Evaluation of Electronarcosis as a Tool for Collection of Biological Data from Adult Steelhead Oncorhynchus *mykiss*

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Abstract

We evaluated electronarcosis (EN) as an alternative to traditional techniques for immobilizing adult steelhead during trapping operations designed to collect broodstock for hatchery operations and gathering data for a variety of management and research activities. We compared the rates of fish injury, adult pre-spawn mortality, embryo survival, and spawner handling efficiency of the handling between EN and standard operating procedures with and without chemical anesthetics. Similar rates of injuries occurred in adult steelhead when EN and tricaine methanesulfonate (MS-222) were used to immobilize fish. Similar rates of mortality were observed for developing embryos from parents treated with EN or MS-222. In comparisons between EN and a V-trough without anesthetic, the use of an EN chamber allowed for scale sampling procedures to be completed faster than V-troughs. Fish sex and handling treatment contributed significantly to the models describing survival distribution of steelhead handled using EN or VT without anesthetic. A lower mortality rate in females treated with EN than the V-trough treatment was observed. These data support the further use and evaluation of EN on steelhead when collecting data, biological samples, or broodstock of salmonids in field or hatchery settings.

Introduction

Large numbers of adult salmonids are captured and handled annually throughout the Pacific Northwest portions of North America to collect broodstock for hatchery programs or to collect data that contribute to understanding population status. Handling adult salmonids safely during these procedures can be difficult for these purposes without some form of anesthesia or platform to restrain fish movements. Currently, tricaine methanesulfonate (MS-222) is the only chemical anesthetic approved by the United States Food and Drug Administration (USFDA) for use on fish (Trushenski et al. 2013). However, the label requires a 21-day withdrawal period and complicates practices of immediate release after sampling. Another anesthetic, Aqui-S 20E (AquaTactics Fish Health, Kirkland, WA, USA), allows for immediate release following field based applications but its use in the USA is currently restricted to participants of an Investigational New Animal Drug permit (USFDA INAD 11-741) requiring detailed reporting of its use and effectiveness. Carbon-dioxide (CO_2) can be used as a fish anesthetic and is considered a Low Regulatory Priority compound by the USFDA (USFDA 2011) and thus allows for immediate release but it can be cumbersome to apply in remote field settings and hyperactivity of fish upon exposure to CO_2 charged water (Bell 1987) has injury potential to both fish and workers. Additionally, wide ranging physiological impact is reported in instances of hypercapnia in fishes (Tufts and Perry 1998) that contributes to a slow recovery from exposure to CO_2 charged water (Wagner et al. 2002; Pirhonen and Schreck 2003). Procedures used in various locations also include sampling platforms that restrain fish movements without the use of chemical anesthesia. The V-trough used by Washington Department of Fish and Wildlife (WDFW; Figure 1) is an example of a platform that limits fish movement to promote efficient sampling and frequently used without anesthesia. Fish routinely attempt to escape the V-trough

78 forcing the worker to expend additional effort to restrain fish while sampling. This practice can
79 add risks of injury to both the fish and the worker while increasing the amount of time necessary
80 to collect samples and data.

81 Electricity is an alternative for immobilizing fish for handling and sampling practices.
82 Electroanesthesia (EA) is conducted routinely with modified electrofishing equipment using
83 direct current (DC) or pulsed DC at voltages ranging 100-300 V (Tipping and Gilhuly 1996; Cho
84 et al. 2002; Vandergoot et al. 2011; Faust et al. 2017). Some studies suggest that EA represents a
85 useful alternative to chemically induced anesthesia with adult response and egg survival within
86 acceptable performance levels for a production hatchery and research settings (Tesch et al. 1999;
87 Jennings and Looney 1998; Trushenski et al. 2012). However, numerous studies that include
88 data for a variety of fish species have described the deleterious effects of EA that include
89 intramuscular hemorrhage, vertebral injuries, reduced gamete viability, reduced juvenile growth
90 rates, delayed hatching, and increased mortality (Sharber and Carothers 1988; Dwyer et al. 1993;
91 Hollender and Carline 1994; Thompson et al. 1997; Ainslie et al. 1998; Redman et al. 1998;
92 Keefe et al. 2000). The majority of these EA studies utilized technology that relied upon
93 voltages > 100-120 V. The use of lower DC voltages ($\leq$ 60 V DC) to conduct fish research and
94 fish culture activities has been revisited (Hudson et al. 2011; Vandergroot et al. 2011; Faust et al.
95 2017). This lower voltage approach is distinguished from EA by the responses of the fish to the
96 electric field and has been termed, electronarcosis (EN). While EA results in a persistent
97 quiescent period lasting up to several minutes, EN induces immobilization and muscle relaxation
98 of the fish only while it is held in the electric field (Vibert 1963). As such, EN allows for sorting
99 and collecting potential broodstock with a near immediate recovery upon release.

