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History and Fluctuating Asymmetry of Utah Salmonid Broodstocks

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Abstract.—The level of potential inbreeding in Utah salmonid broodstocks was assessed by fluctuating asymmetry (FA) of five bilateral meristic characters. Counts were made of the following characters on the left and right sides of 40 fish: gill rakers on the lower first branchial arch, gill rakers on the upper first branchial arch, mandibular pores, pectoral fin rays, and pelvic fin rays. Data from state hatchery records for the last 20 years were examined for trends in development to the eyed stage, percent hatch, and percent cripples (deformity). A brief history of Utah broodstocks is also presented. The mean FA for each of the strains of five species varied from 1.25 (Sand Creek strain rainbow trout *Oncorhynchus mykiss*) to 3.15 (Bonneville cutthroat trout *O. clarki utah*), with no consistent differences among species. The meristic counts were variable, and the overlap made differentiation among strains and species based upon these counts impossible. From 1972 to 1993, percent survival to the eyed egg stage for most Utah hatchery strains did not follow any trend, except for brook trout *Salvelinus fontinalis* ($r = -0.712$) and albino rainbow trout ($r = 0.457$). Eggs stripped from wild stocks of lake trout *S. namaycush* and kokanee (lacustrine sockeye salmon *O. nerka*) had significantly lower survival to the eyed stage and hatching success than eggs from hatchery broodstocks, except for brook trout and albino rainbow trout. Mean crippling rates ranged from 1.5% in kokanee to 6.6% in Strawberry Reservoir cutthroat trout *O. clarki.* Fluctuating-asymmetry, eye-up, hatching, and deformity data indicated either low or no inbreeding in Utah broodstocks.

The poor post stocking performance of hatchery fish relative to wild fish has been a concern of fisheries scientists for many years (Miller 1954; Vincent 1960) and is still a major point of controversy in the Columbia River basin where salmon runs have declined despite a massive stocking program (White 1992). Some authors attribute the poor performance of hatchery fish to behavioral differences (Reimers 1963; Moyle 1969; Ersbak and Haase 1983). Differences in rearing environment are known to affect such fish behavior as the startle reaction to a visual stimulus (Roadhouse et al. 1986) and aggressiveness (Hoelzer 1987; Olla et al. 1992). Behavior and other characteristics that have a genetic basis may play a role in reduced survival (Flick and Webster 1964; Lachance and Magnan 1990). For example, both Vincent (1960) and Green (1964) observed reduced stamina in domesticated strains of brook trout *Salvelinus fontinalis.*

Inbreeding of hatchery broodstocks may be a contributing factor to poor performance. Inbreeding has been shown to reduce the recapture frequencies of marked Atlantic salmon *Salmo salar* (Ryman 1970), indicating an influence on survival. Inbreeding in fish has also been demonstrated to reduce egg hatchability, formalin tolerance, and fry survival and growth (Bridges 1973; Kincaid 1976a). Inbreeding may be assessed by observations of bilateral asymmetry, which is negatively correlated with enzyme heterozygosity (Leary et al. 1983, 1984, 1985). The greater the degree of inbreeding, the more frequently asymmetry is observed (Thoday 1953; Vrijenhoek and Lerman 1982).

Concerns about possible inbreeding in state hatchery stocks have prompted at least one state wildlife agency (Wyoming Game and Fish Department) to conduct an evaluation (Alexander 1993). This report summarizes an evaluation conducted to determine the degree of inbreeding of salmonid species and strains reared by the Utah Division of Wildlife Resources.

Methods

Fluctuating asymmetry was assessed in Sheep Creek strain brown trout *Salmo trutta,* Owhi strain brook trout, and six strains of rainbow trout *Oncorhynchus mykiss* (Sand Creek, Ten Sleep, Fish Lake–DeSmet, Shepherd of the Hills, Erwin, and Shasta). In addition, two strains of Bonneville cutthroat trout *O. clarki utah* were evaluated, one from Utah's Mantua Hatchery Bear Lake broodstock and the other a wild broodstock from Manning Meadow Reservoir, Utah. Cutthroat trout *O. clarki* (N = 40) and brown trout (N = 20) sampled in September 1993 from self-reproducing populations in the Logan River, Utah, were also examined for asymmetry.

Fluctuating asymmetry was assessed by counting five bilateral meristic characters (gill rakers on the lower first branchial arch, gill rakers on the upper first branchial arch, mandibular pores, pectoral fin rays, and pelvic fin rays) on the left and right sides of 40 fish from each strain. A dissecting microscope was used to make all the counts. Alizarin red S was used to stain the mandibular pores and gill rakers for enumeration. All counts were made by the author, except the Sand Creek strain of rainbow trout and half of the Logan River cutthroat trout sample.

To calculate an asymmetry value, the following formula was used:

$$\frac{\sum_{1}^{N} (|UR_{L-R}| + |LR_{L-R}| + |MP_{L-R}| + |PT_{L-R}| + |PV_{L-R}|)}{N};$$

UR = upper gill rakers, LR = lower gill rakers, MP = mandibular pores, PT = pectoral fin rays, PV = pelvic fin rays, N = sample size, L = left, and R = right. Vertical lines signify absolute values between them.

In addition to asymmetry calculations, data from state hatchery records for the last 20 years were summarized to determine possible trends in development to the eyed stage (eye-up), percent hatch, and percent cripples. Percent eye-up was defined as the number of eggs surviving to the eyed stage divided by the initial number of fertilized eggs, multiplied by 100. Percent hatch was defined as the percent of eyed eggs that successfully hatched. Percent cripples were the number of deformed fry divided by the number of eyed eggs.

