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Effects of Electroshock Voltage, Wave Form, and Pulse Rate on Survival of Cutthroat Trout Eggs

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Abstract.—Eggs of cutthroat trout *Oncorhynchus clarki* were exposed for 10 s to continuous direct current (DC), pulsed DC (PDC) at 30 or 60 Hz, or the Coffelt Complex Pulse System (CPS®) wave form. Each treatment was conducted at 150 or 225 V. Treatments occurred every other day from fertilization to development of pigmentation in the eye. A different set of eggs (from the same pooled sample) was tested for each voltage–frequency level and day (i.e., eggs were treated only once). Percent mortality at eye-up of eggs exposed to 150 V PDC was no different from that of controls, whereas mortality of eggs exposed to 150 V DC was greater. Eggs exposed to PDC and DC at 225 V exhibited a significant increase in mortality when shocked on days 4–14 postfertilization. At the higher voltages, CPS also caused significant egg mortality. These results suggest that voltage level is more critical to egg survival than either wave form or pulse rate. If it is necessary to shock over redds, low voltages should be used regardless of the pulse rate or wave form.

Electrofishing is known to injure and sometimes kill juvenile and adult fish (Hauck 1949; Schreck et al. 1976; Sharber and Carothers 1988). Some reports indicate that electroshock reduces egg survival after either broodstock or eggs have been shocked. Marriott (1973) showed that applying 5 A at 110 V of 60-Hz AC to ripe female pink salmon *Oncorhynchus gorbuscha* reduced egg viability by 11.8%. He also showed that shocking freshly fertilized eggs held in a metal container increased mortality. Apparently, the effect is minimal for rainbow trout *O. mykiss* if they are shocked at least 7 months before spawning (Maxfield et al. 1971). Godfrey (1957) exposed several egg stages of brook trout *Salvelinus fontinalis* to 1.7 A at 550 V of DC for 30–300 s. Mortality of early cleavage eggs at 6 d postfertilization increased from 44.4% at 30-s exposure to 100% at 180-s exposure.

In a previous study, Dwyer et al. (1993) showed electroshock can be detrimental to egg survival. Rainbow trout eggs were exposed to a standardized mechanical shock, to electric shock from a backpack electroshocker, or to handling without exposure to either shock. Samples of eggs were exposed to one of the three treatments on alternate days 2–26 postfertilization. Developing eggs were most sensitive to mechanical and electrical shock at 8 d postfertilization at 10.4°C; mechanical shock resulted in 99% mortality, electrical shock in 58% mortality, and handling in only 30% mortality. The mortality of control eggs, which were not handled, was 20%. Results from laboratory tests on eggs of cutthroat trout *O. clarki* showed that the level of electric current used does affect survival of trout eggs. Cutthroat trout eggs placed in artificial redds in a stream were killed by the same voltages used in laboratory tests. Dwyer et al. (1993) concluded that electrofishing over recently deposited trout eggs may increase egg mortality.

Because electroshocking units operate over a wide range of adjustable characteristics, it is important to understand the effects of voltage on egg mortality, as well as the interaction of wave form and pulse rate. The objective of our study was to define the effects of electroshock more clearly by determining the effects of wave form, voltage, and pulse rate on cutthroat trout eggs.

Methods

A Living Stream® fiberglass tank (208 × 55 × 49 cm) was used as an exposure chamber. Water depth was 45 cm. The electrodes were pieces of sheet metal (47 × 56 cm) placed 104 cm apart in screen holders 52 cm from the ends of the tank. The surface of the electrodes covered the entire cross-sectional area of the tank. A shocker connected to the electrodes produced a homogeneous electric field that was verified with a voltage gradient probe attached to a digital voltage meter. The DC and pulsed DC (PDC) were produced with a 5,000-W generator and a Coffelt VVP 10 control box. The duty cycle for the PDC was set at 50% for both frequencies and voltages. The Complex Pulse System (CPS®) wave form was produced with a Coffelt Mark 10 backpack shocker. This is a DC pulsed wave form that consists of three 2-ms spikes 2.1 ms apart with a frequency of 15 Hz (J. Coffelt Manufacturing, personal communication). Conductivity was 388 μS/cm at 7.8°C.

Eggs of Yellowstone cutthroat trout *O. c. bou-*

TABLE 1.—Mean (SD) percent mortalities at eye-up of cutthroat trout eggs electroshocked on one occasion during days 2–18 postfertilization. Values are for three replicates. For a given treatment day (columns), values without a letter in common are significantly different (analysis of variance and Newman–Keuls range tests, $P < 0.05$).

