# EVALUATION OF RAINBOW TROUT STRAINS FOR CAPTIVE AND NONCAPTIVE PERFORMANCE

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Since the origin of artificial propagation of rainbow trout (Salmo gairdneri) over one-hundred years ago (Needham and Behenke, 1962), the world distribution of rainbow trout has changed dramatically (MacCrimmon, 1971, 1972). In the late nineteenth century, eggs from McCloud River rainbow trout were distributed throughout the United States. The McCloud River rainbow are the probable ancestors of many of today's wild and domesticated rainbow trout. With the addition of steelhead forms, hybridization with cutthroat trout (Salmo clarkii), natural and artificial selection, the ancestory and original characteristics of the rainbow trout have been confused, changed or lost (Lewis, 1944; Needham and Behenke, 1962; MacCrimmon, 1971, 1972; Scott et al, 1978; Dollar and Katz, 1964).

Today there are many so called "strains" of rainbow trout maintained at the nation's federal, state and private hatcheries. The lack of records on breeding, egg shipment and stocking have confused the genetic background of these rainbow trout and further confused the meaning of the term "strain". Whether a separated group of rainbow trout is called a "strain", "race" or "broodstock", the important thing to remember is that differences based on genetics may be found.

Dr. H. L. Kincaid of the U.S. Fish & Wildlife Service's Fish Genetics Lab (FGL) in Beulah, Wyoming, has proposed the following definition of strain:

> a fish population which has resided at a single location (hatchery or natural body of water) as a interbreeding unit without major introductions from outside sources for a period of at least 30 years or a broodstock derived from such a population and maintained thereafter without major introductions.

Although rainbow trout not meeting the above definition of a strain may exhibit genetic differences, they may not be useful in management. The genome of such a group may not have undergone a significant level of selection and population differences may not yet even be detectable or repeatable.

Traditionally rainbow trout have been evaluated and selected for characteristics such as growth, egg production, disease resistance and spawning time which are important to fish culturists (Millenbach, 1950). Today rainbow trout "strains" have been shown not only to exhibit distinct differences in captivity but also to show non-captive (field performance) and organismal (physiological and biochemical differences (Table 1).

By matching the known capabilities and characteristics of rainbow trout "strains" to a variety of environments, specific and overall management programs may be enhanced. If the performance of rainbow trout "strains", over the range of captive and non-captive environments, is unknown, then management may be purely guess work. Evaluation of a "strains" hatchery performance and proper selection may point out a specialist which performs well in captive environments. Further evaluation may point out "strains" which perform well in specific non-captive environments. By utilizing a "strain" only in the captive and non-captive environment in which it does well, cultural and stocking programs may be optimized.

## LITERATURE REVIEW

No attempt has been made to uniformly define terms (e.g. strain, wild, domestic) in the literature review. Terminology and strain names are those used by the respective authors. Table 1 summarizes the strain work done on all salmonids. The following review centers on work done on rainbow trout.

### Physiological and Biochemical Characterization

As rainbow strains were selected in nature and in different hatchery environments, it could be expected that each strain developed physiological or morphological characteristics unique to each. For example, when the semi-wild, streamline-shaped New Zealand and Sand Creek strains were compared with the domesticated, more plump-shaped Manchester strain for swimming ability, the latter strain performed poorer (Thomas and Donahoo, 1977). They found that swimming ability was not related to growth rate, but was related to fish size, (e.g. larger fish performed better than smaller fish). The authors therefore concluded that swimming ability differences were related to the genome of the strain. They suggested that poor swimming, fast growing strains be stocked in lakes and put-and-take stream fisheries. Better swimming strains should be stocked in streams where survival might be higher than that of the poorer swimming strains. Klar (1973) compared two strains (Shepherd-of-the-Hills and Fish Lake) for the effects of conditioning and monitored serum lactate dehydrogenase (LDH) in an attempt to identify a physiological parameter which could be used as an index of conditioning. Both strains were exercised at 1/2 and 1 length/sec for several days and then forced to swim at 2 lengths/sec until fatigued. There were no strain differences in swimming ability at 2 length/sec. Serum LDH activity showed a transient increase during conditioning in the Shepherd-of-the-Hills strain but not in the Fish Lake strain, precluding the use of LDH activity as a conditioning index.