Statistical Analysis

To compare differences among the mean asymmetry values, the individual sum of left–right differences were rank transformed for subsequent analysis of variance. Mean comparisons among the 12 strains were performed with the Wilcoxon test. The percent eye-up, hatch, and cripple were analyzed with the general-linear-model analysis of variance procedure of the SAS software (SAS Institute 1990). Subsequent mean comparisons were performed with Fisher's least-significant-difference test (SAS Institute 1990).

Broodstock History

In the descriptions that follow, Egan, Kamas, Mantua, Murray, and Whiterocks are all Utah state fish hatcheries. The locations for other state and national fish hatcheries are provided at first mention.

Cutthroat trout.—The Bonneville cutthroat trout (CTBV) tested were derived from broodstock in Manning Meadow Reservoir, located in the Monroe Mountains of Piute County, Utah, between Koosharem and Marysvale. The reservoir was chemically treated in 1989 and restocked with 469 fish transferred from Pine Creek (northeast of Beaver, Utah, in the Tushar Mountains) in 1990. In 1991, an additional 245 Bonneville cutthroat trout from Pine Creek were stocked in the reservoir. The Pine Creek Bonneville cutthroat trout were originally established by transfers from Birch Creek (just south of Pine Creek) and from Water and Reservoir canyons in the Virgin River drainage (Washington County, Utah). Stocks from the Virgin River drainage were thought to have been transplanted there from the Bonneville basin by pioneers during the early settlement of the area.

Bear Lake cutthroat trout broodstock (CTBL) is derived from spawners that enter Saint Charles and Swan creeks from Bear Lake, Utah–Idaho. This composite stock has been maintained at the Egan Hatchery since 1974 and has been replenished every 2–3 years with eggs from spawners trapped on the Bear Lake tributaries. In 1990, Kamas Hatchery shipped 5,000 cutthroat trout derived from the Bear Lake traps (two groups pooled) to Mantua Hatchery to establish a broodstock program there. An additional 5,000 Bear Lake cutthroat trout were shipped to Mantua Hatchery the following year from the Fisheries Experiment Station, which had also received eggs from Bear Lake. The fish examined in this study were derived from broodstock at the Mantua Hatchery. The Bear Lake strain typically spawns from mid-April to mid-June. Fish are spawned every 7–10 d during this period, and males from one year-class are crossed with females from another.

The Strawberry Reservoir cutthroat trout (CTSB) are Yellowstone cutthroat trout *O. clarki bouvieri* × rainbow trout hybrids (Behnke 1992). Strawberry Reservoir was chemically treated in 1990 and restocked with Bear Lake cutthroat trout and kokanee. Some of the CTSB were established in Electric Lake, Emery County, Utah, in the 1970s. This strain is still found in Electric Lake, and fish are collected from traps in the lake each year and the resulting progeny are used for stocking many lakes and reservoirs in the state.

Brook trout.—The Owhi brook trout (BKOW) were sent to Utah from the Crawford (Nebraska)

National Fish Hatchery, in 1979. After disease clearance at the Fisheries Experiment Station, 5,385 fish were sent to the Egan Hatchery to initiate the broodstock in 1981. The spawning period ranges from late November to early February.

Brown trout.—Brown trout were first introduced into the state sometimes before 1900 and were stocked as fry in many areas (BN?) by the Murray Hatchery by 1910 (Popov and Low 1950). The current broodstock (BNSC) was derived from Sheep Creek, a tributary to Flaming Gorge Reservoir on the Green River. An unknown number of eggs taken from Sheep Creek in November 1972 were shipped "green" to the Whiterocks Hatchery and later sent as eyed eggs to the Egan Hatchery. On December 7 of the following year, Egan Hatchery received 10,200 eyed eggs from Whiterocks Hatchery that had also been taken from Sheep Creek. Subsequent year-classes of brown trout perpetuated at Egan Hatchery were derived from these two year-classes. By the 1977–1978 brood year, there were 375 5-year-old females, 603 4-year-olds (both sexes), 5,242 2-year-olds (both sexes), and 7,802 yearlings (both sexes). The strain spawns from mid-October to mid-December, and females produce an average of 2,400 eggs as 3-year-olds, 3,800 eggs as 4-year-olds, and 5,100 eggs as 5-year-olds.

Rainbow trout.—A. P. Rockwell, warden of the Utah Territorial Prison in Salt Lake City, received over 100,000 rainbow trout eggs from California between 1877 and 1879 (Sigler and Sigler 1986). Utah received additional rainbow trout eggs from California in 1883 and 1893 (Popov and Low 1950). The first shipments to Utah were probably derived from the San Francisco Bay area, where rainbow trout were propagated from 1870 to 1877 (Behnke 1992). The McCloud River rainbow trout (a mixture of anadromous steelhead and resident rainbow trout) were propagated for distribution from 1880 to 1888 (Behnke 1990). From 1895 to 1900, coastal steelhead from Redwood Creek, California, and from the Willamette, Klamath, and Rogue rivers of Oregon were the source for eggs distributed by federal hatcheries at the time (Behnke 1992). In 1894 and 1895, the Neosho (Missouri) National Fish Hatchery provided 43,880 eggs (Popov and Low 1950). The disposition of these fish is unknown, but they were probably distributed around Utah and Salt Lake counties or along railroad lines. The Murray Hatchery, Utah's first state hatchery, received its first eggs (probably steelhead) in 1899–1900 from the U.S. Fish Cultural Station, Portland, Oregon. The Murray Hatchery produced fish and stocked many public waters until it closed around 1944.