Treatment	Postfertilization day of treatment			
	2	4	6	8
Control	5.0 (1.63) z	4.0 (5.56) z	3.7 (0.94) z	5.3 (1.70) z
Continuous DC				
150 V	5.7 (2.88) z	6.0 (3.74) z	10.3 (3.09) z	19.0 (3.56) yz
225 V	47.0 (7.79) y	[a]	[a]	93.7 (0.94) w
Pulsed DC				
150 V, 30 Hz	9.7 (2.49) z	7.3 (1.70) z	4.7 (2.49) z	6.0 (1.41) z
150 V, 60 Hz	4.0 (0.07) z	6.0 (0.82) z	10.0 (3.74) z	5.0 (0.03) z
225 V, 30 Hz	8.3 (1.70) z	21.0 (7.07) z	73.3 (7.59) x	28.3 (4.19) y
225 V, 60 Hz	6.0 (1.63) z	10.0 (0.82) z	76.0 (5.89) x	32.0 (2.45) y
Complex				
150 V				
250 V				
350 V	52.0 (21.65) y	26.0 (7.26) z	41.0 (1.63) y	46.7 (16.42) x
450 V	[a]	97.0 (1.41) y	98.7 (1.53) x	98.3 (0.47) w

[a] All replicates were lost.

vieri (McBride Lake strain) from the Yellowstone Hatchery of Montana Wildlife, Fisheries and Parks were used. Freshly fertilized eggs (progeny of 30 pairs) were pooled and transported to the Bozeman Fish Technology Center. About 200 eggs, determined by volume displacement (11.3 eggs/mL), were measured into screen baskets (9 × 9 × 3 cm deep) and placed in Heath® Incubator trays. The top tray was not used, so no eggs were exposed to a direct light source. Eggs were exposed only to subdued light for 5–6 min when the baskets were removed for exposure to the test treatment.

The egg baskets were gently removed from the Heath® Incubator, and the eggs were poured into a nylon basket in the exposure chamber. The treatment was applied, and the sample was returned to the incubator. Different sets of egg samples were exposed to electroshocking for 10 s on alternate days 2–18 postfertilization. The treatments were: DC at 150 and 225 V; 30-Hz PDC at 150 and 225 V; 60-Hz PDC at 150 and 225 V; and CPS at 150, 250, 350, and 450 V. The 150- and 250-V CPS treatments were used only on day 10 postfertilization. A different set of eggs was tested for each voltage–frequency combination and each exposure day. We tried to compare voltage gradients and to use 1.0 V/cm as a starting point to make the treatments comparable. This did not work, however, because the digital voltage meters measure an average output and a constant reading was not possible because of the cycling of the short-duration packets of spikes. Results of the CPS® wave form test are difficult to compare to those of the pulsed DC and continuous DC wave forms unless one has some idea of relative capture efficiencies of adult fish. Each treatment group was composed of three replicates of approximately 200 eggs each. Mortality was measured when the eggs reached the eyed stage (eye-up) on day 18. The number of dead eggs was divided by the total number of eggs in each replicate to calculate percent mortality.

Data were analyzed with an unweighted-means analysis of variance. Significant differences among the means were identified with the Newman–Keul's range test at the 0.05 probability level (Hintze 1987). Significant differences between the treatment and the control data were determined for each day.

Results and Discussion

Mortalities of eggs used in the tests comparing 150 and 225-V DC treatments during the 18-d period were 4–29% and 3–99%, respectively, depending on the treatment day (Table 1). Mortality of eggs treated at 225 V DC was significantly higher than that of eggs treated at 150 V on all comparable exposure days up to 16 d postfertilization; data from two of the three 225-V replicates were accidentally lost on days 4 and 6. The mortality of eggs treated with 150 V DC was significantly greater than that of control eggs on days 10 and 12, whereas the mortality of the eggs treated with 225 V DC was significantly greater than that of the controls on days 2, 8–14, and 18.

Egg mortality did not increase over that of the controls at the 150-V PDC settings (Table 1). Mortality at 150 V PDC was 3–10% and 2–10% at 30 and 60 Hz, respectively, depending on the treat-

TABLE 1.—Extended.

