AN EXPERIMENTAL STUDY OF THE EFFECTS OF GALVANONARCOSIS ON BEHAVIOR AND GROWTH OF RAINBOW TROUT (SALMO GAIRDNERI, RICHARDSON) AND CHANNEL CATFISH (ICTALURUS PUNCTATUS, RAFINESQUE)

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ABSTRACT

Yearling rainbow trout and channel catfish were subjected to one-half and three-hour periods of narcosis by continuous direct current. The immediate and delayed effects of galvanonarcosis on aspects of behavior were investigated as well as the long-term effects on growth.

Galvanonarcosis treatments decreased the immediate individual and group activity in both fish. Individual and group activity of treated fish increased after 24 hours of recovery to levels of activity equivalent to control fish. Photonegative response was strong in both fish species and was not influenced by direct current treatments. Trout narcotized with direct current were more vulnerable to bass predation than untreated fish. No deleterious effects of galvanonarcosis treatments were evident from growth studies. The potential of galvanonarcosis as a fish immobilization technique is discussed.

INTRODUCTION

Electrical immobilization of fish has been investigated primarily as a means of fish collection. Investigations of the response of fish to electrical immobilization have focused on neurophysiology of immobilization, description of the response of fish during electrical treatment, and gross effects after treatment.

Several hypotheses have been proposed on the reaction of fish in direct current. Harreveld (1938) first reported on the orientation of fish toward the anode (+ plate) while in a direct current field. He hypothesized that this was a reflex response due to stimulus impulses from the periphery. Danyulite and Malyukima (1966) feel that the anodic response is due to the electric field polarizing the spinal cord. How fish are immobilized by continuous direct current still remains a controversy. Scheminzky and Kollensperger (1938) felt that immobilization was the result of a narcotic effect of a biochemical that developed in the spinal marrow. Subsequent investigations have resulted in disagreement over whether immobilization is a result of nerve blockage (Hartley 1967) or inhibition of message transmittal from the brain because of polarization (Vibert 1963).

As the voltage of direct current is increased, fish succumb to a state of narcosis. If the voltage is increased further, the fish goes into the tetanus phase of immobilization. Galvanonarcosis in fish has been defined as a state of

immobility resulting from muscular slackening under the action of constant and continuous current (Vibert 1967). Tetanus is distinct from narcosis and is due to muscular rigidity. Vibert (1963) showed that narcosis from continuous direct current occurs at a much lower voltage gradient than tetanus (0.32 versus 1.2 v/cm).

Investigations of the effects of electrical treatment on fish have focused primarily on survival and growth of rainbow trout, Salmo gairdneri (Taylor, Cole, and Sigler 1957; Maxfield, Lander, and Liscom 1971), bluegill, Lepomis macrochirus (Spencer 1967), channel catfish, Ictalurus punctatus (Ellis 1974). In these studies, fish immobilized with direct current had little to no injuries, especially when voltage gradients were less than 1.5 volts per centimeter. The absence of gross effects does not necessarily mean that fish were not affected. Goddard, Lilley, and Tait (1974) showed that lake trout, Salvelinus namaycush, which recovered from anesthetization by MS-222 did not show normal temperature selection behavior for five days. Direct current immobilization of fish may have similar subtle effects on the behavior of fish.

This study is an experimental investigation of the effects of extended galvanonarcosis on the behavior and growth of channel catfish, Ictalurus punctatus, and rainbow trout, Salmo gairdneri. By evaluating aspects of fish behavior, subtle effects of electrical treatment can be investigated that would not be apparent from gross inspection. Internal motivating mechanisms and external stimuli influence the activity response of an animal (Eibl-Eibesfeldt 1970). Swimming activity is a partial reflection of the general activity and

motivation of a fish. Measurements of swimming activity of individual and groups of treated and untreated fish were used to determine the effects of galvanonarcosis on this activity. The selection of shaded habitat by rainbow trout has been interpreted as a protective response to fright and unfamiliarity with habitat (Ritter and McCrimmon 1973). Any deleterious affect of electrical treatment on this behavior could affect the ability of fish to respond normally in their natural habitat. Photonegative response was investigated in this study to confirm that galvanonarcosis does not affect this behavior in rainbow trout (Kynard and Lonsdale 1975) and to evaluate this habitat preference in treated and untreated channel catfish. Survival of fish can often depend on how it evaluates and responds to the approach of a predator. Coutant (1973) and Coutant, Ducharme, and Fisher (1974) have shown that thermal shock can affect the vulnerability of fish to predation. Growth of fish is often an indicator of its general condition over a long period of time. Kynard and Lonsdale (1975) reported that extended galvanonarcosis did not affect growth in rainbow trout. Growth studies were done in this investigation to confirm that galvanonarcosis has no long-term deleterious effects on growth.

MATERIALS AND METHODS

Treatment

Experiments were conducted at the laboratory facility and the off-campus research complex of the Arizona Cooperative Fishery Unit at The University of Arizona. Fish used in experiments were channel catfish 45-80 mm standard length obtained in October, 1974, from the Arizona Game and Fish Department. Yearling rainbow trout 50-87 mm standard length were obtained from the National Fish Hatchery, Alchesay-Williams Creek, Arizona, in March, 1975. Fish were held in 1600 liter holding tanks for two weeks and fed Purina Fish Chow prior to any experimentation.

Tap water used in all experiments was aged for at least two days. During electrical treatments for growth studies, specific conductance ranged from 350-575 micromhos/cm. Water temperatures were 20.0-24.0° C for catfish and 14.8-17.0° C for trout. In behavioral treatments, conductivity was 1100-1375 micromhos/cm and temperature 15.0-20.0° C for catfish and 12.0-18.0° C for trout.

The ability to distinguish individual fish or groups of fish was necessary in all evaluations. Experimental and control fish were marked for recognition by cold branding with liquid nitrogen (Fujihara and Nakatani 1967). Fish were held for 72 hours after branding to check for mortalities and appearance of brands.

Test fish were narcotized in a plexiglass aquaria (36 cm X 20 cm X 22 cm). Electrodes of sheet aluminum (20 cm X 22 cm) were used during tests on catfish. These were replaced by stainless steel plates for tests on rainbow trout because of deterioration from electrolysis. The average voltage drop from the plate to water interface was 1.5 v in both cases. During experiments, the polarity was reversed every 30 minutes to minimize water quality changes from electrolysis. Air was supplied to all tanks during experiments and evaluations.