The Fish Lake–DeSmet strain (RTFD) is derived from rainbow trout in Fish Lake, Sevier County, Utah, and DeSmet Lake, Wyoming. The DeSmet Lake eggs were received at the Fisheries Experiment Station on June 23, 1969, and transferred to Mantua Hatchery on September 24, 1970. The eggs from Fish Lake were derived from wild stocks spawning in Twin Creeks on August 22, 1969. The two groups were initially kept separate, but in 1970 the screen between them collapsed, combining the two strains into one. The resulting mix of 3,000 fish was used to start the broodstock. The source of rainbow trout in Fish Lake is unknown, but Ron Goede, director of the Fisheries Experiment Station, recalled that Fish Lake was stocked with DeSmet rainbow trout in the years just prior to the initiation of egg collection. Therefore it is possible that the Fish Lake rainbow trout were from DeSmet Lake stock, although rainbow trout of unknown origin were present in Fish Lake prior to stocking of the DeSmet strain.

In 1973, the Mantua Hatchery RTFD broodstock numbered 988 females and 462 males. That year 19,500 eyed eggs were shipped to Egan Hatchery. Between December 7, 1973, and March 28, 1974, the 11 egg "takes" from the Mantua stock resulted in 1,493,345 eggs, which were shipped green to Egan Hatchery to supplement the future broodstock initiated the year before. In the 1977–1978 brood season, an estimated 4.4 million eggs were produced at Egan by 3,048 5-year-old and 1,004 4-year-old females (mean, 1,086 eggs per female).

The source of the rainbow trout originally stocked into DeSmet Lake, Wyoming, is unknown. Mueller and Rockett (1980) reported that DeSmet Lake was first stocked in 1896 with cutthroat trout, lake trout *Salvelinus namaycush*, brook trout, and kokanee (lacustrine sockeye salmon *Oncorhynchus nerka*). Rainbow trout from several sources were stocked later, mostly as fry. After 1953, larger fish were stocked to improve survival and two strains appeared: a fall-spawning strain and a spring-spawning strain. The last year fall-spawning rainbow trout were planted was 1957. Only the spring-spawning strain of rainbow trout from DeSmet Lake were planted back in the lake from 1958 to about 1985, except for 3,000 Kamloop rainbow trout planted in April 1962. Eggs from this strain were collected from 1958 to 1984, and some of these were used to initiate the Utah RTFD strain. In the 1980s, Wyoming Game and Fish Department biologists noted that the DeSmet rainbow trout were not returning to the creel very well, so the strain was discontinued in Wyoming. Eagle Lake rainbow trout derived from captive broodstock were fin-clipped and stocked into DeSmet Lake starting in May 1984; in subsequent years, eggs were taken from both the DeSmet and Eagle Lake strains at the lake, but were not stocked back into DeSmet Lake. From 1984 to 1992, only Eagle Lake strain fish from hatchery stocks were planted into the lake. The DeSmet strain gradually disappeared from the fish traps on the spawning tributary (Shell Creek), which is dewatered every year shortly after the spring spawning season. By 1991, only Eagle Lake fish returned to spawn, and the original DeSmet strain was essentially gone from DeSmet Lake. Since 1992, the spawn of Eagle Lake rainbow trout from DeSmet Lake has been used to restock the lake. Electrophoretic analysis of both the hatchery and lake sources of Eagle Lake rainbow trout indicated no differences between the two (R. McDowell, Wyoming Game and Fish Department, personal communication).

The RTFD is a spring-spawning strain, currently spawning at Egan Hatchery between mid-January and mid-May. Kincaid and Berry (1986) noted that RTFD had the highest percent eye-up (94%) and the best feed conversion of all the Utah strains listed. At DeSmet Lake, the average number of eggs per female from 1958 to 1979 ranged from 560 to 1,994, with a mean of 1,340. Average fecundity for the broodstock at the Egan Hatchery in 1994 was about 1,450–1,500 eggs/female (B. Hilton, Egan Hatchery, personal communication). Egg production was slightly higher than most of the other rainbow trout strains reared at Egan.

The Shepherd of the Hills strain of rainbow trout (RTSH) is named for the picturesque region of the same name in southern Missouri where it originated. The strain is still widely used in Missouri, where it is called the Missouri strain. Missouri's first recorded introduction of rainbow trout was in 1882 (Pflieger 1975). The Neosho (Missouri) National Fish Hatchery played a major role in distributing fish in the early part of this century. It received fish from the Wytheville Hatchery in Virginia. In 1921, the Sequoita Spring Hatchery in Springfield, Missouri, began operation. It received fish from Neosho that were to become the future Shepherd of the Hills strain. The burgeoning growth of Springfield forced closure of the Sequoita Spring Hatchery in 1958, and fish and personnel were transferred to the newly constructed Shepherd of the Hills Hatchery below Table Rock Reservoir near Branson, Missouri (G. Proctor, Shepherd of the Hills Hatchery, personal communication). During this time (1921 or earlier to present) the RTSH was not outbred with any wild fish; thus the strain has been domesticated for over 75 years.

The RTSH was chosen for use in Utah because it performed well in cold water in Missouri, and Utah's future brood facility (Egan Hatchery) had cold water temperatures. Eggs were shipped December 15, 1970, to the Fisheries Experiment Station from the Shepherd of the Hills Hatchery. Mantua Hatchery received 4,678 fish (mean weight, 130 g) from the Fisheries Experiment Station on November 10, 1971. The first eggs were shipped to Egan Hatchery on November 10, 1972. Mantua Hatchery later shipped eggs to Egan on January 22, 1973 (15,328 eyed eggs), November 29, 1973 (341,348 green eggs), December 7, 1973 (167,200 green), December 19, 1973 (105,792 green), and December 28, 1973 (37,842 green). The strain has been perpetuated at the Egan Hatchery from these transfers, with no further crossing to other wild stocks. By 1978, Egan Hatchery had 22,927 broodstock in four lots and produced 3,168,000 eyed eggs that year. The RTSH typically spawns from about November 1 to January 1.

