lack of use have been dulled? Threinen (1958) mentioned this same point in relation to planting hatchery rainbow trout in lakes. He found that if the fish were liberated 20 feet below the surface they immediately came to the top. Also, when stocking in ponds containing a warm epilimnion, 15 feet was as deep as the fish would dive before returning to the surface. Heavy mortality frequently resulted if the thermocline was below 15 feet.

Concealment

A small glass aquarium containing several rocks was used to test hiding reaction. Regardless of how many times the test was repeated, domestic fish made no pretense at hiding but remained fully exposed. Wild fish would immediately seek concealment, rarely venturing into the open.

Stamina

Schuck (1948) listed lack of exercise for hatchery fish as a cause of mortality. Black (1957), in his lactic acid work, wrote that muscular fatigue reduces maximum swimming speed, breaks up schooling behavior, and changes fish behavior from escape to hiding. Exercised coho salmon *(Oncorhynchus kisutch)* showed less susceptibility to fatigue and an increased cruising speed compared to fish that were raised in hatchery troughs (Brett *et al.*, 1958). Hatchery cutthroat trout *(Salmo clarki)* reared in a stream before stocking in a test stream area had better survival than fish reared in a pond (Miller, 1954).

Vibert (1956) used the ability of fish to maintain themselves in a strong current as one of his tests for hardiness. He utilized this test to determine the influence of hatching eggs by the usual hatchery procedure as opposed to hatching them under a layer of gravel. This method could be used, he suggested, as a test of other hatchery practices. In California Reimers (1956) used a 20-foot metal hatchery trough and a controlled current of 0.5 to 3.0 feet per second to test fish stamina. He found that hatchery-raised rainbow trout *(Salmo gairdneri)* were the weakest, stream-conditioned rainbow trout next, wild brown trout *(Salmo trutta)* the strongest.

A small, galvanized metal trough 43 inches long, 2.5 inches wide, and 3 inches deep was used as the testing apparatus (Figure 4).

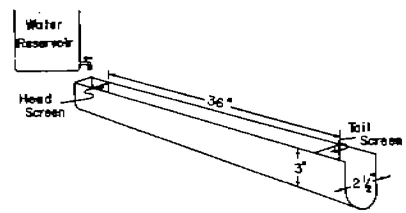

FIGURE 4.—Testing trough used for stamina trials.

It had a rounded bottom to reduce slow current areas. A ¼-inch-mesh, fine wire screen was placed near the lower end and another was placed 5 inches below the water source. These two screens confined the fish into a 3-foot section of fairly uniform and laminar water flow. Water was pumped with a small electric pump out of the rearing trough containing fish to be tested and into a small reservoir. A constant head was maintained by keeping this reservoir full; a small valve regulated flow into the testing trough. The slope of the testing trough could be changed by ⅛-inch adjustments on either end. Water velocity in the several tests varied between 0.3 and 3.0 feet per second.

Extreme care was taken to see that fish of each size range from each group were tested under the same water conditions. Throughout the testing, water temperature in the testing trough and in the rearing trough were the same for any one test.

It was impossible to maintain the same water flow and water velocity throughout the test series. Fish length increased from less than an inch to over 3 inches during the tests. Sufficient water volume and velocity for testing the larger fish would have overwhelmed the smaller. A swimming time of at least 30 seconds and preferably 45 seconds was desired to reduce inaccuracies in timing. On the other hand, too long a swimming time (over 10 minutes) was undesirable because of the time involved and the possibility of other influencing factors aside from stamina. Water volume was increased 1.8 times when fish length was 2.2 inches to provide the larger fish with sufficient water.

This experiment was designed to test differences in stamina among the three lots of fish, not to measure the increase in stamina as fish grew. Temperature fluctuated during the test series, but all lots were tested throughout the temperature range. Restrictions imposed upon the larger fish by the confines of the trough could limit swimming efficiency.

Approximately 50 fish for each test were taken from near the head of the rearing trough and placed in a basket immediately below the testing trough. Individual fish were taken from the basket and placed in the testing trough. As the small net used for the transfer was put in the testing trough, it made a backwater which allowed the fish to orient itself to the current. When the fish was facing the head of the trough (usually within 1 or 2 seconds), the net was removed and an assistant started a stop watch. Occasionally a light touch with a glass rod was needed to keep the fish swimming.