An EICO model 1020 power supply was used as the source of direct current. Fish were narcotized by increasing the voltage until 100 percent of the treatment group were immobilized or resting on one side as a result of muscular slackening (Vibert 1967). Voltage was then decreased until at least 80 percent of the treatment group remained in narcosis. Field intensity ranged from 0.42-0.56 volts/cm for trout and 0.56-0.69 volts/cm for catfish. Approximate head to tail voltages were 2.1-4.9 volts for trout and 2.5-5.5 volts for catfish, depending on the size of the fish. These were determined by the formula $V_{H-T} = E\ (L)$ volts where E is the electric field intensity and L is the length of the fish (Edwards and Higgins 1973; Kynard and Lonsdale 1975).

Fish were treated for periods of one-half and three hours. Six-hour treatments were initially investigated but were discontinued after preliminary tests with catfish.

Individual Activity

The effect of galvanonarcosis on the individual activity of fish (represented by horizontal swimming activity) was investigated immediately after treatment and again after 24 hours to determine if their activity differed from control fish. Experimental and control fish were marked for individual recognition so the activity change of each fish could be followed. Group size was limited to three fish because of the time needed for each evaluation. After treatment, individual fish were placed in a tank (60 cm X 45 cm X 45 cm; water depth 30 cm) and allowed to quieten for five minutes. The immediate effect of galvanonarcosis on activity was evaluated by using a grid of 7.5 cm squares (drawn on the glass tank cover) to measure the number of squares each fish passed through in three minutes. After individual evaluations, treatment and control fish were held together in an equivalent tank and checked again after 24 hours.

Mean activity for immediate and 24 hours were compared within each group to determine if there was a significant change in activity. Means were compared between experimental and control groups to determine if galvanonarcosis affected the activity of treated fish. Students t-test was used in these evaluations.

General Activity and Photonegative Response of Groups of Fish

Preliminary observations of treated individual fish indicated that swimming activity increased when several conspecifics were present. General

activity of treated and untreated groups of fish was studied to determine if it may be influenced by galvanonarcosis. General group activity was defined as the number of fish in a group (n=5) displaying directed upright swimming. The relative number of fish from the group that were in the shaded half of the test environment represented the photonegative response. Photonegative response of experimental and control fish was investigated concurrently with group activity. Both evaluations were done in drums 58 cm in diameter with water 30 cm deep. One-half of the tank was shaded by a cover and one-half illuminated by a 130 v overhead floodlight. Relative light intensity (measured with a submarine photometer) was 50 percent at the surface. Percent of surface light at the bottom was 42 percent in the light area and 0 percent in the shade.

After electrical treatment, experimental and control groups were released in separate tanks at the shade-light interface and initial habitat preference noted. After three minutes, treated and untreated groups were observed for 15 minutes. A score was kept of the number of fish moving and the number of fish in the shade at the end of each minute. Fish were left in the experimental tanks for one hour and observed again for five minutes. Treated and untreated groups were then placed together in a tank (60 cm X 45 cm X 45 cm). After 24 hours, test and control groups were separated and placed in the experimental tanks and were checked again for immediate preference, group activity, and photonegative response.

Chi-square analysis was used to test the hypothesis that experimental and control groups did not differ in their group activity and photonegative

response. The results from each immediate preference test were five or less units. Since this is below the recommended values for individual chi-square comparisons (Sokal and Rohlf 1969), data from the immediate preference tests were pooled for each treatment category so comparisons could be made by chi-square analysis.

Predation

Vulnerability of electrically immobilized fish to predation was examined by exposing equal numbers of treated and control fish to two large mouth bass, Micropterus salmoides (30-35 cm). These predators were starved for 48 hours before each test. At the end of a one- or three-hour electrical treatment, five experimental and five control fish were mixed in a 18.9 liter container. The container was covered by a net and placed on the bottom of the circular predator tank (165 cm diameter; water 60 cm deep, which was bare of any cover for prey). Fish were released simultaneously one to five minutes after introduction by removing the net, inverting the container, and removing the container from the tank.

Experiments were terminated after approximately 50 percent of the total group were eaten or at the end of one-half hour (Bams 1967; Coutant 1973). The number of test and control fish that remained was recorded and pooled with results of all tests of that treatment time. Chi-square analysis was used to test the hypothesis of no difference in vulnerability of treated and untreated fish.

Growth

To evaluate the effects of galvanonarcosis on growth, 25 experimental and 25 control fish were marked so individual growth changes could be followed. The day before electrical treatment, fish were individually weighed and measured. Immediately after electrical treatment, treated and untreated groups for that experiment were held in separate 60 cm X 45 cm X 45 cm tanks. Fish were fed an amount of Purina Fish Chow equal to four percent of the starting biomass of each group so food would not be a limiting factor (Kilambi, Noble, and Hoffman 1970; Kynard and Lonsdale 1975). Tanks were heated during growth studies on catfish (temperature 20.0-28.0^{o} C). Experiments were terminated after 28 days for catfish treated for three hours and after 15 days for the half-hour treatment group. Studies on both treatments of rainbow trout were stopped after 17 days (temperature 12.0-15.0^{o} C).

Fish were individually weighed and measured at the end of the experiment. Mean weights and standard lengths were compared by Students t-test within each group for growth determinations and between experimental and control groups to evaluate the effect of electrical treatment.

RESULTS

Individual Activity

Low levels of mean individual activity in the immediate evaluations indicated that there was a definite effect of galvanonarcosis on fish activity (Table A1). All treatment groups showed an increase in activity after 24 hours (Fig. 1), but only the increase for catfish treated for one-half hour was significant by t-test at the 0.05 level (Table A1). Control groups showed no significant change in activity in the immediate to 24-hour comparisons (Table A1).

In the immediate evaluations, fish treated by galvanonarcosis were less active than untreated fish in mean individual activity (Table A1). There was no apparent difference in mean activity in the 24-hour comparisons. This indicated that the initial depression of individual activity in treated fish did not last.