Eggs of the Ten Sleep strain of rainbow trout (RTTS) were received by the Whiterocks Hatchery in September 1971, from the Wigwam State Hatchery, Ten Sleep, Wyoming. Some of these eggs were transferred to the Fisheries Experiment Station in Logan and later sent to Mantua Hatchery in 1972. In 1973, there were 410 males and 830 females at Mantua. From this parent stock, 8,106 eggs were shipped to the Egan Hatchery in January 1973. An additional 908,430 eggs from seven takes were shipped to Egan the next season. The strain has been perpetuated at the Egan Hatchery since that time. The RTTS typically spawn between mid-November and early January.

The Sand Creek strain of rainbow trout (RTSC) was started in Utah with 22 large broodstock shipped to the Fisheries Experiment Station from the Fish Genetics Laboratory in Beulah, Wyoming, on March 26, 1971. These fish were transferred to Mantua Hatchery on May 28, 1971. About 4,000 fry from the first egg take in November 1971 were transferred to the Fisheries Experiment Station, and an unknown number were eventually shipped to Egan Hatchery as yearlings. Egan Hatchery also received yearlings and about 2,290 fry from the Mantua Hatchery egg take on February 12, 1972. The next spawning season an additional 8,700 eggs were sent to Egan from Mantua. By August 1973, only one male and three females remained at Mantua of the original broodstock, and RTSC was discontinued at that hatchery soon thereafter. Fish from the RTSC spawn between mid-September and late December.

Albino rainbow trout (RTAB) were shipped to the Mantua Hatchery from the Ennis (Montana) National Fish Hatchery in December 1967. In 1973, over 368,000 eggs from four lots were shipped to the Egan Hatchery. By 1978, Egan had 178 5-year-olds, 982 2-year-olds, and 1,790 1-year-olds. The stock at Egan Hatchery has been outbred at least twice with other rainbow trout strains (RTSH or RTTS) to enhance the hatchery performance of the strain. The RTAB typically spawn between mid-November and mid-January.

The Shasta (RTSS) and the Erwin (RTER) strains of rainbow trout tested are not kept as broodstock. Both strains were imported as eggs from Ennis National Fish Hatchery.

Kokanee.—The kokanee eggs were taken from wild stocks in Porcupine Reservoir, Cache County, Utah, and from Sheep Creek, a tributary to the Green River at Flaming Gorge Reservoir, Daggett County, Utah. Porcupine Reservoir was first stocked with kokanee in May 1963 (48,384 fry) and again in May 1967 (213,910 fingerlings) (Janssen 1983). The source of fish for Porcupine Reservoir is unknown, but the similarity in spawning time (mid-September to mid-October) with the Sheep Creek population suggests a similar origin for both groups. Sheep Creek (Flaming Gorge Reservoir) was stocked with kokanee from British Columbia, presumably from Kootenay Lake, in January 1963 (450,000 fingerlings); in spring 1964, an additional 707,984 fingerlings were released into Sheep Creek and Henry's Fork Bay (Eiserman et al. 1966). There are two additional spawning populations of kokanee at Flaming Gorge Reservoir, one in the Green River below Fontanelle Reservoir and the other on the eastern shore of the reservoir itself. These populations, thought to originate from Granby Lake, Colorado, in 1983, are genetically similar but differ from the Sheep Creek population (Hubert et al. 1992). The Granby Lake kokanee originated principally from Flathead Lake, Montana, which was stocked with kokanee from Whatcom Lake near Bellingham, Washington (R. J. Behnke, Colorado State University, personal communication).

Lake trout.—Lake trout from Northville, Michigan, were first stocked into Utah Lake as fry in 1894 (Popov and Low 1950). In 1900, the Murray Hatchery stocked 400 fry originating from Duluth,

TABLE 1.—Mean asymmetry (±SD) for species and strains of trout reared in Utah or sampled from self-reproducing populations. A sample size of 40 was used for each asymmetry evaluation unless otherwise noted. Mean asymmetry values followed by the same letter are not significantly different.

Strain[a]	Stock origin	Asymmetry (mean ± SD)
	Rainbow trout	
RTER	Ennis Hatchery	1.95 ± 1.24 yxw
RTFD	Egan Hatchery	2.57 ± 1.55 xwvu
RTSC	Egan Hatchery	1.25 ± 1.02 z
RTSH	Egan Hatchery	2.54 ± 1.50 yxwvu
RTSS	Ennis Hatchery	3.08 ± 2.28 xwvu
RTTS	Egan Hatchery	2.10 ± 1.28 yxwv
	Cutthroat trout	
CTBL	Mantua Hatchery	3.05 ± 1.61 u
CTBV	Manning Meadow, Monroe Mountains, Utah	3.15 ± 1.64 u
CTBV[b]	Logan River, Cache County, Utah	2.65 ± 1.61 wvu
	Brown trout	
BN? (N = 20)	Logan River, Cache County, Utah	1.70 ± 1.45 zy
BNSC	Egan Hatchery	1.95 ± 1.09 yx
	Brook trout	
BKOW	Egan Hatchery	2.62 ± 1.26 vu

[a] Strain abbreviations: RTER = Erwin, RTFD = Fish Lake–DeSmet, RTSC = Sand Creek, RTSH = Shepherd of the Hills, RTSS = Shasta, RTTS = Ten Sleep, CTBL = Bear Lake, CTBV = Bonneville, BN? = unknown brown trout strain, BNSC = Sheep Creek, BKOW = Owhi.

[b] The fish sampled for mean asymmetry were also used for counting additional meristic characters which indicated that Logan River cutthroat trout most closely matched the Bonneville subspecies description (Trotter 1987; Behnke 1992).