Many locations where EN would be considered contain fish populations protected by the Endangered Species Act where new protocols for handling these sensitive species requires careful screening for negative impacts. Many authors (Cho et al. 2002; Schill and Elle 2000; Tipping and Gilhuly 1996; Sharber and Carothers 1988) have recommended studies on the long-term effects of EA and EN on the target organism prompting investigations on the application to salmonid species. Keep et al. (2015) found no difference in migratory behavior of adult Chinook Salmon *Oncorhynchus tshawytscha* following EN treatment relative to carbon dioxide treatments. Hudson et al. (2014) observed that survival of embryos produced from adult Coho Salmon *O. kisutch* treated with EN was similar to those from MS-222 treated adults. In these studies, EN was considered preferable to carbon dioxide or MS-222 due to faster induction and recovery times. The objectives of this study were to examine the responses of pre-spawning adult summer-run steelhead *O. mykiss* following EN treatments compare these observations to established practices used to handle these fish (MS-222 or V-trough), compare injuries to spawning adult fish exposed to EN versus MS-222, and the resultant embryo survival, and characterize survival distributions of adult summer-run steelhead following the use of EN or V-trough (with no anesthetic).

Methods

Study location and broodstock collection. – Summer-run steelhead broodstock were trapped in the fall (Sep-Nov) following entry to a fish ladder at the Lyons Ferry Hatchery (LFH) outfall into the Snake River in 2010 and 2011. Fish were sorted from the adult trap by hatchery staff using a series of pipes with hydraulic gate valves that direct fish back to the Snake River when not needed or into adult holding raceways when they are selected for broodstock. LFH adult holding raceways are 3.1 x 24.4 x 1.8 m with a water flow of 3,785 liters/minute. The

123 water supply at LFH is specific pathogen free well water with a constant temperature of ~11°C.
124 Water conductivity at LFH was recorded between 220-240 µS/m.

125 *Electronarcosis Chambers*. – WDFW personnel constructed two different EN chambers
126 (Figure 1) for these studies. Both chambers received electrical current from a Protek 3006B DC
127 Power Supply (0-60 V, 1.5A; Protek Devices, Tempe, AZ). One of the chambers (CH1) was
128 constructed using a 90 cm section of 21.3 cm diameter PVC pipe cut open along the top and
129 capped on each end. Round, 21.3 cm diameter, thin-plate aluminum electrodes were inserted
130 into the cap ends of the pipe, which when fitted held the electrodes in place. A small portion of
131 the cap on each end was cut away exposing the aluminum plate, where leads from the EN power
132 supply were attached. A second chamber (CH2) was constructed following the design described
133 by Hudson et al. (2011), using a 130 l (95 cm x 38 cm x 36 cm) Igloo ™ cooler. A hose receiver
134 was fitted to allow an input of freshwater, and a standpipe installed to maintain constant water
135 depth.

136 A preliminary exercise to test the efficacy of the EN equipment was performed using
137 CH1 on hatchery origin summer-run steelhead captured from the Touchet River adult trap in
138 Dayton, WA. Several fish (55-70 cm) were captured at the trap and introduced individually to
139 CH1 via dip net and their behavioral responses to settings ranging from 30-60 V DC observed.
140 Water temperature in the Touchet River during this initial testing was ~2 ºC and conductivity
141 ranged from 45-50 µS/m. All fish reached a state of EN that permitted sampling the animal at or
142 above 50 V DC output. The best results obtained when settings were at 60 V DC. Fish behavior
143 in the chamber included a loss of equilibrium with the muscles remaining relaxed with a regular
144 opercular rate that was similar to that reported by Hudson et al. (2011). Upon removal from the
145 electrical field, fish resumed their normal orientation and were capable of swimming nearly

immediately (< 3 s). Based on these results, power supply settings for subsequent tests at LFH were established at 60 V output and not exceeding 0.15 amps representing estimates for output at 0.66 V/cm in CH1 and 0.63 V/cm in CH2.