General Activity of Groups of Fish

In all treated groups except trout treated for three hours, the level of activity immediately after treatment was lower than after 24 hours of recovery (Fig. 2). There was no significant change in the activity of control groups except for the one half-hour rainbow trout group (Table 1, Table A2). The individual treatment chi-square values of this group showed that activity levels were approximately the same after 24 hours in four of the six individual comparisons

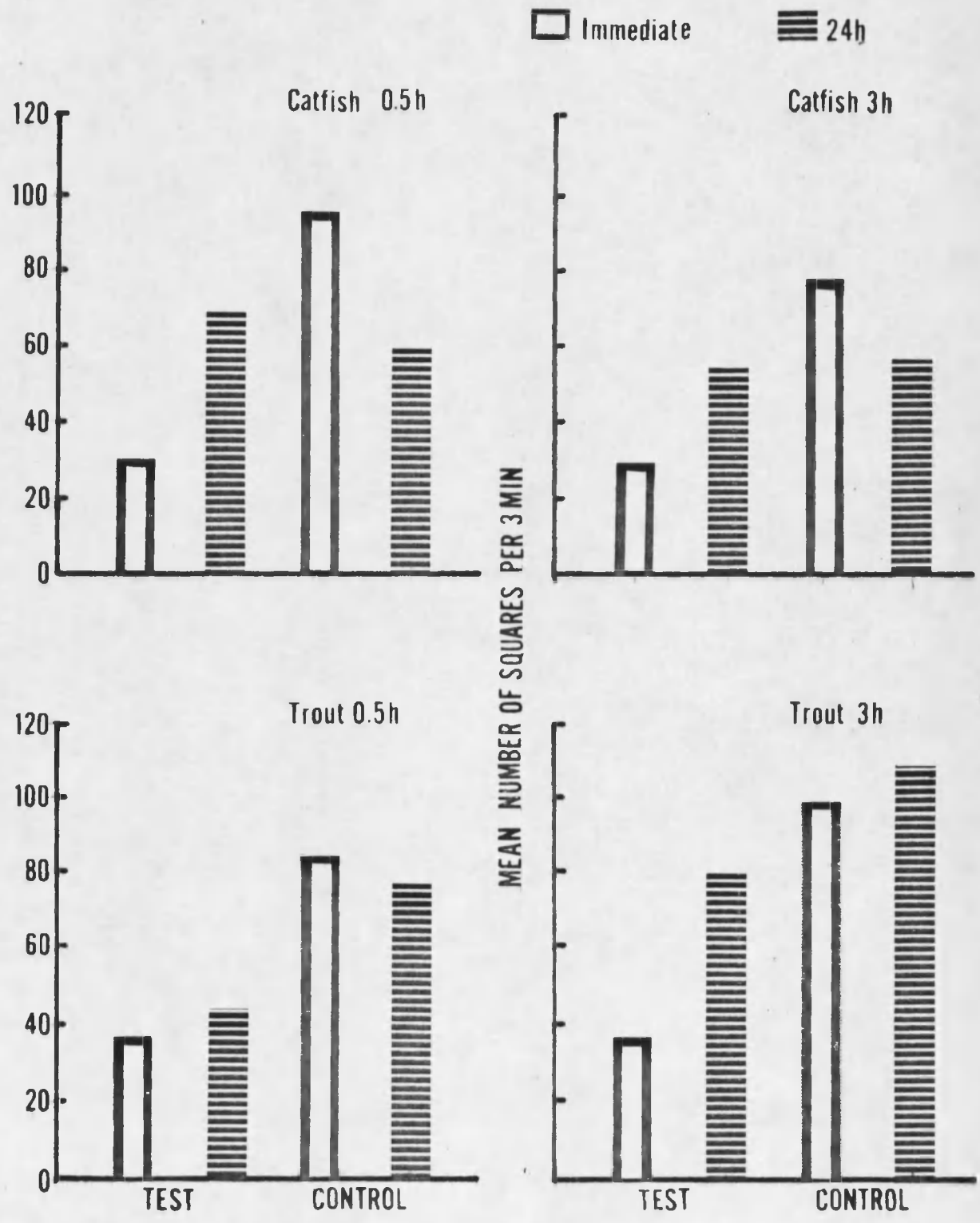

Fig. 1. Individual activity.

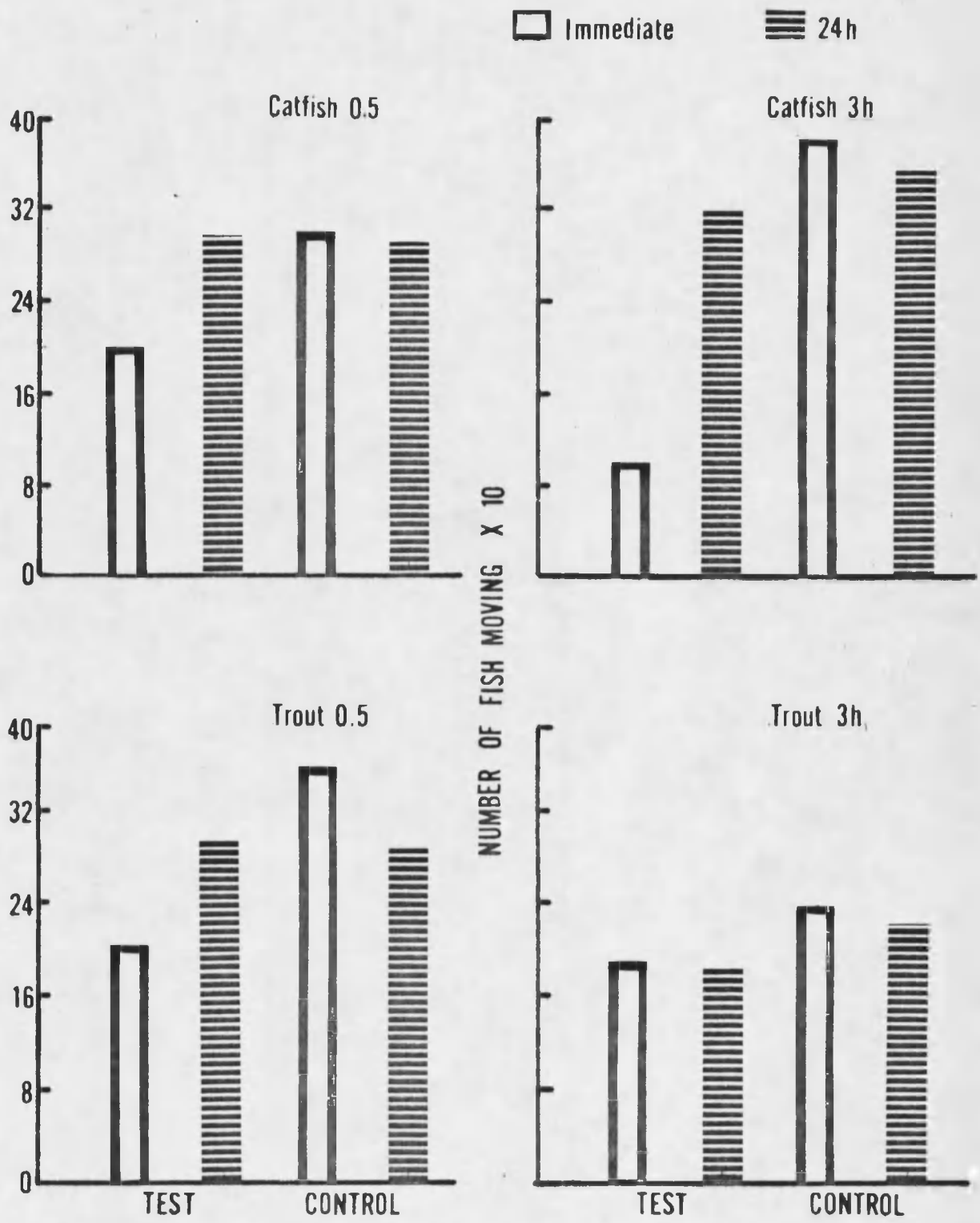

Fig. 2. General activity of groups of fish.