Minnesota, into Fish Lake, Sevier County. Subsequent introductions were also made in several of the larger bodies of water in the state, including Bear Lake, Utah–Idaho, in 1911 (Popov and Low 1950). Some lake trout derived from hatchery stock of the Michigan Conservation Department were reared at Mantua Hatchery in hopes of establishing a broodstock. In 1973, over 366,000 eggs were shipped to Egan Hatchery, but disease problems forced termination of strain. Fish Lake became the source of eggs for many of the lake trout reared in the last 20 years and is still used as a disease-free source of eggs. Eggs have also been imported into the state from regional sources such as Jenny Lake, Wyoming.

Broodstock Management

At the broodstock hatcheries, sexes and year-classes of each strain are maintained separately upon reaching sexual maturity. Eggs from five or more females of a year-class are pooled and fer-

TABLE 2.—Mean, SD, and range of six bilateral meristic characters in 10 salmonid broodstocks. Strain abbreviations are defined in Table 1.

Strain	Meristic counts		
	Mean	SD	Range
	Lower gill rakers		
RTER	11.6	0.82	10–13
RTFD	12.6	0.71	11–14
RTSC	11.7	0.56	11–13
RTSH	12.7	0.73	11–15
RTSS	11.7	0.83	7–13
RTTS	11.5	0.73	9–13
CTBL	11.8	0.82	10–13
CTBV	11.1	1.00	9–13
BNSC	11.5	0.69	10–13
BKOW	11.1	0.75	10–13
	Upper gill rakers		
RTER	7.0	0.67	6–8
RTFD	7.8	0.83	6–11
RTSC	6.9	0.49	5–8
RTSH	8.0	0.65	7–10
RTSS	7.4	0.51	6–8
RTTS	6.8	0.52	5–8
CTBL	5.9	0.64	4–8
CTBV	6.3	0.71	5–8
BNSC	6.2	0.58	5–8
BKOW	7.5	1.15	5–10
	Total gill rakers		
RTER	18.6	1.31	16–21
RTFD	20.3	1.19	18–23
RTSC	18.6	0.77	17–21
RTSH	20.7	1.18	18–24
RTSS	19.0	1.10	14–21
RTTS	18.3	1.02	16–21
CTBL	17.7	1.18	14–20
CTBV	17.4	1.29	14–20
BNSC	17.7	0.98	15–20
BKOW	18.5	1.44	15–23
	Mandibular pores		
RTER	7.4	0.95	6–10
RTFD	8.0	1.00	6–10
RTSC	8.1	1.06	5–10
RTSH	8.0	0.95	5–10
RTSS	8.4	0.90	6–11
RTTS	7.7	0.95	5–9
CTBL	8.8	1.07	6–11
CTBV	8.6	1.16	6–11
BNSC	7.4	0.61	6–9
BKOW	7.3	0.80	5–9
	Pectoral rays		
RTER	14.2	0.68	13–16
RTFD	14.4	0.66	13–16
RTSC	14.0	0.32	13–15
RTSH	14.6	0.67	13–16
RTSS	14.0	0.62	13–15
RTTS	14.0	0.73	12–15
CTBL	15.4	0.78	14–18
CTBV	13.5	0.65	12–15
BNSC	13.6	0.56	12–15
BKOW	13.0	0.58	12–15

TABLE 2.—Continued.

Strain	Meristic counts		
	Mean	SD	Range
	Pelvic rays		
RTER	9.9	0.26	9–10
RTFD	10.0	0.50	9–11
RTSC	10.1	0.31	9–11
RTSH	10.0	0.59	8–11
RTSS	9.7	0.46	9–10
RTTS	10.0	0.39	9–11
CTBL	9.4	0.52	9–11
CTBV	9.1	0.63	7–10
BNSC	9.2	0.44	9–10
BKOW	8.4	0.57	8–10

tilized by pooled sperm from five or more males a year older or younger to preclude the possibility of full-sibling mating. Five-year-olds of most strains are stocked after spawning, although brook trout are stocked after 4 years. About 15,000 eggs are taken each year for the purposes of brood replacement. These are derived from five egg takes, two before the peak of spawning, one during the peak, and two afterwards. The fish for this spawn are randomly selected; only deformities, exceptionally small fish, and eggs that are exceptionally small or of poor quality are culled. As the replacement broodfish are reared, some additional culling occurs at the time the fish are first sexed as 2-year-olds; when deformed and exceptionally small individuals are removed.

Results

The mean asymmetry for each of the strains varied from 1.25 to 3.15 (Table 1). Cutthroat trout generally had higher mean asymmetry values than the other species examined (range 2.65–3.15). Cutthroat trout from the Logan River had a lower mean asymmetry value that hatchery fish, but the difference was not significant. Mean asymmetries of brown and brook trout were similar to rainbow trout. The Sand Creek strain of rainbow trout had the lowest mean asymmetry, and it was significantly different from all other strains except the Logan River brown trout.

The meristic counts were variable, with considerable overlap among strains and species (Table 2, wild fish not shown). Among the four species evaluated, lower gill raker counts ranged from 7 to 15, upper gill rakers from 4 to 11, and total gill rakers from 14 to 24. The Fish Lake–DeSmet (RTFD) and Ten Sleep (RTTS) stains tended to have the highest gill raker counts, but the counts could not be used to differentiate among the species or