Behavior of fish within the testing trough usually followed a standard pattern. Orienta-

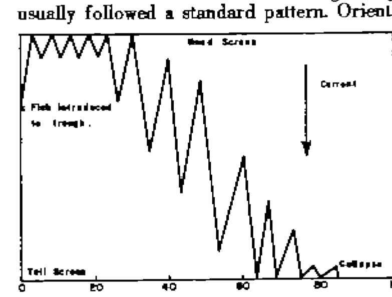

FIGURE 5.—Schematic presentation of fish movement in testing trough. Fish length, 1.5 inches.

tion to the current was immediate except in a few cases where the fish swam to the tail screen. These individuals were removed and excluded from the test. Fry and Hart (1948), in quoting Roger's unpublished work on goldfish, stated that 6 out of 82 goldfish refused to swim so were discarded, while Brett *et al.* (1958) had to remove one tenth of their test fish because of inconsistent behavior.

Vigorous swimming followed orientation with fish butting their noses against the head screen. Then followed a series of downcurrent drifts and swimmings back to the head screen (Figure 5). The drifts lengthened each time until, when at approximately the midway point in the trough, the upstream burst of swimming was not long enough to carry the fish to the head screen. As fatigue increased, body movements became exaggerated. The first time or two the fish's caudal fin touched the tail screen there was vigorous response and upstream progress was often past the midway point. Soon tactile response lessened, and frequently collapse was sudden and complete with the fish making no attempt to resist the current; they were then held crosswise against the screen. (Both the quick collapse and reduced tactile response were noticed by Brett *et al.* (1958) in their work on sockeye and coho salmon.) If the exhausted fish did not respond to two taps with a glass rod on the tail screen, the test was concluded.

After removal from the testing trough, the fish were allowed to recuperate overnight in a basket. Then each was measured and returned to its rearing trough.

Deviations from mean swimming time were fairly wide. Figure 6 illustrates these deviations and shows the increased spread as the fish become larger. A different design of testing trough might produce more constant results. Radcliffe (1950) in his work on effect of fin-clipping and cruising speed also had wide standard deviations.

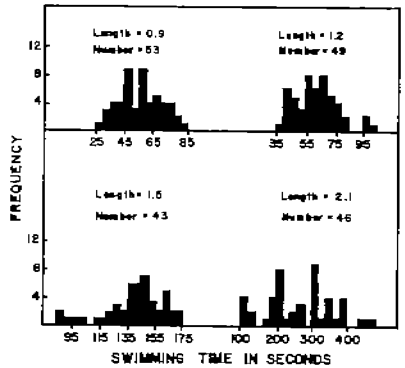

FIGURE 6.—Swimming time frequencies for four sizes of wild fish. Lengths recorded in inches.

Tables 4, 5, and 6 give the data on the stamina tests for each of the three groups. Altogether 1,522 fish were given individual tests. Figure 7 presents the increase in swimming time as the fish increased in length. A linear increase could be expected for Gray (1957) reported Bainbridge as finding a generally linear relation between swimming speed and length of fish when they have the same frequency of tail beat. However, more stamina trials are needed to determine if a true linear relationship exists. In Figure 7 the last two points make a sharp deflection. Values of these two points were doubled for increased clarity of presentation. There are two partial justifications for this: (1) water flow in the testing trough was nearly doubled at this same time and (2) this places the points in an approximate linear position to the previous points.

TABLE 4.—*Stamina trials of a domesticated stock of brook trout as measured by swimming under controlled test conditions*

Date	Water temperature (degrees F.)	Number measured	Mean length	Standard deviation	Number tested	Swimming time (seconds)	Standard deviation	Swimming time per inch of fish
February 24	52	113	0.92	0.067	157	38.28	13.54	41.60
March 13	52	47	1.04	0.072	47	45.11	13.07	42.41
March 17	51	55	1.05	0.074	54	51.01	12.14	48.58
March 27	52	52	1.22	0.109	49	68.29	21.50	55.97
April 9	50	47	1.33	0.163	48	65.75	16.37	49.44
April 28	48	42	1.50	0.174	50	79.50	17.12	53.00
May 23	56	49	2.04	0.245	48	153.33	40.41	75.16
June 13	60	51	2.62	0.331	53	105.90	32.99	40.41
June 30[1]	66	41	3.35	0.417	40	140.43	29.42	43.07

[1]Water flow increased 1.8 times on June 13 and 30.