Table 1. Within group comparisons of the number of Rainbow Trout moving immediately after treatment and after 24 hours of recovery.[a]

Immediate	24 Hour	Expected	χ^2	df	p
			Treatment 1/2 hr.		
4	37	20.5	26.5610	1	<.005[d]
10	59	34.5	34.7971	1	<.005[d]
55	26	40.5	10.3827	1	<.005[d]
38	48	43.0	1.1628	1	<.50
72	67	69.5	0.1799	1	<.75
18	51	34.5	15.7826	1	<.005[d]
			88.3661	6	<.005[d]
197	288	242.5	17.0742	1	<.005[d]
			71.7919	5 (H)	<.005[d]
			Control 1/2 hr.		
Immediate	24 Hour	Expected	χ^2	df	p
67	54	60.5	1.3967	1	<.25
61	65	63.0	0.1269	1	<.75
54	25	39.5	10.6456	1	<.005[d]
52	44	48.0	0.6667	1	<.50
57	61	59.0	0.1356	1	<.75
69	32	50.5	13.5545	1	<.005[d]
			26.5260	6	<.005[d]
360	281	320.5	9.7364	1	<.005[d]
			16.7900	5 (H)	=.01[c]

Table 1. (Continued)

Treatment 3 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
43	49	46.0	0.3913	1	< .75
32	26	29.0	0.6207	1	< .50
32	17	24.5	4.5910	1	< .50[b]
39	37	38.0	0.0526	1	< .90
47	46	46.5	0.0175	1	< .90
			5.6739	5	< .50
193	175	184	0.8804	1	< .50
			4.7935	4 (H)	< .50

Control 3 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
46	56	51.0	0.9804	1	< .50
70	46	58.0	4.9655	1	< .05[b]
40	34	37.0	0.4864	1	< .50
48	53	50.5	0.2475	1	< .75
41	33	37.0	0.8649	1	< .50
			7.5447	5	< .75
245	222	233.5	1.1327	1	< .50
			6.4120	4 (H)	< .75

[a]Summed over 15 minutes. [b]Significant at .05. [c]Significant at .01.

[d]Significant at .005. H = heterogeneity chi-square.

P = probability of a larger value of χ^2

(Table 1). This trend was not reflected by the pooled comparison because of the influence from treatments three and six (Table 1).

Immediate activity of groups of fish exposed to galvanonarcosis was also lower than the activity of control groups (Fig. 2). In some experiments, this difference was still significant after one hour of recovery (Table 2, Table A3). This pattern of low group activity immediately after galvanonarcosis was not as distinct in trout treated for three hours. Four of the six individual treatment chi-square values of this group indicated treated and control groups did not differ in group activity (Table 2). The pooled chi-square value of the three-hour trout comparisons indicated a significant difference in the group activity of treated and untreated groups of fish ($X^2 = 6.17 : p = 0.025$). The general group activity of trout treated for three hours did differ behaviorally from control groups even though four of the individual treatment comparisons indicated equivalency (c.f. discussion).

After 24 hours of recovery, almost all treated groups increased in group activity and were equivalent in activity level to control groups (Table 2, Table A3). Trout treated for three hours were still less active than controls after 24 hours. This trend was not evident from the individual treatment comparisons of this group (Table 2).

Photonegative Behavior

Rainbow trout and channel catfish were photonegative in their immediate habitat preference and continued to be photonegative after initial introduction.

Table 2. Comparison of the activity of treated and untreated groups of fish immediately after treatment, one hour after treatment, and after 24 hours of recovery.

Rainbow Trout 0.5h treatment						
Observation Period	Observed Test	Control	Expected	χ^2	df	p
Immediate	4	67	35.5	55.9014	1	$<.005^c$
	10	61	35.5	36.6338	1	$<.005^c$
	55	54	54.5	0.0092	1	$<.95$
	38	52	45.0	2.1778	1	$<.25$
	72	57	64.5	1.7442	1	$<.25$
	18	69	43.5	29.8966	1	$<.005^c$
	197	360	278.5	126.3630	6	$<.005^c$
				47.7002	1	$<.005^c$
				78.6628	5 (H)	$<.005^c$
1 hr.	4	24	14.0	14.2857	1	$<.005^c$
	18	25	21.5	1.1395	1	$<.50$
	23	24	23.5	0.0213	1	$<.90$
	4	22	13.0	12.4615	1	$<.005^c$
	23	23	23.0	0.0000	1	$=1.00$
	22	19	20.5	0.2195	1	$<.75$
	94	137	115.5	28.1275	6	$<.005^c$
				8.0043	1	$<.005^c$
				20.1232	5 (H)	$<.005^c$
24 hr.	37	54	45.5	3.1758	1	$<.1$
	59	65	62.0	0.2903	1	$<.75$
	26	25	25.5	0.0196	1	$<.90$
	48	44	46.0	0.1739	1	$<.75$
	62	61	64.0	0.2813	1	$<.75$
	51	32	41.5	4.3494	1	$<.05^a$
	288	281	284.5	8.2903	6	$<.25$
				0.0861	1	<1.00
				8.2042	5 (H)	$<.25$

Table 2. (Continued)

Observation Period	Observed Test	Observed Control	Expected	χ^2	df	p
			Rainbow Trout 3h treatment			
Immediate	43	46	44.5	0.1011	1	< .90
	32	70	51.0	14.1568	1	< .005[c]
	32	40	36.0	0.8889	1	< .50
	39	41	40.0	1.0500	1	< .90
	47	48	47.5	0.0105	1	< .95
	193	245	219.0	15.2073	5	< .005
				6.1735	1	< .005
				8.0338	4 (H)	< .100
1 hr.	12	16	14.0	0.5714	1	< .50
	11	25	18.0	5.4444	1	< .025[a]
	17	25	21.0	1.5238	1	< .25
	3	25	14.0	17.2857	1	< .005[c]
	15	25	20.0	2.5000	1	< .25
	58	116	87.0	27.3253	5	< .005[c]
				19.3333	1	< .005[c]
				7.7920	4 (H)	< .25
24 hr.	49	56	52.5	0.4667	1	< .50
	26	46	36.0	5.5556	1	< .025[a]
	17	34	25.5	5.6667	1	< .025[a]
	37	33	35.0	0.2286	1	< .75
	46	53	49.5	0.4949	1	< .50
	175	222	198.5	12.4125	5	< .05[a]
				5.5642	1	< .025[a]
				6.8483	4 (H)	< .25

P = probability of larger value of χ^2

H = heterogeneity chi-square.