Electronarcosis versus MS-222. – Summer-run steelhead broodstock (44 - 87 cm) were collected from the LFH fish ladder/adult trap from September to November, 2010. All fish retained for broodstock were sorted on 17 November 2010. A divider panel was placed in the middle of the adult holding raceway during sorting, with females retained on the upstream side, and males on the downstream side. On 28 December 2010, all retained females were sorted again, with any ovulating females removed. On that same date, 40 females and 60 males were transferred to an adjacent adult holding raceway, making up the group of fish treated with EN during spawning operations. Prior to the first spawn date, two females and six males had died in the raceway leaving 38 females and 54 males for treatment with EN. Weekly inspections of all fish to determine those ready to spawn in both raceways commenced on 11 January 2010.

During the first inspection, groups of 3-4 fish were placed in the EN unit (CH2) to simulate what might be experienced during hatchery sorting or at a fish trap for broodstock collection or tagging. All fish during this first time in the EN unit were exposed to the electric field for at least one minute. After one minute, fish were removed individually and checked for readiness to ovulate or to shed milt. If fish were determined ready for gamete collection they were euthanized with a sharp blow to the head and placed on a spawning rack until gametes were collected. If the fish were not ready for gamete collection they were injected with a passive integrated transponder (PIT) tags into the dorsal sinus and returned to the adult holding raceway. PIT tags were only applied to the EN group to identify individuals so that the cumulative amount of time exposed to the electric field over the course of the seven-week spawning period be

169 determined. Times for this initial EN exposure varied from 60 to 150 s (average time 85 s, SD =
170 23 s). In subsequent weeks, groups of 3-4 fish were transferred into the EN unit but only
171 remained there until they could be inspected for spawning readiness and PIT tag number
172 recorded (average time 41 s, SD = 21 s). Fish selected for gamete collection were processed as
173 described previously and fish not ready were returned to the holding raceway.

174 A second group maintained during this study was represented by broodstock held in the
175 adjacent raceway and inspected for spawning readiness using MS-222 anesthesia. This group of
176 males and females were crowded in the raceway and groups of 5-10 fish were netted and placed
177 into a ~380 l galvanized metal trough filled with ~230 l water containing 19 g of dissolved MS-
178 222 (Tricaine-S, Western Chemical, Ferndale WA). At this dosage, fish reached a state of lost
179 equilibrium within 1-2 minutes before initiating inspections to determine readiness for gamete
180 collection or returned to the adult holding raceway; the entire time to work through 5-10 fish
181 using MS-222 was 5-10 minutes. Eggs from all ovulating females from both EN and MS-222
182 groups were stripped directly into 4-l buckets. Milt from males of both groups were collected in
183 59 ml Whirlpak® bags that were sealed after the addition of oxygen and placed into a cooler.
184 These procedures for both groups were repeated weekly for seven consecutive weeks thus
185 animals may have been exposed multiple times over the course of the study. At each handling,
186 we identified individual fish treated with EN by recording PIT tag number on each spawning
187 date and recorded the amount of time in the EN chamber to calculate cumulative exposure time
188 (seconds) to the electric field for each animal over the course of the study. Similar data were not
189 recorded for fish treated with MS-222 females as PIT tags were only applied to fish treated with
190 EN.

Spawning crosses were restricted to combining gametes from individual male and female fish within each treatment group (EN x EN, MS-222 x MS-222). From spawn weeks 1-7, all EN treated fish that were spawned were filleted, the carcasses photographed, and the injuries recorded as described by Zydlewski et al. (2008). For the MS-222 treated group, ~20 fish each week were selected from spawn weeks 2-5 to be filleted and photographed. No spawning occurred after week five in the MS-222 group, as production levels for the hatchery program had been reached.

Fertilization procedures for both treatment groups were as follows. After eggs and milt were combined, ~100 mL of water was added to each bucket to activate sperm and enable fertilization. After 1-2 minutes, the buckets were partially filled with an iodophor solution (100 ppm; Ovadine, Western Chemical, Ferndale, WA) and the fertilized eggs then poured through a metal strainer to remove the iodophor solution, excess ovarian fluid, and coagulated blood. Eggs were returned to the bucket, new 100 ppm iodophor solution was added, and the eggs were allowed to harden for one hour. After water hardening, the eggs were then transferred into incubators constructed from two nested 4-gallon square buckets. Water was introduced to the buckets from the bottom of the outside bucket and flowed upward through second bucket containing the eggs through a screen to provide even flow across all eggs. After 14-16 days (161-184 temperature units), the incubating eggs were removed from the buckets and shocked by pouring eggs from the incubation bucket into a second bucket to coagulate nonviable eggs. The following day dead eggs were removed and counted. Weights (0.1 g) of a sample of 300 live eggs and all the remaining live eggs in each bucket were recorded to calculate the number of viable eggs remaining for each spawning pair. Total fecundity for each female was determined as the sum of dead eggs plus live eggs remaining and the percent survival for each spawning pair

calculated. After this shocking date, inventoried eggs were pooled into aggregate EN and MS-222 treated groups with no replicates.