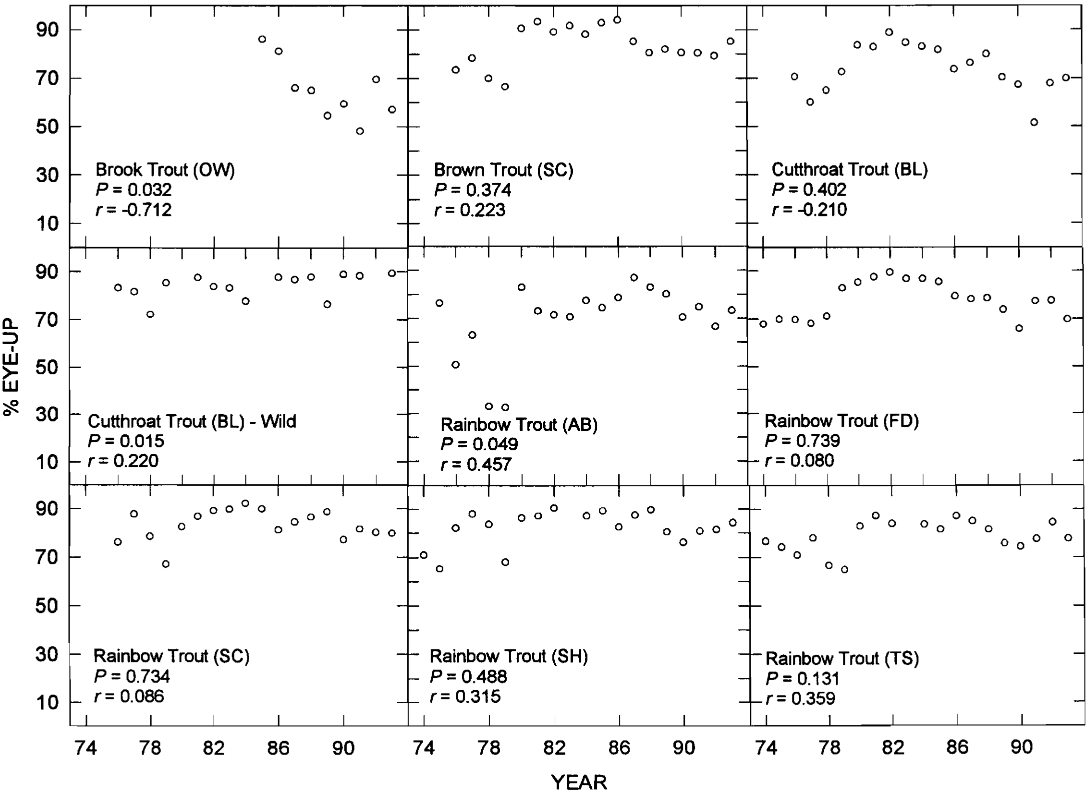

FIGURE 1.—Correlations between mean annual percent survival of eggs to the eyed state (eye-up) and year (1974–1993) for Utah salmonid broodstocks. Strain abbreviations are OW = Owhi, SC = Sheep Creek, BL = Bear Lake, AB = albino, FD = Fish Lake–DeSmet, SH = Shepherd of the Hills, and TS = Ten Sleep). Least-squares regression coefficients (r) and probabilities (P) are given for each correlation.

strains. Similarly, counts of mandibular pores, pectoral fin rays, and pelvic fin rays had greater variation among individuals and strains than among the four species.

The percent survival to the eyed egg stage (eye-up) from 1972 to 1993 (Figure 1) for most Utah hatchery strains did not follow any trend (correlation coefficients not significantly different from zero). The Owhi brook trout had a negative regression slope that was significant ($P = 0.03$; $r = -0.712$), but the trend appears to be heavily influenced by the high eye-up in 1985 and 1986. The albino rainbow trout had a significant positive slope ($r = 0.457$) in eye-up, which was influenced by very low values in 1978 and 1979. The percentage of eggs hatched was highly variable and did not decrease over the time period examined (Figure 2). Similarly, the percentage of cripples did not increase over time, and for Sheep Creek brown trout the percentage actually decreased significantly (Figure 3).

The mean percents for eye-up, hatch, and cripples for each strain are presented in Table 3. Mean eye-up was calculated from annual averages, but the mean percent hatch and percent cripples are derived from individual lots. Eggs stripped from wild strains (lake trout and kokanee) had significantly lower eye-up and hatching success than the hatchery broodstocks, except for brook trout and albino rainbow trout. Mean crippling rates ranged from 1.5% in kokanee to 6.6% in Strawberry Reservoir cutthroat trout.

Discussion

Inbreeding is simply the mating of related individuals, resulting in greater homozygosity (Tave 1986). Inbreeding can be detrimental by increasing the incidence of deformities (Piron 1978; Mrakovčić and Haley 1979; Winemiller and Taylor 1982). In the present study there was no increase in deformities (cripples) over the 20-year period examined. Percent deformities were also relatively