[a]Significant at .05. [b]Significant at .01. [c]Significant at .005.

This agrees with the findings of McCrimmon and Kwain (1966) and Ritter and McCrimmon (1973) on the photonegative behavior of rainbow trout. This photonegative response was not affected in fish subjected to galvanonarcosis (Tables A4, A5, A6). This supports the findings of Kynard and Lonsdale's (1975) study.

Vulnerability to Predation

Thirty trout treated for three hours and fifty trout treated for one-half hour were exposed to predation. Trout held in galvanonarcosis for one-half hour appear to be more vulnerable to bass predation than untreated fish. Although it is not significant at the 0.05 level, the pooled chi-square value for this group was high ($X_1^2 = 2.77 : p = 0.1$). Trout treated for three hours were more vulnerable to predation than half-hour treated fish. The pooled chi-square value ($X_1^2 = 6.12$) is significant at the 0.025 level which clearly indicates the increased vulnerability of this group to bass predation. Results of individual experiments showed a pattern of three-hour treated fish being more vulnerable to predation (Table 3). It appears that treatment time increased the vulnerability of trout to bass predation. Data from predation tests on catfish were inconclusive because of a procedural bias that was corrected for tests on trout.

Growth

Growth experiments showed galvanonarcosis had no effect on the growth of either fish treated for one-half hour or trout treated for three hours. Comparisons of mean weights and standard lengths within each group showed a

Table 3. Comparison of the number of treated and untreated rainbow trout remaining after exposure to predation.

Treatment Duration							
0.5h				3h			
# left				# left			
Test	Control	Expected	df	Test	Control	Expected	df
3	2			-	4		
2	3			1	3		
4	1			2	3		
2	5			3	3		
3	4			2	5		
2	5			1	5		
2	5						
3	5						
1	4						
2	3						
Σ 24	37	30.5	1	9	23	16.0	1
χ^2		2.7705				6.1250	
p		< 0.1				<.025	

p = probability of a larger value of chi-square.

significant growth occurred in all groups except the three-hour catfish control group, which does not increase significantly in weight (Tables A6, A7). T-test comparisons of experimental and control means showed treated fish did not differ significantly in growth except the channel catfish treated for three hours. This group was significantly larger than the control (Table A7). Mortalities that occurred during the one-half hour and three hour catfish growth studies were a result of temperature control complications. Preliminary investigations of six-hour treatments resulted in 50 percent mortalities by the end of treatment.

DISCUSSION

Group activity of trout treated for thee hours was not decreased immediately after electrical treatment and did not recover to levels equivalent to controls after 24 hours. During immediate evaluation of narcosis, trout displayed bursts of upright swimming while flaring operculars as if coughing. Swimming action of control fish was more continuous and without opercular flaring. The behavior of the treated fish was recorded as directed upright swimming, even though they exhibited coughing behavior. The activity was probably higher in immediate evaluations because of this activity in trying to clear the gills. Group activity of these fish appeared to be equivalent to controls in the individual treatment chi-square comparisons though both groups differed behaviorally. Behavior of three-hour experimental and control fish appeared to be equivalent after 24 hours, but equivalency was not indicated by pooled chi-square analysis. Further replications are needed before a definite trend is apparent, but it appears that treated fish have recovered after 24 hours.

An additional measure of group activity may have been helpful in further analysis. Control fish were observed to cluster more during the immediate evaluations than treated fish. Treated fish would be dispersed and not start responding as a group until the end of the evaluation period. This clustering behavior was evident in both experimental and control groups after 24 hours.

Quantifying this schooling behavior may be a better way of evaluating the effect of electrical treatment in this case.

This influence on group behavior would have to be considered if yearling fish were to be introduced into natural habitat. Dispersal of fish in a school can confuse a predator when it approaching prey. Treated fish would not have this element of protection offered in schooling immediately after electrical treatment, but would after 24 hours.

The immediate effects of galvanonarcosis seem most evident in decreasing motor activity or the ability to move naturally. Their ability to detect habitat differences (as indicated by photonegative response) was not influenced. In the predation tests, prey had to evaluate their environment and quickly react by escape. During these experiments, fish responded to the approach of a predator by escape swimming and dispersed to the surface along the tank-water interface. Treated fish did not react to predator approach or disperse directly to the surface as quickly as control fish. It is not known whether the immediate effects of extended galvanonarcosis influenced the sensory-feedback system or just fatigued the muscles so motor response is slowed. The photonegative tests showed that treated fish were not impaired in their sensory ability. The immediate activity evaluations indicated motor response was affected. These observations on predation suggest that the speed of the sensory reaction may be affected.

Conditions used to test prey vulnerability were developed only after intensive manipulation of experimental conditions. Several weeks were needed

to acclimate bass predators to the conditions in the holding tank and to feeding on a regular basis. At 17° C, a starvation period longer than 48 hours would greatly increase the hunger motivation of a predator. This voraciousness made it difficult to terminate experiments when 50 percent of the group was eaten. Coutant (1973), Coutant et al. (1974), and Bams (1967) did not encounter this problem, possibly because their prey group size was larger (50). Several predators were needed in their studies so 50 percent of the prey group would be consumed within one-half hour. This procedure was used in the present study, but territorial interactions of the bass predators were so intense that only one bass would feed when prey were introduced. The best results were obtained when there was only one bass per tank. This required a reduction of the total prey group size introduced in each test. Netting a bass to terminate a test would often disrupt all previous conditioning to the tank and feeding regime. By acclimating one bass to the tank and the regular 48-hour feeding, the hunger motivation of the bass would greatly decrease after five fish were eaten. A test could then be terminated before more than half of the total group was eaten.

Growth data from this study support the findings of Maxfield et al. (1971), Ellis (1974), and Kynard and Lonsdale (1975) of no effects of electrical treatment on growth. However, catfish treated for three hours grew more than controls in this study. This anomaly was not reflected in trout treated for three hours and remains unexplained. Control of temperature complicated the growth

study on catfish treated for one-half hour and caused an early termination. Catfish mortalities in both studies were a result of this problem and not electrical treatment.

During galvanonarcosis treatment, fish would produce copious amounts of mucous. Collection of mucous on the gill surfaces may have been a cause of the opercular flaring the swimming activity discussed in the immediate group activity of trout treated for three hours. It is not known whether the direct current irritates the mucous cells or causes them to relax so mucous is released. However, this reaction may affect a fish's resistance to fungus infection. Some treated fish did contract fungus when placed in a community tank after evaluation. The question of whether treated fish are more susceptible to infection seems worthy of investigation.