Rainbow strains have also been found to have strain specific disease susceptibility. Steelhead, Kamloops and University of Washington strains were tested for susceptibility for aflatoxin induced heptoma (Wales, 1970). The Steelhead were less susceptible to aflatoxin carcinogenesis but more sensitive to high level aflatoxicosis than the other two more domesticated strains. Observations concerning the variable nature of rainbow strain susceptibility to hepatoma had been made earlier by Dollar and Katz (1964). Rainbow strain differences to ceratomyxosis have also been found (Johnson, 1975). Similar observations have been made concerning the susceptibility of chinook salmon strains (hatchery stocks) to ceratomyxosis (Zinn et. al, 1977). The authors summarized that the resistance of some stocks was genetically acquired and that resistance to infection should be considered when introducing salmonids into any drainage system. Strains of other salmonids, such as brook trout and brown trout, have been found to differ in susceptibility to bacterial diseases such as ulcer disease and furunculosis (Wolf, 1953).

Trout strains have also been found to differ in their resistance to unfavorable environmental conditions, toxicants, and therapeutics. Three strains of rainbow (Donaldson, New Jersey, and a hybrid of the two strains) were found to differ in temperature tolerance in ponds where temperatures reached as high as 84.5°F during parts of the year (Soldwedel, 1967). The New Jersey strain survived (83%) and grew better at 20 months (10.5 in), than the Donaldson (67% survival), or the hybrid (55% survival, average length 9.8 in). Strain variability in temperature tolerance has also been examined for 16 brook trout stains and 12 hybrids between strains (Wahl, 1974). Several strains were found to be more tolerant; hybrids were generally intermediate in tolerance. On the other hand, no difference was found between the Ennis and Winthrop strains of rainbow for tolerance to lethal temperatures or in survival times at different temperatures (Kaya, 1978).

Some work has been conducted on the susceptibility of brook trout strains to acid mine drainage, a common environmental problem in the East (Robinson et al., 1976, Falk and Dunson, 1977). In general, significant difference in strain tolerance has been found. In one study for example, differences in survival time between two strains (Belfonte Open and Edray) at 3.15 pH were from 6 to 16 hours. Similar results have been found between strains of brown trout (Gjedrem, 1976).

Formalin is frequently used to control external parasites in hatcheries. A recent survey was conducted to define the scope of formalin toxicity problems within federal hatcheries. Several hatcheries reported a correlation between the strain reared and formalin toxicity (Piper and Smith, 1973). For example, the Wytheville rainbow strain experienced less than 1% mortality compared to up to 60% in the Manchester strain when both were treated under the same conditions. No work was been conducted to determine the resistance of strains to other xenobiotics, however, one study did show that strains varied in their ability to detoxify pollutants which entered the body. Hepatic microsomal enzyme activity was highest in Spokane and Chambers Creek strains of rainbow, intermediate in Mt. Whitney and Hagerman strains and lowest in the Chester Morse strain (Pederson et al., 1976). The authors suggested that the possession of the detoxifying enzyme systems may relate to the degree of degradation of the environment from which the strains were derived. They further pointed out that when undesignated strains are used in toxicity studies, data from one study to the next is difficult to compare due to possible strain differences in susceptibility. Lennon (1967) suggested that a standard bioassay strain of various fish species be established and maintained to allow reproducable and comparable bioassay results. Gall (1969) suggested that different strains with different resistance to stress be maintained in bioassay laboratories.

Biochemical genetic studies of fish in general and salmonids specifically have increased in the past 10 years because of the use of electrophoretic protein separation methods and histochemical staining.

Much of the biochemical work conducted with rainbow trout has been with the identification of anadromous rainbow (steelhead) stocks. Allendorf (1975) found considerable genetic heterogeneity among 32 steelhead loci examined. A major division in the stocks of the Pacific Northwest occurred at a point coinciding with the crest of the Cascade Mountains and was based on the distribution of variant forms of LDH and tetrazolium oxidase. The results suggested that geographic separation is the principal basis for genetic isolation of rainbow trout.