A Fisher's exact test was used to determine differences in the frequencies of fish with and without observed injuries between EN and MS-222 treated fish. Differences in fecundity and egg survival between EN and MS-222 treated fish were determined using t-tests. Egg survival during incubation is highly variable in LFH summer-run steelhead and frequently deviates from normal distributions. As a result, percent survival for eggs was rank-transformed before the t-tests were performed (Zar 1996). The cumulative impact of EN was determined using rank correlation tests to determine any relationship between egg mortality and : 1) the number of times (1-7) the female fish had been exposed to the electric field, and 2) the cumulative amount of time (s) in the EN chamber over the entire seven week spawning season.

Electronarcosis versus V-Trough sampling. – WDFW personnel trapped 549 summer-run steelhead broodstock (50-90 cm) at LFH during early October, 2011 for this test. All fish were held in an adult holding raceway and were crowded and sorted on 12 October. Four hundred summer-run steelhead were assigned equally to two groups, the groups consisting of sampling using EN (CH1) or the V-Trough (VT). The VT used by WDFW allows a fish to lie between two panels (each panel angled at ~45^0 off the base of the platform) with the head covered as data and samples are collected without the use of an anesthetic. Individual fish were captured with a dip net, removed from the net and inserted into the VT or netted and held in the net while being immersed into CH1. The transfer of fish alternated between VT or the CH1 as they were collected. Fork length and fish sex were recorded for all fish. A scale sampling procedure was added for 75 fish from each group. These actions mimic handling procedures that would occur

236 at an adult trap for sampling or broodstock collection. The remaining crowded fish in the
237 holding raceway (N=149) were left unhandled and served as a control group (CT).

238 For both EN and VT methods, the time required to collect data and samples (seconds)
239 was recorded for a subset of animals collected at random from the entire population of both
240 treatments. The amount of time to net and insert individual fish into either the EN unit or the
241 VT, determine fish sex, collect fork length data was recorded for 25 EN fish and 38 VT fish.
242 When scale sampling was added to the process, times for 25 fish from both EN and VT groups
243 were recorded. One staff member was assigned to collect data and samples using EN, another
244 staff member collected the same data using the VT, and a third staff member recorded the
245 biological data and sampling times for both groups. Following data collection and sampling, the
246 upper or lower portion of the caudal fins were clipped for later identification of EN and VT
247 treatment groups and returned to the holding raceway. The CT fish that were not
248 handled/sampled received no mark but were subjected to the same raceway crowding as test fish
249 and maintained in the same adult holding raceway. All mortalities were removed daily from the
250 raceway by hatchery staff with data regarding fin clips recorded until the end of the evaluation
251 on January 17, 2012, for a total of 97 d. The number of fish from each group were confirmed at
252 the end of the study through a tally and examination of records of all mortalities and live fish
253 remaining after 97 d. On 16 December 2011, 32 fish were removed (10 EN, 10 VT, 12 CT) and
254 killed for a basic necropsy inspection and these animals were censored from survival distribution
255 analyses described below.

256 Differences in the amount of time to collect data and samples for EN and VT were
257 determined using t-tests. The threshold for significant differences was $P < 0.05$. Patterns of
258 survival over time for the three groups were modeled using parametric and non-parametric

statistical procedures that characterize time-to-event data (Lawless 1982; Sandford et. al. 2012; Tableman and Kim 2004). In this study the event was the death of a fish of a particular treatment (EN, VT, and CT) and time (days). We modeled survival distributions using two different procedures. First, we used the non-parametric Kaplan-Meier (KM) method (Lawless 1982) to visualize and make straightforward comparisons of survival for each treatment in a data set containing censored observations. We followed this analysis with parametric modeling approaches using commonly applied distributions to describe survival data: logistic, log-logistic, lognormal, Gaussian, Weibull, and exponential (Tableman and Kim 2004). The parametric approach included evaluation of the factors of fish sex, treatment, and their interaction in determining the best model fit for the survival distribution. For each distribution we fit five models: constant (no explanatory variables), treatment alone, sex alone, both treatment and sex, and both including an interaction term. We calculated a measure of the explanatory information for each model, Akaike's Information Criterion (AIC; Burnham and Anderson 2002) as well as the difference between each model's AIC and the minimum of the five, ΔAIC. We chose the model with the minimum AIC as the model that best described the observed data provided $\Delta AIC > 2$ for the other models. In the instance of $\Delta AIC < 2.0$ we omitted models that added a single term to the best model, as the term was not adding information, rather it was just "benefitting" from being added to the best model (i.e., "pretender variables"; Arnold 2010). For each distribution, we selected the best model and then selected the minimum AIC from this group as the best model from all distributions. Analyses of survival distributions were conducted using R, specifically with the survival package (R Core Team 2017, Therneau 2015).