Fish were narcotized with direct current for one-half and three hours in this study with no apparent gross injury. This supports the findings of Kynard and Lonsdale's (1975) study on the effects of extended galvanonarcosis. Past investigations of the effects of short periods of electrical immobilization have shown direct current to have less effects than alternating current. Taylor et al. (1957) reported vertebral damage and mortalities of 4.2 percent in 46 trout immobilized with alternating current. No mortalities resulted from immobilization of 91 rainbow trout (50-75 mm) with continuous direct current (0.52 v/cm). Spencer (1967) did find that direct current immobilization caused vertebral injuries and hemorrhaging in bluegills (Lepomis macrochirus). Fish exposed up to 120 seconds to 115 v direct current (approximately 3.5 v/cm) had a 1.5

incidence of injury. This was still fewer injuries than bluegills subjected to equivalent levels of alternating current (4.6 percent injuries).

Mortalities and delays in recovery time in fish subjected to direct current immobilization has been reported by Adams, Behmer, and Weingarter (1972). Voltage gradients of 1.5-3.6 volts per centimeter were used to narcotize 65-85 mm Notropis cornutus for 10-25 seconds in his study. Fish held in galvanonarcosis did not always recover to an upright position within 120 seconds and those which took longer often died. Although Adams et al. (1972) found a correlation of recovery time and energy density, the voltage gradients used were well in excess of those needed to narcotize similar sized fish in this study and in Taylor et al. (1957). It is more likely that tetanus was induced rather than narcosis in the Adams et al. (1972) study. Vibert (1963) has shown narcosis to occur at much lower voltage gradients than tetanus. Injuries from direct current immobilization are probably a direct result of tetanic levels of electricity. This seems to be the case in Spencer's (1967) and Adams et al. (1972) studies, since voltage gradients were close to 3.5 volts per centimeter in both. Data from this study, Taylor et al. (1957), Vibert (1963), Ellis (1974), and Kynard and Lonsdale (1975) indicates that direct current gradients below 1.5 volts per centimeter cause no injury to electrically treated fish.

Perhaps voltages used during electro-shocking collections could be regulated so only narcotizing levels of electricity are applied. This would affect the size range of fish that could be taken since it takes a higher voltage gradient to narcotize smaller fish (Vibert 1967). The decrease in injuries by using

narcotizing levels of direct current may outweigh the ability to immobilize a large size range of fish. This should be a primary consideration when electroshocking techniques are used in studying populations of endangered species.

Voltages needed to immobilize fish in this study were slightly higher when water temperatures were higher. At 18° C an applied voltage of 20 volts (0.55 v/cm) was needed to keep trout in narcosis, while 17 volts (0.47 v/cm) was needed at 15° C. Halsband (1967) reported that the respiratory frequency of trout increased from 50 per minute at 5° C to 145 per minute at 15° C. He observed that when the metabolic rate increased, the current necessary to induce galvanonarcosis increased. Since metabolic rates increase with temperature, narcosis of fish at high temperatures may interfere with a fish's ability to meet a metabolic demand such as oxygen. Kynard and Lonsdale (1975) observed a decrease in opercular activity in fish during galvanonarcosis. It is believed that the mortalities in the six-hour galvanonarcosis treatments may have resulted from this. These initial tests were conducted at 30° C. Extended narcosis and decrease in opercular activity coupled with the oxygen demand at this warmer temperature probably caused the mortalities. Therefore, the voltages used to narcotize fish in this study should only be applied to the temperature ranges reported.

The results of this study suggest that galvanonarcosis could be a possible alternative to chemical anesthetics as a method of fish immobilization. Immobilization techniques are usually employed in handling operations such as marking and transport to minimize the chance of injury and to facilitate the operation.

Concentrations of chemicals needed to produce narcosis for long periods can be close to lethal levels (Nelson 1953; McFarland 1959; Bell 1964). Fish have been anesthetized up to 12 hours with methylparafynol without demonstrable long-term effects (McFarland 1959). However, chemical concentrations are not easily monitored or regulated which can cause difficulties during long-term immobilization. Also, chemical anesthetics can affect the physiology and behavior of fish after recovery (McFarland 1959; Wedemeyer 1970; Crowley and Berinati 1972; Goddard et al. 1974). These problems further complicate the use of chemicals for immobilization of fish.

Galvanonarcosis can be used to safely immobilize fish up to three hours. There are definite immediate effects on fish behavior that were not evident in the study of Kynard and Lonsdale (1975), but these are not apparent after 24 hours. Electricity can be adjusted and monitored easily so voltages needed to produce narcosis can be regulated by an inexperienced person. Galvanonarcosis has been used successfully for short-term immobilization for tagging Atlantic salmon, Salmo salar (Hartley 1967). Data from this study indicates that galvanonarcosis has strong potential as an alternative technique to chemical anesthetics for operations which require long periods of immobilization for extensive handling of fish.

APPENDIX

STATISTICAL DATA

Table A1. Individual activity.[a]

Species and Group	Immediate				24 Hour				T - values			
	Test	S_D	Control	S_D	Test	S_D	Control	S_D	Imm $M_{T=}M_C$	24 $M_{T=}M_C$	Test $M_{I=}M_{24}$	Control $M_{I=}M_{24}$
Channel Catfish 0.5 hr.	30.7(19)	60.2	96.6(19)	79.1	69.0(19)	42.1	62.3(19)	69.2	2.890[b]	0.360	2.238[b]	1.962
Channel Catfish 3 hr.	29.2(16)	45.5	78.0(16)	76.6	54.8(15)	54.4	57.1(15)	49.8	2.191[b]	0.084	1.426	0.892
Rainbow Trout 0.5 hr.	37.6(18)	59.5	83.9(18)	68.8	45.1(18)	60.4	75.0(18)	86.5	2.162[b]	1.204	0.327	0.340
Rainbow Trout 3 hr.	36.7(18)	55.3	98.6(17)	87.1	80.5(18)	63.8	108.6(18)	81.2	2.546[b]	0.694	1.941	0.552

[a] represented by the mean of the number of squares that individual fish passed through in three minutes.