Non-migratory populations of rainbow trout and domesticated strains have not been extensively examined from a biochemical basis. Utter and Hodgins (1972) analysed biochemical genetic variation at 6 loci in 4 stocks of rainbow from hatcheries in Washington (Entiat, Quilcene, Arlington, and Seward Park). They found that each stock had a distinct genetic profile based on the frequency of enzyme variants and suggested that the genetic profile could be strain (stock) marker which could be used to identify each stock. The LDH enzyme variability has been investigated in 10 strains of hatchery rainbow and 9 stocks of steelhead (Stalnaker et al., 1973). Three phenotypes were found. Migratory fish (Steelhead) had a greater frequency of the $B^{2''}$ gene than hatchery fish. The frequency decreased in stocks which migrated long distances. In hatchery fish, the $B^{2''}$ gene was found only in Beitey, Shepherd-of-the-Hills, Fish Lake and White's Trout Farm strains. The gene appeared only as the heterozygote with the $B^{2'}$ gene; no $B^{2''}$ homozygotes were found. They also found that rainbow trout (Beitey strain) and steelhead LDH phenotypes for serum, liver, eye, and muscle were similar.

Wydoski et al. (1977) found variable hemoglobin electrophoretic patterns in Sand Creek and New Zealand strains of rainbow trout but not in the Shepherd-of-the-Hills or Fish Lake strains. The variation was in the form of additional bands in the cathodal region which corresponded to one or more of the cathodal bands in cutthroat trout. No hemoglobin variability was found in the Ten Sleep strain of rainbow (Berry et al., 1978).

Present studies are being conducted at the Northwest Fisheries Center (National Marine Fisheries Service) in Seattle, Washington, to develop biochemical profiles of each strain presently being held at the U.S. Fish and Wildlife Service's FGL. Eight strains have been characterized for a series of 15 different biochemical traits by starch gel electrophoresis. Gene frequency estimates have been determined for each locus based on a sample of 100 fish from each strain (G. Millner, Fish Biologist, NMFS, Northwest Fisheries Center, Manchester, Washington, personnal communication).

In summary, it is clear that strains vary to some degree in physiological performance and may possess enzyme profiles which will allow identification of a specific strain. There is no data on behavioral differences between strains. Both behavioral and physiological performance information will be useful in explaining strain differences in a captive environment - - the fish hatchery.

## Captive Performance

Identification and characterization of present day strains is a problem facing modern fish culturists. Hatchery biologists have observed that in certain situations, one strain will out perform another, but these observations are rarely published. In 1974, the FGL initiated a program designed to genetically characterize strains of rainbow trout for a wide variety of cultural and non-cultural traits. The first phase of this work was to examine the performance of each strain in a standardized environment for one generation, i.e. egg fertilization to sexual maturity. An innovation in the program was the development of two strains (spring and fall spawning standard strains) with which the performance of all other strains could be compared. These strains were especially important when performance evaluations were conducted in several different hatchery environments. The program is ongoing to date, but several preliminary reports indicate that there are significant differences between some strains. For example, 4 rainbow strains (Manchester, Kamloop, McLeary, and a strain developed at the FGL for fast growth - Growth strain) were compared at the Gleghorn Hatchery in South Dakota (Ford, 1978). At 147 days, the Kamloops strain grew the fastest (mean weight 4.9 g) and the Manchester and slowest (mean weight 3.1 g). At 1 yr, the Growth strain (181.9 g) had more than doubled the growth of the Manchester strain (94.6 g) and McLeary strain (83.1 g) and almost doubled the growth of the Kamloops strain (101.8 g). Feed conversion ranged from 1.02 for McLeary to 1.16 for Kamloops at the 147-day point, and from 1.13 for McLeary to 1.18 for the Growth strain at the 1-year point. In another study (Reintz, et al., 1978) the Growth strain was compared with Fish Lake, Sand Creek, and the Spring Standard strain. Strains were compared for average weight gain, feed conversion, daily growth increment and percent mortality. Several diets were also tested. It was found that while growth depended on diet, the ranking of each strain for growth was independent of diet. The Fish Lake strain grew the poorest and also had the poorest feed conversion, weight gain and daily length increment and highest mortality. The Growth strain performed the best in all areas. Further studies by Reintz et al. (1979) compared 5 hybrid strains and one standard strain for body composition after reaching 1.5 g on starter diet and again after 180 days on an experimental diet. Body composition, feed conversion and growth varied significantly between strains. Body composition was influenced by genotype. Conversion ranged from 2.1 - 3.6. Mortality at 300 days ranged from 3.3 to 12.7.