Results

Electronarcosis versus MS-222. – Injuries consistent with spinal and intramuscular hemorrhage occurred at low frequency and at similar rates in both the EN and the MS-222 treated group of adult summer-run steelhead ($P > 0.99$; Table 1). Mean fecundity did not differ significantly between treatment groups ($P = 0.43$; Table 2). Mortality of 100% of the developing embryos was observed between fertilization and the eyed stage in 13.6% of spawned females collected in the MS-222 treated group and 3.1% of spawned females in the EN treated group. Median rates of mortality between fertilization and the eyed stage in EN and MS-222 treated fish were 10.5 and 10.0%, respectively. No significant difference in the rank-transformed percent mortality from fertilization to eyed-egg stage between the EN and MS-222 treated groups were observed ($P = 0.11$). Results of the rank correlation test indicate weak negative relationships for both egg mortality versus the number of exposures (R = -0.25, N=31) and between egg mortality versus cumulative exposure time (R = -0.12, N=31). Losses from individual spawns were not followed from the eyed stage through hatching as eggs were combined following initial inventory, but mortality between the eyed egg stage and the hatched alevin stage from MS-222 broodstock was 2.7% and in EN treated, 3.1%.

Electronarcosis versus V-Trough sampling. – A similar amount of time elapsed for sampling fish using EN and the V-trough when no scales were collected, ~25-26 s. However, when scales were collected, the average time required to net, sample, and release fish in the EN group, 40 ± 1 s (Mean ± SE), was significantly ($P < 0.01$) less than fish processed in the V-trough, 51 ± 2 s.

Following return into the raceways, no mortality was observed for any cohort for nearly 40 d (Figure 2). At ~40 d, VT females began to die, followed two weeks later by females from other treatment groups. The rate of mortality increased in VT and EN treated males ~2 weeks

after it was observed in females and followed finally by an increase in the mortality rate in CT males. At the termination of the study, 97 days after treatment, the surviving proportions among groups of females were 40, 52, and 54% for VT, EN and CT , respectively. Surviving proportions among groups of males were 82, 84 and 90% for EN, VT, and CT , respectively. Parametric survival distribution analyses revealed that regardless of distribution employed in the survival estimation modeling, except for the exponential model, the model of treatment and sex (and no interaction) was best supported by the data (Table 3). We rejected the exponential distribution since the exponential distribution is a special case of the Weibull distribution with scale parameter = 1.0. The estimated scale parameter from our Weibull fit was 0.16. Four of five remaining interaction-term models had ΔAIC near 2.0 (range 1.4-1.8; exception was Weibull at 3.12) but were omitted from further consideration as the edition of the interaction term fit the 'pretender' variable description (Arnold 2010). Comparison by AIC of the all the distributions indicated the Gaussian model of fish sex and treatment was best (Table 4). The estimated curves for VT treated fish were very similar to the unhandled controls for both males and females (Figure 2). Mortality in males was very low relative to females and only began dying at an increased rate between days 70 and 80.

Discussion

The EN units developed for these studies were successful at handling and sampling adult summer-run steelhead relative to MS-222 or V-board treatments. As the number of tasks surrounding sampling and data collection increased, the benefits of EN relative to the use of no anesthetic became more apparent. The added time required to sample scales, identify fish sex, and collect length data for the V-board with no anesthetic group are likely the result of a single worker required to better secure the fish while sampling. Handling fish without any anesthesia