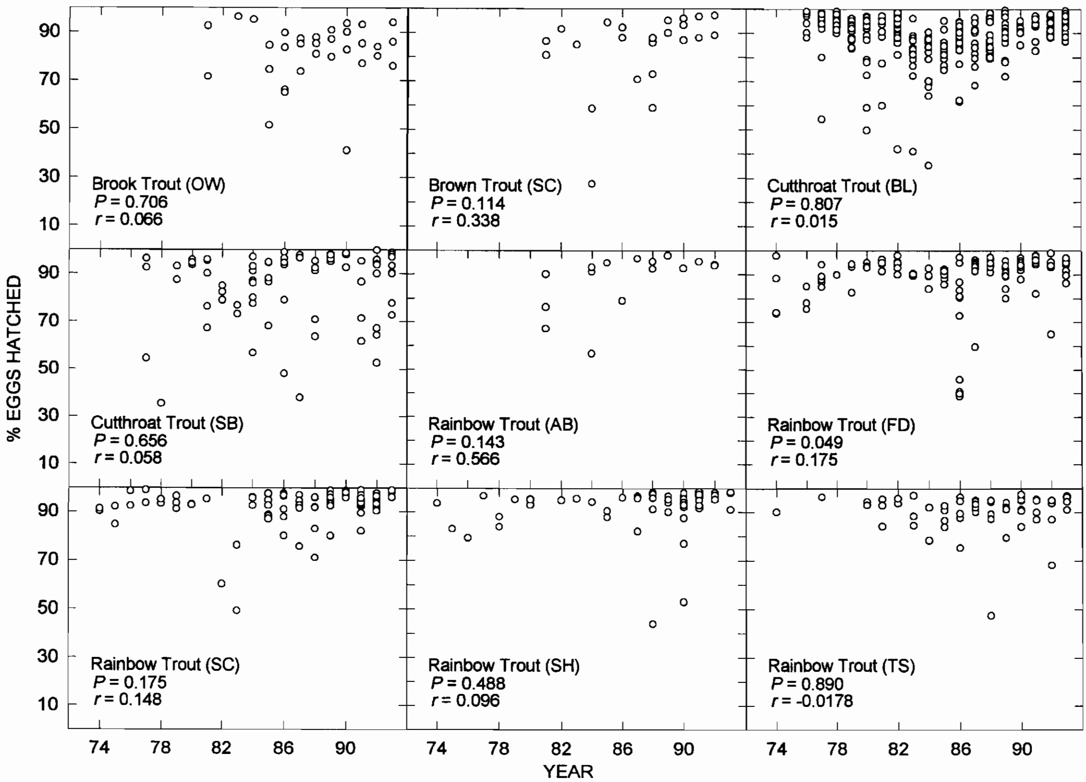

FIGURE 2.—Correlations between mean percent survival to hatching and year (1974–1993) for Utah salmonid broodstocks. Strain abbreviations are defined in Figure 1; SB = Strawberry Reservoir. Least-squares regression coefficients (r) and probabilities (P) are given for each correlation.

low (1.5 to 6.6%) compared with percentages reported for inbred zebra danio *Brachydanio* (=*Danio*) *rerio* (10–75% deformed fry; Piron 1978; Mrakovčič and Haley 1979), convict cichlid *Cichlasoma nigrofasciatum* (84%; Winemiller and Taylor 1982), and rainbow trout (11–18%; Kincaid 1976b). Deformity incidence increased with the degree of inbreeding for zebra danio and rainbow trout. In the convict cichlid, the deformities were not apparent until the fourth or fifth generation of full-sibling matings. However, Aulstad and Kittelsen (1971) noted lethal deformities averaging 12.6% in five inbred groups of rainbow trout after only a single generation of full-sibling mating.

Inbreeding has also been shown to reduce rainbow trout egg hatchability by up to 53% (Kincaid 1983). In this study, the percent hatch was higher than that reported for inbred stock by Kincaid (1976a) and ranged from 82 to 93% in the hatchery broodstocks. Also, there were no significant trends in hatching or eye-up percentages over the last 20 years. There were some significant differences among the stocks, with wild stocks having lower eye-up and hatching success than the hatchery broodstock. A valid hatchery versus wild comparison of eye-up could not be made because comparisons were not made within a species or strain. The difference in eye-up may be related to the transport of eggs from the spawning site, species differences, or the greater probability of mating with a sibling in wild-stock spawning. Also, hatchery strains are spawned every 10–15 d during the spawning period, insuring that ripe females are spawned as soon as they are ready. Conversely, wild stocks may have a greater proportion of females with older, less-viable eggs.

Fluctuating asymmetry (FA) is the difference between counts of left and right of bilateral meristic characteristics, such as setae, fins, pores, and scales (Van Valen 1962). Fluctuating asymmetry has been associated with increased homozygosity or inbreeding in fruit flies *Drosophila* spp. (Thoday 1953), side-blotched lizards *Uta stansburiana* (Soulé 1979), house mice *Mus musculus* (Leamy 1984), the poeciliid *Poeciliopsis monacha* (Vrijenhoek and Lerman 1982), rainbow trout (Leary et