TABLE 5.—*Stamina trials of a first-generation stock of brook trout as measured under controlled test conditions*

Date	Water temperature (degrees F.)	Number measured	Mean length	Standard deviation	Number tested	Swimming time (seconds)	Standard deviation	Swimming time per inch of fish
February 17	47	94	0.87	0.045	231	36.57	11.86	42.03
March 10	50	46	0.94	0.062	51	51.51	9.70	64.79
March 29	49	46	1.15	0.128	60	49.10	10.04	42.69
April 21	52	51	1.30	0.459	50	61.42	17.07	47.25
May 19	61	44	1.84	0.562	45	160.42	26.88	87.18
June 3	60	52	2.19	0.489	53	202.61	25.32	92.51
July 1[1]	66	35	2.78	0.374	39	117.07	35.68	41.03

[1]Water flow increased 1.8 times on July 1.

The difference between the wild and domestic stocks becomes more divergent as the fish increase in size. Figure 7 shows that under these test conditions wild-stock fish have greater stamina than domestic-stock fish throughout the entire size range tested. The plot of points from first-generation fish has been omitted from Figure 7 to avoid crowding, but this group is more scattered than the other two, in general falling between them.

Stamina of the three lots of fish can be compared in relation to time (Figure 8). It could be that the faster growth of the domestic lot counteracted their reduced stamina. When testing started, all three groups were near the same stage of development, but as the domestic stock grew faster, it was larger throughout the tests. Even though smaller, wild stock had greater stamina at a given time (except for a short period) than domestic trout.

This same figure also suggests that stamina tests are indicative of the general well-being of the fish. Between April 2-9 high mortality was experienced in all three lots. Each of the three groups of test fish had a drop in stamina at this time. (Note area marked by left arrow on Figure 8.) Wild- and first-generation-stock fish showed the effects earlier than the domestic fish. Domestic fish did not begin feeding poorly until nearly a week after the other two groups were off their feed.

The abrupt decline shown by the last two points was the result of an increase in water flow in the testing trough. Even with the increased flow the confines of the testing trough probably reduced swimming efficiency as the fish grew larger. Domestic fish, being the largest, were possibly hindered more by the trough. However, the consistent results experienced throughout the size range tested suggested that trough restrictions were not masking stamina differences.

FIELD EXPERIMENTS

Field trials were limited to small controlled situations because of the exploratory nature and limited fish available. Two habitats with extreme environmental conditions (a stream and a pond) were chosen — one severe, the other mild. To intensify the influence of competitive and environmental factors, both the stream and the pond were stocked more heavily than would usually be advisable.

TABLE 6.—*Stamina trials of a wild stock of brook trout as measured under controlled test conditions*

Date	Water temperature (degrees F.)	Number measured	Mean length	Standard deviation	Number tested	Swimming time (seconds)	Standard deviation	Swimming time per inch of fish
February 27	49	69	0.92	0.037	59	44.39	18.56	48.25
March 14	50	52	0.99	0.082	53	67.22	16.06	57.79
April 1	53	50	1.16	0.080	49	65.51	15.32	47.85
April 14	51	53	1.17	0.121	51	62.20	14.43	53.16
May 13	56	54	1.55	0.167	52	133.30	28.50	86.00
May 24	55	49	1.83	0.213	48	190.21	24.57	103.94
June 11	60	30	2.14	0.308	48	263.38	25.11	123.07
June 23[1]	60	53	2.20	0.355	52	136.40	22.37	62.00
July 7[1]	66	46	2.44	0.283	47	150.91	42.78	61.84

[1]Water flow increased 1.8 times on June 23 and July 7.

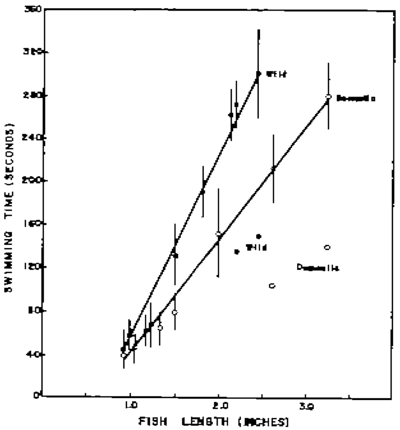

FIGURE 7.—Stamina relationship of wild and domestic stock of brook trout. Last two points on both lines were doubled to continue straight lineation. The two points for the wild and the two for the domestic which group below the lines are the original values. Vertical lines are standard deviations.