also had a negative impact on female steelhead vitality relative to the use of EN. Our data illustrate that female steelhead handled using EN had higher survival than females handled using VT without anesthetic. Mortality in females was high relative to males in all groups in this study. Factors contributing to this higher mortality include female fish with diminished vitality as eggs may have matured to a post-ovulatory state combined with the absence of any prophylactic treatments with formalin to control fungus. Immobilization in the absence of anesthesia likely promotes more assertive practices to restrain fish movement leading to a greater rate of surface injuries and loss of surface mucus that promotes fungal infection (Green and Haukenes 2015). Our choice in this study was to avoid confounding variables that would mask the impact of handling treatment such as prophylactic treatments with formalin that would not be available in the context of an immediate release to the environment. We acknowledge that the maintenance of steelhead in concrete raceways without formalin treatments likely contributed to the overall mortality reported here. However, our interpretation of the data, females treated with VT in the absence of chemical anesthesia were compromised and had lower long-term vitality relative to those treated with EN. Complete losses of entire families of progeny between fertilization and inventory (161-184 temperature units) were more frequent among MS-222 treated parents than in EN treated parents. Questions surrounding anesthetic use during spawning operations and gamete quality have prompted study on this topic for decades (Billard 1980; Redman et al. 1998) but a targeted evaluation of MS-222 impact on egg and sperm quality at relevant concentrations revealed no direct impact (Holcomb et al. 2004). We acknowledge that confounding factors can contribute to losses of eggs incubation trays but our observation should illustrate, at minimum, that there is no evidence of a relationship between exposure time to the electric field and increased embryo mortality and suggest that EN may be a suitable

alternative to MS-222 in handling pre-spawning steelhead. Finally, the rates of injury on broodstock were low during spawning operations and comparable to those using MS-222. Our data are consistent with experiments performed on Coho Salmon using similar equipment and also illustrated no effect on EN on progeny of treated parents (Hudson et al. 2014). While not a new technology (Kynard and Lonsdale 1975) reports describing the impacts of EN on fish and their progeny is sparse (Vandergroot 2011; Hudson et al 2014) relative to EA induced by V DC used at higher voltage gradients (Tipping and Gilhuly 1996; Barton and Dwyer 1997; Ainslie et al. 1998; Zydlewski et al. 2008). In aggregate our data on adult steelhead provide further support the continued use of EN in situations where the withdrawal times of chemical anesthetics cannot be controlled.

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Zydlewski G. B., W. Gale, J. Holmes, J. Johnson, T. Brigham, and W. Thorson. 2008. Use of electroshock for euthanizing and immobilizing adult spring chinook salmon in a hatchery. North American Journal of Aquaculture 70:415-424.

475 Table 1. Incidence of hemorrhaging near the spine and non-spinal for male and female summer-
476 run steelhead spawned at LFH in 2010. No significant differences ($P > 0.99$) in the frequency of
477 injuries was observed between chemical anesthesia (MS-222) and electronarcosis (EN).

	MS-222		EN	
	Males	Females	Males	Females
Number examined	40	41	35	32
Number of injuries				
Non-Spinal	4	0	2	0
Spinal	0	1	1	1
Total	4	1	3	1
Percent	6.2%		6.0%	

478

479

480 Table 2. Mean fecundity (eggs/female) for female summer-run steelhead on each spawning date.

481 No overall difference in fecundity was observed between treatments ($P = 0.43$).

	Electronarcosis		MS-222	
Spawn Date	Number of Females	Fecundity	Number of Females	Fecundity
11 Jan	7	5897	27	5789
18 Jan	7	5241	18	5853
25 Jan	5	5498	20	6321
1 Feb	1	7610	15	5965
8 Feb	6	6471	8	5308
16 Feb	5	5189		
23 Feb	1	5779		
Mean (± SD)		5737 ± 992		5909 ± 1066

482

483

484

485 Table 3. Model comparisons by Akaike's Information Criterion (AIC) for survival distributions
486 of male and female summer-run steelhead handled using electronarcosis, V-board, or unhandled
487 control within different parametric distributions. ΔAIC is comparison with minimum AIC in
488 each distribution.

Distribution	Model	df	AIC	ΔAIC
Weibull	Constant	2	2193.88	70.58
	Sex	3	2125.91	2.61
	Treatment	4	2193.94	70.63
	Treatment + Sex	5	2123.30	0.00
	Treatment + Sex + Interaction	8	2126.43	3.12
Exponential	Constant	1	2602.23	49.44
	Sex	2	2552.79	0.00
	Treatment	3	2604.06	51.28
	Treatment + Sex	4	2554.19	1.41
	Treatment + Sex + Interaction	7	2558.25	5.46
Gaussian	Constant	2	2194.71	83.78
	Sex	3	2119.87	8.94
	Treatment	4	2188.47	77.55
	Treatment + Sex	5	2110.93	0.00
	Treatment + Sex + Interaction	8	2112.44	1.51
Logistic	Constant	2	2195.66	79.02
	Sex	3	2122.92	6.27
	Treatment	4	2193.03	76.38
	Treatment + Sex	5	2116.65	0.00
	Treatment + Sex + Interaction	8	2118.26	1.61
Lognormal	Constant	2	2210.81	82.09
	Sex	3	2138.55	9.83
	Treatment	4	2203.67	74.96
	Treatment + Sex	5	2128.72	0.00
	Treatment + Sex + Interaction	8	2130.13	1.42
Loglogistic	Constant	2	2196.26	76.20
	Sex	3	2126.10	6.04
	Treatment	4	2193.71	73.65
	Treatment + Sex	5	2120.06	0.00
	Treatment + Sex + Interaction	8	2121.84	1.78