Treatment	Postfertilization day of treatment				
	10	12	14	16	18
Control	5.70 (1.25) z	11.0 (7.12) z	7.5 (2.50) yz	3.3 (0.94) yz	3.0 (0.82) z
Continuous DC					
150 V	22.3 (1.25) xy	29.0 (5.35) y	10.0 (2.16) xyz	4.7 (0.47) yz	4.0 (2.16) z
225 V	84.3 (1.25) w	99.3 (0.47) v	88.0 (0.82) v	3.0 (2.16) yz	14.3 (2.36) y
Pulsed DC					
150 V, 30 Hz	7.0 (1.63) z	7.0 (1.41) z	2.7 (0.47) z	5.3 (0.94) yz	3.0 (0.90) z
150 V, 60 Hz	7.0 (2.16) z	10.3 (2.62) z	2.7 (1.25) z	2.0 (0.82) z	3.7 (1.25) z
225 V, 30 Hz	22.0 (4.90) xy	74.7 (3.68) w	19.0 (3.27) wx	8.0 (0.82) y	6.3 (1.25) z
225 V, 60 Hz	27.7 (13.2) x	61.3 (4.11) x	16.0 (7.07) wxy	7.2 (2.63) y	3.7 (1.25) z
Complex					
150 V	9.3 (3.3) yz				
250 V	10.7 (0.94) yz				
350 V	29.3 (3.77) x	35.7 (6.02) y	9.3 (4.50) xyz	6.0 (0.36) yz	6.0 (1.63) z
450 V	81.3 (4.50) w	81.7 (10.66) w	21.0 (4.90) w	11.7 (2.62) x	6.7 (0.94) z

ment day. Mortality of eggs exposed to 225 V PDC was significantly greater than that of control eggs and that of eggs exposed to 150 V PDC on days 6–12. On day 12 mortality of eggs exposed to 225 V of 30 Hz was greater than that of control eggs and that of eggs exposed to 225 V, 60 Hz (Table 1).

Wave form was also tested to determine if there were less harmful forms. Eggs exposed to the CPS wave form at 150, 250, 350, and 450 V showed considerable mortality at the 450 V CPS® setting on exposure days 4–12, and the mortality was significantly greater than that at 350 V during the same period. Mortality at 350 V ranged from 6.0 to 46.7% and was significantly greater than that of controls on days 2 and 6–12 (Table 1). The 150- and 250-V measurements were done only on day 10, and the 350- and 450-V measurements were not done on day 2. The lower two settings were similar in voltage to the 150- and 225-V setting from the Coffelt VVP 15 control box.

Mortalities were also compared between DC and both frequencies of PDC at 150 V (Table 1). There were no significant differences between the control eggs and those exposed to 30-Hz or 60-Hz PDC at 150 V. Mortality of eggs exposed to 150 V DC was significantly greater than that of the other treatments and the control on days 10 and 12 (Table 1).

We compared mortality at 225 V among treatments of DC, 30-Hz PDC, and 60-Hz PDC (Table 1). Mortality of eggs exposed to PDC was significantly greater than that of the control eggs at days 6–16. Eggs exposed to DC had higher mortality than those exposed to PDC on days 2–16, a finding similar to that found for eggs exposed to DC at 150 V on days 10–12. This may have been the result of the continuous setting, which allowed more total electricity into the water than the pulsed settings.

Trout eggs are known to be sensitive to physical shock or handling during development (Rutter 1902; Wales 1941; Post 1974). The data from this study demonstrate that cutthroat trout eggs are also sensitive to electroshock. Susceptibility to electroshock mortality was related to stage of egg development, intensity of shock, and duration of exposure.

Results of these tests demonstrated that lower voltage is less harmful to developing cutthroat trout eggs from fertilization to eye-up than higher voltage. Furthermore, eggs exposed to 150 V or 225 V DC had a significantly greater mortality rate than eggs exposed to the same voltages with PDC on some days.

There was no difference in mortality between the controls and the CPS® wave form treatments at 150 and 250 V, nor was there any difference in mortality related to pulse rate. At 150 and 225 V, the DC produced greater mortality than the PDC at 30 and 60 Hz, indicating that total power may be more important than wave form.

Our findings indicate that electrofishing over recently deposited trout eggs can increase egg mortality. Caution should be exercised when electrofishing is done around redds, especially where populations of wild fish depend on natural reproduction. The most significant effect on mortality of eggs seems to be a result of voltage level rather than wave form or pulse rate. We recommend using low voltage levels for shocking over redds, regardless of the pulse rate or wave form.

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