East Lake Outlet

The outlet of East Lake provided a situation for testing the survival of two lots of fish under stream conditions. This stream is located on the Adirondack League Club Preserve near Old Forge, New York, where it drains East Lake. The latter was reclaimed in 1954 and restocked with brook trout in 1955.

A 1,600-foot section of stream located 0.5 mile below the lake was used as a test section. A Wolf-type fish trap at the downstream end and an incline screen at the upstream end prohibited fish movement out of the test area. For one night (July 17) the downstream trap was only partially operative when it was damaged by high water and debris. The low catch throughout the balance of the time, including high water periods, suggests that the lack of a barrier for one night was of little consequence.

Stream width at medium water flow was 5 to 8 feet and water depth was 4 to 12 inches except for a few 2-foot-deep pockets. The bottom was almost completely rock except for scattered small sand bars and quiet silt areas. Throughout the stream course undercut banks, brushy shorelines, and fallen logs were common. A canopy, predominantly of spruce *(Picea)* and beech *(Fagus)*, shaded much of the stream. Previous to stocking, 15 small rock barriers were built to increase suitable habitat for the introduced fish. Water temperature ranged from 52 to 66° F. during the test period of June 7 to August 20, 1958.

Five hundred each of domestic (3.1 pounds) and wild fish (1.4 pounds) were planted in the stream on June 7. Further data are recorded in Table 9. Domestic fish, marked by removing the right ventral fin, were 2.41 inches in mean length; the wild, marked by removing the left ventral fin, were 2.04 inches in mean length. Fish of the same length at stocking would have been preferable as, other factors being equal, larger fish have a survival advantage.

The fish were spot planted throughout the stream. Sections of good habitat were subjectively stocked more heavily than shallow or exposed areas. Twice during the planting, resident fish darted out to catch an introduced fish immediately after it was put into the stream. Fifty fish were confined 3 days to observe any undue mortality caused by transportation or from the different water. All survived and were liberated.

Recovery of the fish was by electrofishing, using a 500-volt "Homelite" DC generator. Salt was added to increase conductivity. The stream was divided into 200-foot sections, and each section was electrofished twice. Approximately 75 percent of the fish were taken the

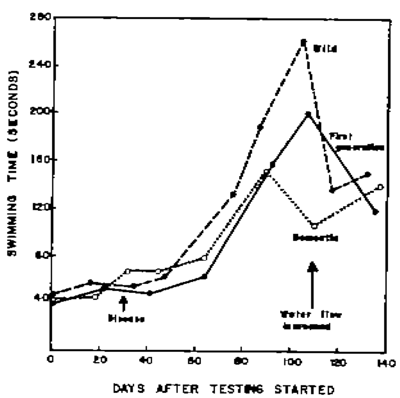

FIGURE 8.—Stamina of three lots of brook trout as related to time. Fish length ignored.

first time a section was electrofished. This made a DeLury-type estimate possible (DeLury, 1947). All fish taken from the stream were preserved in a 10 percent formalin solution for conventional processing and enumeration after returning to the laboratory.

On August 20, after being in the stream for 73 days, 94 domestic trout (0.6 pounds), 144 wild trout (0.5 pounds), and 229 resident trout (6.8 pounds) were captured (Table 7). A DeLury estimate gives 102, 167, and 247,

TABLE 7.—*Brook trout taken from experimental area of East Lake Outlet by electrofishing*
[Parenthetical figures represent trout taken on first and second electrofishing, respectively]

Section	Domestic[1]	Wild	Resident	Total
1	17 (15 + 2)	18 (13 + 5)	23 (19 + 4)	58
2	13 (11 + 2)	21 (15 + 6)	23 (17 + 6)	57
3	15 (14 + 1)	16 (12 + 4)	34 (26 + 8)	65
4	15 (10 + 5)	10 (7 + 3)	29 (21 + 8)	54
5	11 (9 + 2)	17 (15 + 2)	38 (32 + 6)	66
6	12 (9 + 3)	18 (12 + 6)	23 (21 + 2)	53
7	8 (6 + 2)	20 (14 + 6)	29 (22 + 7)	57
8	3 (2 + 1)	24 (21 + 3)	30 (24 + 6)	57
Total	94	144	229	467

[1]Chi-square (domestic and wild) = 10.60, P < 0.01.

respectively, as the total population in the stream (Table 8). Of the 500 trout stocked from each group, these estimates represent survivals of 20 percent of the domestic and 33 percent of the wild trout. More wild trout than domestic fish survived in seven of the eight stream sections.