[b] significant at 0.05 probability level. S_D = standard deviation M = mean ( ) = sample size

Table A2. Group activity--channel catfish.[a]

Treatment 1/2 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
27	44	35.5	4.0704	1	< .05[b]
43	60	51.5	2.8058	1	< .10
62	56	59.0	0.3050	1	< .75
57	74	65.5	2.2061	1	< .25
22	60	41.0	17.6098	1	< .005[d]
			26.9971	5	< .005[d]
211	294	252.5	13.6416	1	< .005[d]
			13.3555	4 (H)	< .01[c]

Control 1/2 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
52	44	48.0	0.6667	1	< .50
66	71	68.5	0.1825	1	< .75
71	58	64.5	1.3100	1	= .25
72	66	69.0	0.2609	1	< .75
41	53	47.0	1.5319	1	< .25
			3.9520	5	< .50
302	292	297.0	0.1684	1	< .75
			3.7836	4 (H)	< .50

Table A2. (Continued)

Treatment 3 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
14	64	39.0	32.0513	1	<.005[d]
17	29	23.0	3.1304	1	<.10
10	51	30.5	27.5571	1	<.005[d]
33	64	48.5	9.9072	1	<.005[d]
16	70	43.0	33.9070	1	<.005[d]
11	49	30.0	24.0067	1	<.005[d]
			130.6200	6	<.005[d]
101	327	214.0	119.3364	1	<.005[d]
			11.2836	5 (H)	<.05[b]

Control 3 hr.					
Immediate	24 Hour	Expected	χ^2	df	p
72	68	70.0	0.1143	1	<.75
69	68	68.5	0.0073	1	<.95
58	56	57.0	0.0351	1	<.90
67	46	56.5	3.9267	1	<.05[b]
67	66	66.5	0.0075	1	<.95
55	47	51.0	0.6275	1	<.50
			4.7184	6	<.50
388	351	369.5	1.8525	1	<.25
			2.8659	5 (H)	<.25

H = heterogeneity chi-square P = probability of a larger value of χ^2

[a]Within group comparisons of activity from immediate and 24-hour evaluations based on the sum of the number of fish moving over a 15-minute period.

[b]Significant at .05. [c]Significant at .01. [d]Significant at .005.

Table A3. Group activity--channel catfish--test vs control.[a]

Channel Catfish 0.5h						
Observation Period	Observed Test	Control	Expected	χ^2	df	p
Immediate	27	52	39.5	7.9114	1	< .005[d]
	43	66	54.5	4.8532	1	< .05[b]
	62	71	66.5	0.6090	1	< .50
	57	72	64.5	1.7442	1	< .25
	22	41	31.5	5.7302	1	< .025[b]
	211	302	256.5	20.8480	5	< .005[d]
				16.1423	1	< .005[d]
				4.7057	4 (H)	< .50
1 hr.	4	23	13.5	13.3704	1	< .005[d]
	14	16	15.0	0.1333	1	< .75
	10	3	6.5	3.7692	1	< .10
	5	5	5.0	0.0000	1	= 1.00
	18	22	20.0	0.4000	1	< .75
	6	13	9.5	2.5789	1	< .25
	57	82	69.5	20.2518	6	< .005[d]
				4.4964	1	< .05[b]
				15.7554	5 (H)	< .01[c]
24 hr.	55	41	48.0	2.0417	1	< .25
	44	44	44.0	0.0000	1	= 1.00
	60	71	65.5	0.9237	1	< .50
	56	58	57.0	0.0351	1	< .90
	74	66	70.0	0.4571	1	< .50
	60	53	56.5	0.4336	1	< .75
	349	333	341.0	3.8912	6	< .75
				0.3754	1	<
				3.5158	5 (H)	< .75

Table A3. (Continued)

Observation Period	Observed Test	Observed Control	Expected	χ^2	df	p
			Channel Catfish 3h			
Immediate	14	72	43.0	39.1163	1	< .005[d]
	17	69	43.0	31.4419	1	< .005[d]
	10	58	34.0	33.8824	1	< .005[d]
	33	67	50.0	11.5500	1	< .005[d]
	16	67	41.5	31.3374	1	< .005[d]
	11	55	33.0	29.3333	1	< .005[d]
	101	388	244.5	176.6613	6	< .005[d]
				168.4437	1	< .005[d]
				8.2176	5 (H)	< .25
1 hr.	2	10	6.0	5.3333	1	< .025[b]
	3	11	7.0	4.5714	1	< .05[b]
	2	12	7.0	7.1428	1	< .01[c]
	10	20	15.0	3.3333	1	< .10
	11	23	17.0	4.2353	1	< .05[b]
	9	11	10.0	0.2000	1	< .75
	37	87	62.0	24.8161	6	< .005[d]
				17.8871	1	< .005[d]
				5.9290	5 (H)	< .5
24 hr.	64	68	66.0	0.1212	1	< .75
	29	68	48.5	15.6804	1	< .005[d]
	51	56	53.5	0.2336	1	< .90
	64	46	55.0	2.9455	1	< .10
	70	66	68.0	0.1176	1	< .75
	49	47	48.0	0.0417	1	< .90
	327	351	339.0	19.1400	6	< .005[d]
				0.8496	1	< .50
				18.2904	5 (H)	< .005[d]

H = hetergeneity chi-square P = probability of larger value of χ^2

[a]Between group comparisons of the number of fish moving at the end of each minute summed over the observation period.

[b]Significant at .05. [c]Significant at .01. [d]Significant at .005.

Table A4. Immediate photonegative response.[a]

Species and Group	Observed Test	Control	Expected	df	χ^2 Pooled	p
Immediate						
Channel Catfish 0.5 h	20	16	18	1	0.4444	<.75
Channel Catfish 3 h	14	15	14.5	1	0.0345	<.90
Rainbow Trout 0.5 h	25	28	26.5	1	0.1698	<.75
Rainbow Trout 3 h	25	28	26.5	1	0.1698	<.75
24 Hr.						
Channel Catfish 0.5 h	23	23	23	1	0.0000	=1.00
Channel Catfish 3 h	26	22	24	1	0.3333	<.75
Rainbow Trout 0.5 h	27	27	27	1	0.0000	=1.00
Rainbow Trout 3 h	25	25	25	1	0.0000	=1.00

[a]The number of fish fisplaying immediate shade preference summed for five treatments Test/Control.

p = Probability of a larger value of chi-square.