489

Table 4. Model comparisons by Akaike's Information Criterion (AIC) for survival distributions of summer-run steelhead handled using electronarcosis, V-Board, or unhandled control between parametric distributions. The best model chosen from within the five models in each distribution. ΔAIC is comparison with minimum AIC for all distributions.

Distribution	Best Model	df	AIC	ΔAIC
Weibull	Treatment + Sex	5	2123.30	12.38
Exponential	Sex	2	2552.79	441.86
Gaussian	Treatment + Sex	5	2110.93	0.00
Logistic	Treatment + Sex	5	2116.65	5.72
Lognormal	Treatment + Sex	5	2128.72	17.79
Loglogistic	Treatment + Sex	5	2120.06	9.13

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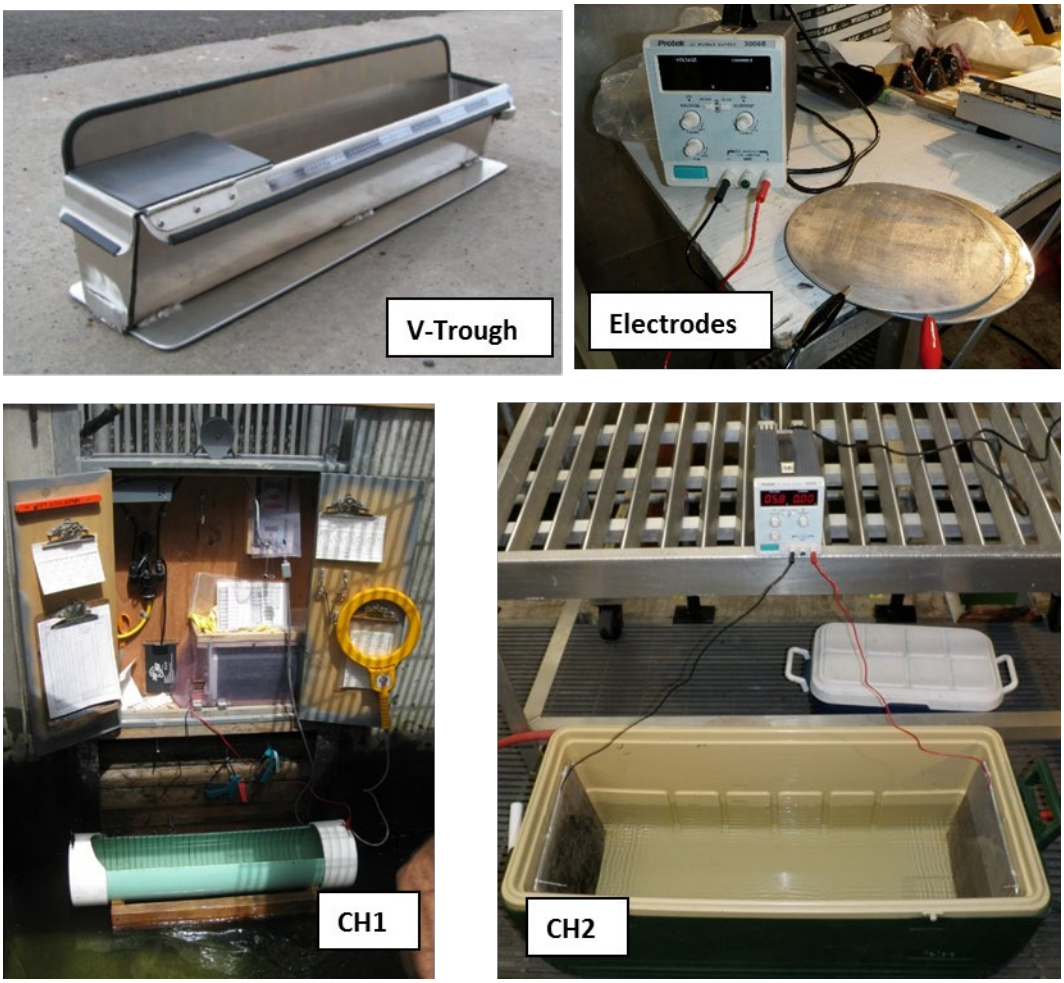

Figure 1.