The nearly equal number of fish in each of the eight sections (60 to 70) attests to uniformity of habitat throughout the test area and efficiency of the electrofishing gear.

Wild fish greatly outnumbered the domestic in only the lowest two sections (Table 8). Water flow was considerably swifter and many

TABLE 8.—*Population estimates (DeLury-type) for three groups of brook trout in East Lake Outlet experimental area*

Section	Domestic	Wild	Resident	Total
1	17	21	24	62
2	13	25	26	64
3	15	18	37	70
4	20	12	34	66
5	11	17	39	67
6	13	24	23	60
7	9	25	32	66
8	4	25	32	61
Total	102	167	247	516
Percentage of survival	20	33	—	—

pools were smaller in these two sections than the remainder of the stream. Exactly how swifter water influenced the two stocks was not determined.

Fish conditioned in a stream had better survival than fish reared in a hatchery pond (Miller, 1954). Needham and Slater (1945) had poor results with stream conditioning of fish but quoted H. S. Davis as having better survival with stream-conditioned rainbow trout. It is necessary, as Miller (1954) pointed out, for an introduced fish to find a suitable location before being overcome by exhaustion; otherwise it has to combat the current or other undesirable habitat. Thus, the wild stock with their greater stamina would have an advantage over the domestic fish. Increased stamina is certainly not the only factor aiding wild fish. As was evident in the laboratory tests, behavior differences might be detrimental or advantageous.

Better adaptation to higher temperature was given by Greene (1952) as one factor for higher survival of wild stock in Stillwater Pond, New York. Although the wild stock planted in East Lake Outlet could withstand higher water temperature, the creek temperature never approximated the lethal range.

FIGURE 9.—Wild (left) and domestic (right) fish after 73 days in East Lake Outlet.

Both groups planted in East Lake Outlet increased slightly in length. The mean length of the wild stock increased 0.48 inches, and the domestic, 0.34 inches (Table 9). As the wild fish were smaller when planted, their relative increase was greater than the actual increase suggests (Figure 9). Change in weight, an increase for the wild and decrease for the domestic, was slight for each group. This change is probably not enough to be important, but the total pounds planted and recovered shows a change. Approximately twice as many pounds of domestic fish were stocked, but nearly equal poundage of the two stocks were recaptured. The condition factor[2] of both groups at time of capture was lower than when stocked and lower than that of the resident trout (Table 9).

Statistics of age distribution and size of the 229 resident trout are as follows:

Age	Number	Mean length (inches)	Total weight (pounds)
0+	76	2.1	0.30
I+	129	4.0	4.13
II+ (and older)	24	6.6	2.40

The resident fry were approximately 1 inch long at the time the test section was stocked. When captured at the end of the experiment, they had a mean length of 2.1 inches. Growth of the resident fry was greater than either of the planted groups.

Along with the resident population 1.1 pounds of stocked fish were recovered. As the area of the test section was approximately one-fourth acre, the standing crop at the end of the period was 30 pounds of fish per acre.

The first reaction of nearly all fish when put into the stream was to orient to the current, then move downward into a desirable water velocity. During this initial period the fish exhibited practically no fright from shadows or disturbances of the water. Frequently the introduced trout would move into a small hole or eddy with a resident fish.

About 10 percent of the domestic fish swam directly into a rock, sand bar, or even partially out of water, giving the impression that they were confused by their new surroundings. Several fish buried their heads in the soft sand by their aimless swimming. This was not observed in the wild stock. Behavior of this type is characteristic of fish that have been transported under adverse conditions where carbon dioxide is allowed to build up in the water. Accumulated metabolic wastes appeared to have greater effect upon domestic stock than wild stock. This agrees with earlier laboratory tests.

Downstream movement of fish out of the test area was slight. One wild, two domestic, and six resident trout were captured in the lower trap. The six resident fish were liberated below the test section, and the planted fish were returned upstream within the test area. A section of stream below the weir was electrofished to recheck on downstream movement, but only resident fish were recovered.