Work at the Fish Cultural Development Center in Bozeman, Montana (Piper and Osborne, 1976) was conducted to compare the captive performance of several spring spawning strains (Growth, New Zealand, Spring Standard, Sand Creek, Winthrop, and a strain selected for its resistance to formalin toxicity - Formalin Resistant strain) and fall spawning strains (Growth, Fall Standard, Manchester, and mutant color morph strain - Metallic-blue strain). Strains were compared for survival at one month after feeding, feed conversion, growth rate and mortality at one year. Many differences were found. For example, The New Zealand strain had poorer conversion than Sand Creek, 2.07 and 2.33 respectively. Sand Creek had faster growth (0.017 in/day) than New Zealand (0.015 in/day). The New Zealand strain had 22.9% mortality from age 1 month to 1 year compared to only 10.2% mortality for the Sand Creek strain.

In another study which compared domesticated strains (Wytheville, Manchester, Growth) with wild strains (Fish Lake, New Zealand), domesticated strains appeared to perform better than wild strains (R. Simon, Fish Geneticist, U.S. Fish and Wildlife Service, Leetown, West Virginia, personal communication). Of the domesticated strains, Growth was the best performer followed by Manchester and Wytheville in decending order of magnitude. This study suggested the occurrence of hybrid vigor since Growth was actually a cross between the Wytheville and Manchester strain. Among the wild strains, Fish Lake has better 147-day survival and weight - almost double that of the New Zealand strain. Fish Lake strain also had a lower feed conversion, 1.82 compared to 2.67 for New Zealand. Percent hatch was 58.5% for Fish Lake and 67.6 for New Zealand. In tests of hybrids between various strains, many differences were found. For example, the percent eye-up ranged from 32% to 90%, and 1-year weight ranged from 138 g to 206 g. In general, hybrids were intermediate in performance to the parents, a trend noticed in other studies at the FGL (H. Kincaid, Fish Geneticist, FGL, Buelah, Wyoming, personal communication).

On study at the FGL compared 9 strains (Wytheville, Manchester, Fall Standard, Growth Fish Lake, New Zealand, Sand Creek, Spring Standard and McConaughy) for captive performance (Kincaid, 1978). The two most domesticated strains (Wytheville and Manchester) had the highest rate of crippling (15%) compared to wild strains which had 4-7% crippling. Growth rate differences ranged from 85 g (Fish Lake) to 202 g (Growth) at 1 year. At 2 years, strains differed in attained weight from 335 g (Fish Lake) to 1034 g (Wytheville). At 3 years, size differences were less but still present. The age at sexual maturity was related to growth, e.g. the fastest growing strains had the highest rate of 1-year precocious males and 2-year maturity in females.

Several strains (domesticated lines) of rainbow in California hatcheries have been compared for certain captive performance characteristics. Gall and Cross (1978) found differences in post spawning body weight, egg volumne, egg size, egg number and fertility to the eyed egg stage in three domestic rainbow trout broodstocks at 2 years of age. Gall (1968) found that number of eggs spawned per 2 year old female ranged from 2467 to 3673. Two stocks increased egg production with age to age 4 years and two other stocks did not. Each stock had different egg sizes and each increased egg size with age.