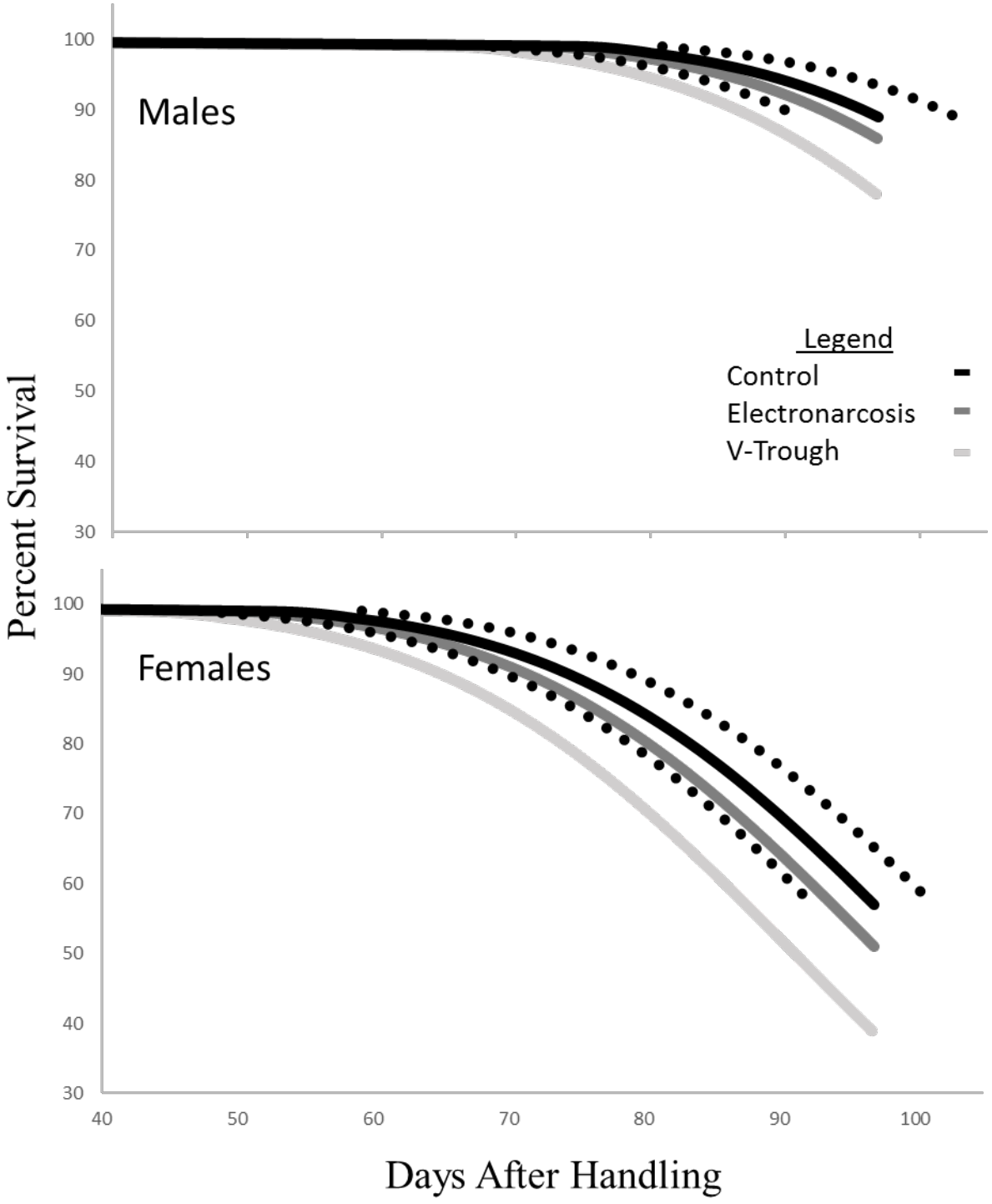
Males
Females
Legend
Control
Electronarcosis
V-Trough
Percent Survival
Days After Handling
100
90
80
70
60
50
40
30
40
50
60
70
80
90
100

Figure 2

516

517