Laramie Pond

Laramie Pond provided an opportunity to investigate survival of test fish in a mitigated environment. This pond is in the northern Adirondack Mountains on the Brandon Preserve near Paul Smiths, New York. In 1957 a dam was constructed across a small tributary of the St. Regis River forming a pond with a surface area of approximately 0.5 acre and maximum depth of 8 feet. The temperature of the spring-fed inlet remains nearly constant at 48 to 52°F. Pond surface water temperature (1958) was 54°F. on June 16, rose gradually to 68°F. in mid-July, and cooled to 54°F. again by late September. On May 27, June 8, and July 14 a total of 1,500 pounds of agricultural lime was applied around the pond shore and at the inlet entrance. All fish in the watershed above the dam were eradicated by rotenone.

Movement of fish out of the pond was prevented by a screened box at the inlet and a Wolf-type fish trap at the spillway of the dam.

Six hundred and twenty-five fish from each of three different stocks were planted on June 16, 1958. The stocks were:

Stock	Mark	Total pounds
Domestic	RV	4.8
Wild	LV	2.2
Backcross	RP	2.0

Additional data are given in Table 11. The backcross were planted in connection with another project and consisted of a male "splake" (brook trout x lake trout hybrid) backcrossed to female brook trout.

Forty domestic, 13 wild, and 15 backcross trout were taken at the downstream trap and replaced in the pond. Eighteen of the domestic, eight of the wild, and three of the backcross moved downstream after August 19. Domestic male trout maturing at 0+ could account for the greater movement of domestic stock. However, movement of wild fish increased also during the same period even though they did not mature at this time.

The pond was drained and seined on October 2, 1958. Stragglers were recovered by DC electrofishing. For all practical purposes recovery was complete. Numbers of fish recovered were:

Stock	Number	Total pounds
Domestic	269	17.1
Wild	405	11.6
Backcross	388	11.8

Survival was 65 percent for the wild, 62 percent for the backcross, and 43 percent for the domestic.

The standing crop when the pond was drained was approximately 40 pounds of trout (80 pounds per acre). This was produced from 9.0 pounds of stocked fish.

Dead fish that collected at the downstream trap were counted each time the pond was visited (Table 10). The domestic fish had several periods of high mortality but never more than two wild or backcross fish were found dead at any one time. Highest mortality coincided with warmest water surface temperature. Some of the dead fish from each lot were gorged with maggots which came from fox carcasses suspended over the pond as a source of supplemental food. As domestic fish had mortality before maggots were available, it does not seem that they were the cause of a selective mortality.

Increase in length was comparable in all three groups (Table 11). Absolute increase in weight was more for the domestic stock, but as their weight at planting was greater the relative weight increase was similar for

[2]Condition factor = $\frac{\text{Weight (pounds)} \times 100{,}000}{\text{Fork length}^3 \text{ (inches)}}$

TABLE 9.—*Growth of three stocks of fish after 73 days in East Lake Outlet*
[Standard deviations in parentheses]

Comparative factor	Item	Stock of fish		
		Domestic	Wild	Resident
Length	Mean length at stocking (inches)	2.41 (0.312)	2.04 (0.209)	
	Mean length at recapture (inches)	2.75 (0.372)	2.52 (0.303)	
	Length increase (inches)	0.34	0.48	
	Relative length increase (percentage)	14	23	
Weight	Number per pound at stocking	163	351	
	Number per pound at recapture	176	334	
	Weight change (number per pound)	−13	+17	
	Relative weight increase[1]	—	—	
Condition factor[3]	At stocking	44.85	33.50	
	At recapture	35.50	19.20	42.11

[1]Change was so slight it was considered insignificant.
[3]Based on mean weight and length.

FIGURE 10.—Wild (left) and domestic (right) fish after 103 days in Laramie Pond.

TABLE 10.—*Observed mortality in Laramie Pond*

Date	Water temperature (degrees F.)	Mortality		
		Domestic	Wild	Backcross
July 16	60	2	—	2
18	62	5	1	—
20[1]	—	9	—	1
23	64	1	—	2
25	—	—	—	1
29	65	6	2	1
30	66	3	—	—
31	64	2	2	—
August 1	66	6	2	—
3	63	15	2	—
19	68	4	—	1
22	66	12	2	2
25	66	1	—	—
27	64	4	—	1
29	65	2	—	2
September 2	62	—	1	—
4	62	6	2	—
Total		78	14	13

[1]Maggots were not available until after this date.

domestic and wild stocks (Figure 10). Wild stock was the only lot to have a lower condition factor at recapture than at planting.