Several strains held in Utah State hatcheries have been evaluated for captive performance to fingerling stage (13 weeks) and catchable stage (38 weeks) (Leppink, 1977). Among the parameters measured were hatching percent, crippling, feed conversion, length, weight, K factor, mortality rate and feed cost to pounds gained. Strains evaluated were Beitey, Fish Lake, New Zealand, Sand Creek, Shepherd-of-the-Hills, Ten Sleep, and Albino. Feed conversion was poorest at 13 weeks in Fish Lake fingerlings; other strains were not different from each other. The Beitey strain fingerlings at 13 weeks had the largest

K factor; those of other strains were not significantly different from each other. Albino and Ten Sleep strains had the highest percent mortality per week; Beitey, Shepherd-of-the-Hills, and New Zealand strains were intermediate in percent mortality; Fish Lake and Sand Creek strains were lowest. Shepherd-of-the-Hills attained the greatest weight in 13 weeks (12.34 g) followed by Ten Sleep (8.82 g), Sand Creek (8.44 g), Albino (8.26 g), Beitey (7.33 g), New Zealand (7.0 g), and Fish Lake (5.6 g). However at 38 weeks, the Fish Lake strain had attained the greatest weight (3.31 fish/lb). In general, good growers throughout the study were the Shepherd-of-the-Hills and Ten Sleep strains, poor growers were the New Zealand and Beitey strains. When the fingerling portion of the study was repeated under different hatchery conditions, results in attained weight were generally the same in that the New Zealand strain was the poorest grower (Berry et al., 1978).

It is presently difficult to rank the strains which have been evaluated because of the different conditions under which studies have been conducted. Fish in general are much more susceptible to the influences of the environment than mammals and therefore strains do not always rank the same from one environment to the next (Gall, 1969). However, it is clear that there are appreciable differences between strains and their hybrids in captive performance. Certainly each commercial hatchery wishes to raise a strain with the greatest survival and growth. However, intelligent choices may be hampered by lack of information about most strains. Other aquaculturists (e.g. state, federal and private hatcheries) need information on captive performance of strains, but also need information from a second step in strain evaluation - - the evaluation of non-captive performance.

Non-captive Performance

The value of a strain's hatchery characteristics to it's performance once stocked in non-captive environments has often been questioned (Schuck, 1948). Imprinting by the hatchery environment has even been suggested (Smith, 1957). Studies in California reservoirs and elsewhere have shown the importance of non-captive evaluation of rainbow trout strains. Cordone and Nicola (1970) showed that the return to creel can be greatly influenced by strain selection in a fingerling program. The average return to the creel of the Kamloops strain (14%) and Shasta strain (11%) was superior to that of the Whitney (3.7%) and Virginia (4.2%) strains. The Shasta strain had the highest ratio of pounds planted to pounds caught and the lowest cost per pound in the creel. The Kamloops strain was found to be more susceptible to boat fishermen indicating a more limnetic distribution. Rawstron (1973, 1977) demonstrated the importance of strain differences in a catchable program. The Coleman Kamloops strain was consistently superior in repeated tests to the Whitney and Shasta strains. No growth differences were found between the three strains, but the Kamloops limnetic distribution enabled it to escape early vulnerability and reach a larger size. Based on return data and hatchery costs, each kilogram of Kamloops caught was produced for up to $0.55/kg less than the Shasta strain and $0.24/kg less than the Whitney strain. Boles and Borgeson (1961) found higher returns of catchable Mt. Shasta and Hot Creek strains when compared to the Whitney and Virginia strains. The higher catchability in the first year and their consequent reduced (relative) winter mortality was attributed to their success. Wales and Borgeson (1961) found the Kamloops strain more susceptible to fly fishing than the Mt. Shasta strain.

Ayles (1975) evaluated three strains of rainbow trout for aquaculture potential in central Canadian pot hole lakes. A domestic strain was superior in growth and intermediate in survival to two wild strains. Strain differences between lakes indicated a significant lake-strain interaction (Ayles, 1975).

Reisenbichler and McIntyre (1977) investigated the survival and growth of rainbow trout of different levels of domestication. In a non-captive environment wild trout had the highest survival and intermediatly domesticated trout the highest growth.

In a fingerling stocking in two South Dakota reservoirs, Ford (1978) found differences in total percent return. The Growth strain (32.5%) was the highest, followed by the Kamloops (27.4%), Washington (23.6%) and Manchester (15.7%).