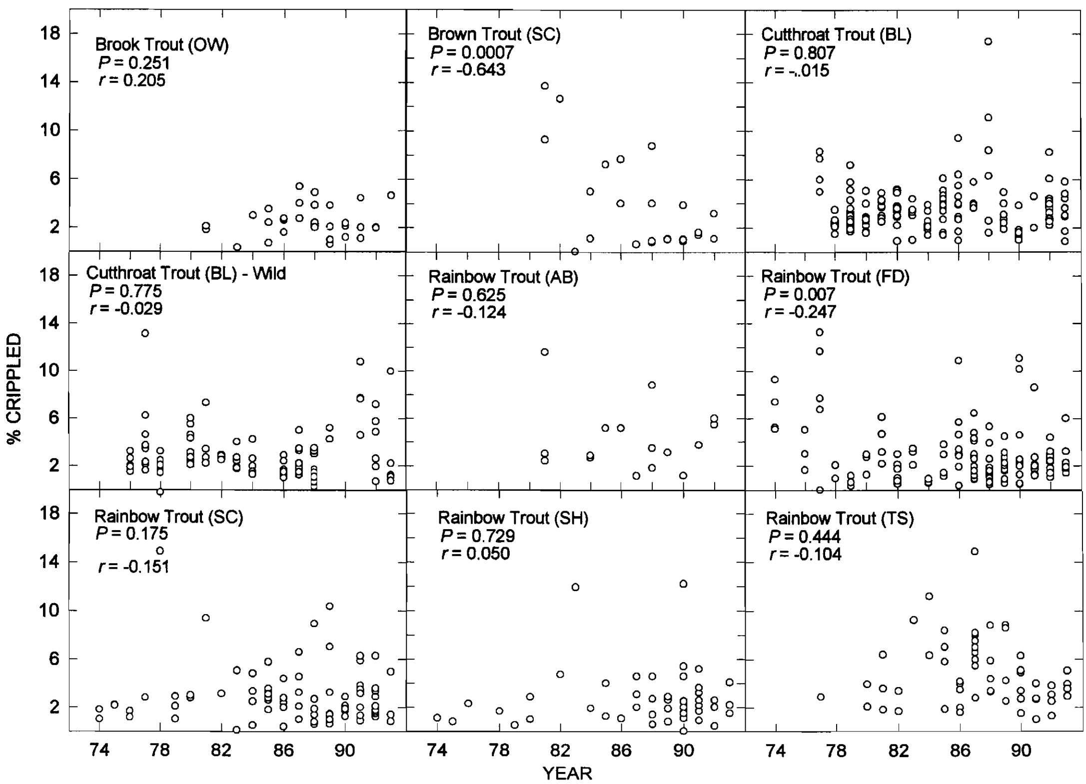

FIGURE 3.—Correlations between the mean percentage of crippled (deformed) fry and year (1974–1993) for Utah salmonid broodstocks. Strain abbreviations are defined in Figure 1. Least-squares regression coefficients (r) and probabilities (P) are given for each correlation.

al. 1983), brook trout, and cutthroat trout (Leary et al. 1984, 1985). However, in a recent evaluation of inbreeding in Wyoming broodstocks, Alexander (1993) found no correlation between enzyme heterozygosity and FA for the twelve stocks examined. It is possible that a certain degree of inbreeding is necessary for the relationship between FA and enzyme heterozygosity to become apparent.

In the present study, the mean FA between hatchery and wild stocks of brown and cutthroat trout were not significantly different, although values for the wild stocks tended to be lower. This indicated that inbreeding was not a problem in Utah hatchery broodstocks. It is remotely possible that FA of wild stocks may be influenced by environmental conditions (Valentine et al. 1973; Ryabov and Kryshev 1990), but alterations are generally associated with toxicants.

Alexander (1993) and Hubert and Alexander (1995) noted considerable variation among observers and by the same observer on different occasions in the counts of the bilateral characteristics. In my study, I conducted all the counts except the RTSC and half the wild fish sampled from the Logan River, which were counted by Scott Miller. This may explain why RTSC had significantly lower mean asymmetry than the other strains. I did not conduct repeated counts on the same fish to determine how precise my counts were, but I did repeat counts relatively frequently on characters for which I was unsure of getting an accurate number. This action would reduce the variability among repeated observations and validate comparisons among the strains evaluated in this study.

Fluctuating asymmetry values of this study were generally higher than those previously published. Alexander (1993) reported values for rainbow trout (1.44–1.76), cutthroat trout (1.89–2.22), brook trout (2.00), and brown trout (1.66). Fluctuating asymmetry in westslope cutthroat trout sampled by Leary et al. (1985) ranged from 1.82 to 1.93 in four wild populations and was 2.24 in a hatchery population. Leary et al. (1984) also measured FA in two brook trout populations (1.43,

TABLE 3.—Mean (±SD) percents for egg survival to the eyed stage (eye-up), hatch, and cripples for salmonid species and strains reared in Utah. Sample sizes are in parentheses. Within a column, means followed by a common letter are not significantly different ($P > 0.05$, Fisher's least-significant-difference test).

Species and strain	Eye-up (%)	Hatch (%)	Cripple (%)
Brook trout			
Owhi	68.1 ± 12.9 xw (11)	81.7 ± 11.8 w (35)	2.6 ± 1.3 yxw (33)
Brown trout			
Sheep Creek	83.5 ± 8.1 z (18)	83.2 ± 16.2 xw (23)	3.8 ± 4.0 yx (24)
Lake trout			
Unknown	66.2 ± 6.5 w (4)	61.1 ± 23.8 v (13)	4.4 ± 1.8 yx (13)
Kokanee			
Sheep Creek	66.0 ± 1.4 w (2)	52.4 ± 19.7 u (7)	1.5 ± 0.4 w (7)
Cutthroat trout			
Bear Lake	79.2 ± 9.0 zy (34)	88.9 ± 9.8 zyx (261)	4.0 ± 5.2 yx (254)
Strawberry Reservoir	82.1 ± 8.1 z (5)	84.7 ± 15.8 yxw (61)	6.6 ± 5.2 z (55)
Rainbow trout			
Albino	70.6 ± 15.0 yxw (21)	88.7 ± 11.4 zyx (18)	3.9 ± 2.8 yx (18)
Fish Lake–DeSmet	77.6 ± 7.7 zyx (20)	89.6 ± 10.9 zy (126)	2.9 ± 2.5 yxw (120)
Sand Creek	82.9 ± 5.9 z (22)	92.1 ± 8.0 z (86)	3.2 ± 3.0 yxw (82)
Shepherd of the Hills	82.3 ± 7.1 z (20)	93.4 ± 4.5 z (50)	2.4 ± 1.9 xw (48)
Ten Sleep	78.6 ± 6.4 zy (19)	91.5 ± 5.4 zy (61)	4.7 ± 2.7 zy (55)

1.59) and ten rainbow trout populations (1.35–1.89).

Are the higher FA values for Utah strains indicative of inbreeding, observer differences, or that FA is essentially unrelated to heterozygosity in some populations? The higher values in the wild stocks evaluated in this study relative to values reported by Leary et al. (1984, 1985) and the observer bias data by Hubert and Alexander (1995), indicate that observer bias is likely responsible for the higher values. The data on egg hatchability, crippling rates, and percent eye-up also tend to support the hypothesis that inbreeding is not a problem among Utah broodstocks. This conclusion does not preclude the possibility that the broodstocks may have suffered genetic drift and lost rare alleles. However, the current broodstock management program is providing viable fish, good egg eye-up and hatching percentages, and high fry survival rates. Further tests of interstrain heterosis and comparison of field survival of hatchery and wild-origin stock are recommended to further explore possibilities for increasing survival and improving the genetics of hatchery strains.

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