Comparison of fish growth in Laramie Pond with fish growth from the same lots that remained in the hatchery should indicate adaptation to natural or to hatchery conditions. Wild fish that had been in Laramie Pond for the summer grew more than fish from the same lot that remained in the hatchery. (Laramie Pond wild fish had grown 1.0 inch more in mean length and 0.01 pound more in mean weight per fish than the hatchery fish.) Domestic fish grew nearly the same in both situations. (Laramie Pond domestic fish had grown 0.1 inch more in mean length and 0.01 pound less in mean weight than their hatchery counterparts.)

Twelve of 105 domestic fish recovered from Laramie Pond were mature males. The length of three males was less than the mean of 5.3 inches, and the remaining nine were longer. No wild or backcross stock was ripe. Cornell University personnel who have handled this domestic stock previously have noted that many males mature at 0+.

Fifty domestic and 50 wild fish were returned to the Cornell University Experimental Fish Hatchery. The domestic fish began feeding immediately and were not frightened by a hand placed in the trough nor by movements around the trough. The wild fish, on the other hand, did not begin feeding well for 4 days and after this time were easily frightened by the presence of a person or the feeding routine.

DISCUSSION

Throughout this study it has become evident that domestic and wild stocks of brook trout may differ in many ways and that these differences are, to a certain degree, genetical.

Genetical variations are difficult to assess. An individual fish is the culmination of interplay between the genes of the fish and the environment in which it is reared. In some situations genetical factors dominate, but in others environmental factors have their forte. Variable growth rates of different stocks of brook trout (Phillips *et al.*, 1957) and lake trout (Haskell, 1952) and the difference between stream and lake forms of brown trout (Alm, 1949) when reared under similar conditions illustrate genetical control. Environmental control is presented by Smith (1951) who found that sea-run brook trout could be recruited from trout that had not been to sea

TABLE 11.—*Growth of three stocks of fish after 108 days in Laramie Pond*
[Standard deviations in parentheses]

Comparative factor	Item	Stock of fish		
		Domestic	Wild	Backcross
Length	Mean length at stocking (inches)	2.7 (0.331)	2.1 (0.308)	2.2 (0.292)
	Mean length at recapture (inches)	5.3 (0.683)	4.6 (0.459)	4.3 (0.593)
	Length increase (inches)	2.6	2.5	2.1
	Relative length increase (percentage)	96	119	95
Weight	Mean weight at stocking (pounds)	0.008	0.004	0.003
	Mean weight at recapture (pounds)	0.064	0.028	0.030
	Weight increase (pounds)	0.056	0.024	0.027
	Relative weight increase (percentage)	731	700	838
Condition factor	At stocking	39.12	37.79	30.05
	At recapture	45.00	28.77	37.73

TABLE 12.—*Chemical composition of two lots of brook trout*
[Determinations were made on a wet and a dry basis and recorded as percentage]

Source	Length (inches)	Dry basis				Wet basis		
		Water	Ash	Fat	Protein	Ash	Fat	Protein
Hatchery domestic	6.2	68.7	7.6	21.9	58.9	2.4	6.8	18.4
Hatchery wild	3.7	75.7	8.9	18.8	60.9	2.2	4.6	14.8

for many generations and by Wilder (1952) in the similarity of anadromous and freshwater brook trout when reared together.

Morphological, physiological, behavioral, and genetical factors interact and mask specific cause and effect relations. Chain-like reactions can be triggered whereby a genetical change causes a behavioral change which in turn affects the physiology until finally a morphological change results.

Hatchery practices which continue for a long period may exert selective influence upon which fish are chosen for brood stock. The following three examples illustrate this point. (1) Hess (1935) found that a reduction of the Islets of Langerhans could be caused by a high fat diet, overeating, or lack of exercise. (2) Fish that remain near the surface of a raceway or trough have first choice of food, thus getting more as well as unleached food to eat. (3) Robust fish (high condition factor) are preferred by most hatchery managers even though a heavy-bodied fish appears to have no apparent survival advantage as shown by the wild stock planted in both East Lake Outlet and Laramie Pond. In the cases just mentioned, fish with characteristics that might be of doubtful survival value may be selected as brood stock.