In two Montana ponds, Dolan and Piper (1979) found a higher catchability of domestic strains (Winthrop and Standard Growth) compared to that of two wild strains (Fish Lake and McConaughy).

A highly domesticated strain (Wytheville) and a wild strain (Fish Lake) were evaluated at the FGL in Beulah, Wyoming. Fish Lake had a higher total recovery but the Wytheville strain was 35.8% heavier (R. Simon, personal communication). Further work on 3 fall and 5 winter spawning strains found significant differences in growth, susceptibility to angling and total return (Kincaid, 1978).

Hudy (1979) found significant sifferences in catchability of 6 strains stocked as fingerlings in a Utah reservoir. After one year, the return to the creel was as follows: Ten Sleep (29.2%), Shepherd-of-the-Hills (9.7%), Beitey (4.5%), Sand Creek (4.5%), New Zealand (3.5%) and Fish Lake-Desmet (2.6%). Leppink (1977), again in Utah, found the Ten Sleep strain (62.8%) more catchable than the Sand Creek (54.8%) and New Zealand (45.0%) when stocked as catchables in a large spring.

Several papers have investigated the migration tendencies of rainbow trout strains. Ratledge and Cornell (1953) found no significant differences in migration between the Manchester strain and control groups (Wytheville heritage) when stocked as catchables in three North Carolina creeks.

In a study on four California impoundments (Rawstron, 1973), emigration rates of the Whitney strain were greater than the Kamloops and Shasta strains.

Cordone and Nicola (1970) found emigration rates of the wild Kamloops strain to be greater than that of domesticated strains.

Moring (1978) investigated downstream loss of two strains stocked as catchables in a small Oregon stream. During high flows in April, up to 37.2% of the Roaring River strain migrated downstream and removed themselves from the major fishery. The Cape Cod strain was less migratory (up to 18.2% in April) and was caught in higher numbers. Economic analysis (Moring, 1978) determined that by stocking the less migratory strain, the benefit/cost ratio of the stream could increase from 14.1:1 to 18.0:1. The Cape Cod strain is now recommended for stream stocking in Oregon (Kinunen and Moring, 1978).

In summary, it is clear that non-captive differences occur between strains of rainbow trout. People in the occupation of raising trout for recreational use need to carefully consider a strains non-captive performance. Depending on the magnitude and type of program, a strains non-captive performance advantages may greatly outweigh it's disadvantages in the hatchery.

Table 1. Summary of literature dealing with strain evaluation. Each number corresponds to an entry in the Literature Reviewed section.

| Catagory | Reference: Rainbow Trout | Reference: Other Salmonids |
|---|---|---|
| **Captive Performance -** | | |
| Body Composition | 64 | |
| Crippling | 36, 42 | |
| Feed Conversion | 17, 42, 55, 63, 64 | |
| Growth | 4, 17, 36, 42, 55, 63, 64 | |
| Mortality | 4, 42, 55, 63, 64 | |
| Sexual Maturity/Egg Production | 20, 30 | |
| **General -** | 7, 8, 13, 18, 19, 21, 31, 35, 37, 40, 41, 43, 45, 46, 48, 53, 66, 67 | |
| **Non-Captive Performance -** | | |
| Catchability | 5, 10, 11, 17, 29, 36, 42, 58, 59, 60, 61, 81 | 23, 73 |
| Growth | 2, 3, 5, 10, 11, 17, 29, 36, 58, 59, 60, 61, 63, 68 | 15, 16, 23, 25, 73 |
| Migration | 10, 29, 50, 51, 57, 59 | |
| Survival | 2, 3, 5, 10, 11, 17, 29, 36, 58, 59, 60, 61, 63, 68, 71 | 6, 15, 16, 23, 47, 49 |
| **Physiological/Biochemical Studies -** | | |
| Disease Resistance | 12, 32, 79, 82 | 84 |
| Enzyme Analysis | 1, 4, 70, 76, 83 | |
| Pollution Tolerance | 33, 54, 56, 69 | 14, 22, 65, 78 |
| Stamina | 38, 72 | |

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