Chemical composition was determined for a sample of domestic and wild-stock fish that had been reared together and fed the same diet (Table 12). The only significant difference is in the fat content, wild stock having less fat than the domestic fish. Phillips *et al.* (1955) found a similar situation with fat and ash content between hatchery-reared brook trout and wild brook trout. These fish, however, were from different bodies of water, and one group had a hatchery diet while the other had natural food. The differential utilization of the same food by the wild and domestic fish could be a basic underlying factor that attributes to other dissimilarities.

Selection rarely produces anything new but it does sort, isolate, recombine, and differentially preserve certain genetic traits. When the wide range of genetic preadaptness found in trout and the plasticity within this range are realized, selection becomes a powerful tool in the hands of the fish-culturist. On the other hand, the phenotypic selection usually practiced often has unknown influence through pleiotrophy and multiple factors upon the genotype. To maintain equilibrium, a change in any gene frequency or position by artificial selection requires a compensatory change in the frequency and position of other genes. By this means artificial selection for fast growth or early maturity can precipitate slight but insidious changes in behavior or physiology.

Selective breeding is often carried on in order to attain a specific body form, fast growth, and early maturity. The latter two are important in determining the first. Early maturity in many species is related to fast growth as was demonstrated by the Laramie Pond domestic trout. Time of sexual maturity (Alm, 1949; Brown, 1957) and growth rate (Haskell, 1952; Phillips *et al.*, 1957) are genetically controlled. The similar growth rate of test fish in both East Lake Outlet and Laramie Pond shows that under certain conditions wild stock can grow as rapidly as domestic. Environment, however, operates within the genetic framework. Slower growth rate of wild stock in a hatchery exemplifies this as well as Greene's (1955) transplanting of stunted brook trout. Sexual maturity can also act as an inhibitor of growth, especially in males (Graham, 1956; Brown, 1957; Hoar, 1957).

The dual effect of fast growth and early sexual maturity upon longevity has been discussed by several authors. McCay (1933) found that early-maturing, fast-growing rats have a shortened life span and concluded that "it is possible that longevity and rapid growth are incompatible." Ratcliff (1943), reporting on further work of McCay and others, said that fish and rats on a semi-starvation diet were stunted but longer-lived than their well-fed counterparts. Osborne *et al.* (1917) and

Zabinski (1929) suggested the possibility of prolonging the life of insects and rats by retarding growth. From the preceding statements it seems that fast growth and early maturity are frequently at the sacrifice of longevity. McCay (1952) and Comfort (1956) have examined this problem from a more general approach.

If Medawar's (1945) first law of growth (length), "size is a monotonic increasing function with age," is accepted as applying to fish, we can expect slow-growing, late-maturing individuals to attain a larger maximum size than those individuals that grow rapidly for a short period. Accelerated growth increases only the early growth and slows down the later, but retarded growth is just the opposite, often resulting in a larger individual (Hubbs, 1926).

Gerrish (1935) noted that few domestic trout lived over 4 years in England's streams, whereas natural fish may live twice as long. Greene (1952) found almost no survival of hatchery-strain brook trout after 3 years. In Wisconsin 95 percent of the male brook trout in St. Lawrence Creek mature at the end of their first summer and 85 percent of the females mature as yearlings (Brasch *et al.*, 1958). The same authors said that a Wisconsin brook trout over 3 years old is fairly rare. Presumably this included St. Lawrence Creek. Hatch (1959), working with the same stock of domestic brook trout as used in this present study, found few of them surviving more than 3 years in some of New York's Adirondack Mountain ponds. Brook trout stocked from hatcheries that bred for fast growth were shorter-lived than brook trout from hatcheries which obtained eggs from wild stock.

Not only is artificial selection operating, but also natural selection is absent. Many unfit are allowed to survive along with the fit. No premium is awarded for viability, stamina, wariness, or agility. Competition in a hatchery is greatly reduced allowing individuals to survive that would be eliminated in nature. These marginal individuals then contribute their genes to the population's progeny.

Since their origin each species of trout has evolved to fit a particular natural ecological situation. Fish-culturists, through artificial selection, are producing a fish adapted to a particular ecological situation, but it is a hatchery pond and not a stream or lake. When the environment suddenly changes, *i. e.* at planting, many of the adaptive advantages of artificial selection are not only of little or no value but may be detrimental.

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