Table A5. Photonegative response--channel catfish.[a]

C. Catfish 0.5h					
Observing Period	Σ # in shade Test	Control	χ^2	Expected	p
Immediate	73	72	0.0069	72.5	< .95
	73	65	0.4637	69.0	< .50
	75	75	0.0000	75.0	=1.00
	75	73	0.0270	74.0	< .90
	72	72	0.0000	72.0	=1.00
	73	75	0.0270	74.0	< .90
Σ	441	432	0.5246	Σ χ^2 (6)	=1.00
			0.0927	χ^2 (1)	< .90
			0.4319	χ^2 (5)	< .995
1 Hr.	25	20	0.5556	22.5	< .50
	25	19	0.8182	22.0	< .50
	25	25	0.0000	25.0	=1.00
	25	23	0.0833	24.0	< .90
	25	25	0.0000	25.0	=1.00
	25	21	0.3478	23.0	< .75
Σ	150	133	1.8049	Σ χ^2 (6)	< .95
			1.0212	χ^2 (1)	< .50
			0.7837	χ^2 (5)	< .99
24 Hr.	72	75	0.0612	73.5	< .90
	74	73	0.0068	73.5	< .95
	74	70	0.1111	72.0	< .75
	74	75	0.0067	74.5	< .95
	74	75	0.0067	74.5	< .95
	74	75	0.0067	74.5	< .95
Σ	442	443	0.1992	Σ χ^2 (6)	=1.00
			0.0110	χ^2 (1)	< .95
			0.1882	χ^2 (5)	< .90

Table A5. (Continued)

C. Catfish 3h

Observing Period	Σ # in shade Test	Control	χ^2	Expected	p
Immediate	73	71	0.0278	72.0	< .90
	70	75	0.1724	72.5	< .90
	60	69	0.6279	64.5	< .50
	74	67	0.3475	70.5	< .75
	74	74	0.0000	74.0	=1.00
	53	60	0.0339	59.0	< .90
	Σ 409	416	1.2095	Σ χ^2 (6)	< .99
			0.0594	χ^2 (1)	< .90
			1.1501	χ^2 (5)	= .95
1 Hr.	20	25	0.5555	22.5	< .50
	25	25	0.0000	25.0	=1.00
	25	25	0.0000	25.0	=1.00
	25	25	0.0000	25.0	=1.00
	25	23	0.0833	24.0	< .90
	25	20	0.5555	22.5	< .50
	Σ 145	143	1.1943	Σ χ^2 (6)	< .99
			0.0139	χ^2 (1)	< .95
			1.1804	χ^2 (5)	< .95
24 Hr.	74	75	0.0067	74.5	< .95
	75	70	0.1724	72.5	< .90
	75	58	2.1729	66.5	< .25
	75	75	0.0000	75.0	=1.00
	74	75	0.0067	74.5	< .95
	57	59	0.0345	58.0	< .90
	Σ 430	412	2.3932	Σ χ^2 (6)	< .90
			0.3848	χ^2 (1)	< .75
			2.0084	χ^2 (5)	< .90

[a]Number of fish in the shade at the end of each minute summed for total observation period.

p = probability of a larger value of chi-square.

( ) = degrees of freedom.

Table A6. Photonegative response--Rainbow Trout.[a]

Rainbow Trout 0.5h					
Observing Period	Σ # in shade Test	Control	χ^2	Expected	p
Immediate	67	56	0.9837	61.5	< .90
	61	45	2.4151	53.0	< .25
	61	56	0.2137	58.5	< .75
	57	60	0.0769	58.5	< .90
	75	69	0.2500	70.0	< .75
	70	55	1.8000	62.5	< .25
	Σ 391	341	5.7394	Σ χ^2 (6)	< .50
			3.4153	χ^2 (1)	< .10
			2.3241	χ^2 (5)	< .90
1 Hr.	19	12	1.5806	15.5	< .25
	20	23	0.2093	21.5	< .75
	19	9	3.5714	14.0	< .10
	18	13	0.8064	15.5	< .50
	18	14	0.5000	16.0	< .50
	16	14	0.1333	15.0	< .75
	Σ 110	85	6.8010	Σ χ^2 (6)	< .50
			3.2051	χ^2 (1)	< .10
			3.5959	χ^2 (5)	< .75
24 Hr.	61	53	0.5614	57.0	< .50
	55	50	0.2381	52.5	< .75
	38	27	1.8615	32.5	< .25
	64	71	0.3629	67.5	< .75
	64	72	0.4706	68.0	< .50
	68	63	0.1908	65.5	< .75
	Σ 350	336	3.6853	Σ χ^2 (6)	< .10
			0.2857	χ^2 (1)	< .75
			3.3996	χ^2 (5)	< .10

Table A6. (Continued)

Rainbow Trout 3h					
Observing Period	Σ # in shade Test	Control	χ^2	Expected	p
Immediate	59	49	0.9259	54.0	< .50
	31	65	12.0417	48.0	< .005[d]
	59	54	0.2212	56.5	< .75
	65	75	0.7143	70.0	< .50
	66	71	0.1825	68.5	< .75
	57	61	0.1356	59.0	< .75
	Σ 337	375	14.2212	Σ χ^2 (6)	< .05[b]
			2.0322	χ^2 (1)	< .25
			12.1890	χ^2 (5)	< .05[b]
1 Hr.	25	11	5.4444	18.0	< .025[b]
	17	18	0.0286	17.5	< .90
	19	15	0.4706	17.0	< .50
	24	17	1.1951	20.5	< .50
	20	21	0.0244	20.5	< .90
	20	17	0.2432	18.5	< .75
	Σ 125	99	7.4063	Σ χ^2 (6)	< .50
			3.0178	χ^2 (1)	< .10
			4.3885	χ^2 (5)	< .50
24 Hr.	65	65	0.0000	65.0	< 1.00
	54	51	0.0857	52.5	< .90
	54	57	0.0811	55.5	< .90
	75	70	0.1724	72.5	< .75
	71	61	0.7576	66.0	< .50
	Σ 319	304	1.0968	Σ χ^2 (6)	< .99
			0.4984	χ^2 (1)	< .50
			0.5984	χ^2 (5)	< .99

[a]Number of fish in the shade at the end of each minute summed for total observation period test/control.

p = probability of a larger value of chi-square. ( ) = degrees of freedom.

[b]Significant at .05. [c]Significant at .01. [d]Significant at .005.

Table A7. Growth.[a]

Species and Group	Standard Length					Weight					t-values	
	Start	S_D	End	S_D	N	Start	S_D	End	S_D	df	S. L. $M_S = M_E$	W $M_S = M_E$
Channel Catfish Test 0.5 h	55.6	5.8	59.1	5.9	15	2.39	0.72	2.61	0.73	28	4.888[b]	2.348[b]
Channel Catfish Control 0.5 h	56.0	6.3	59.9	5.7	18	2.47	0.78	2.74	0.88	34	5.673[b]	3.159[b]
Channel Catfish Test 3 h	52.9	4.9	60.6	6.4	17	2.37	0.67	2.91	0.93	32	10.037[b]	4.654[b]
Channel Catfish Test 3 h	55.9	7.6	60.3	8.9	21	2.71	1.16	2.81	1.44	40	10.719[b]	1.054
Rainbow Trout Test 0.5 h	71.3	4.7	75.6	5.5	25	5.35	1.15	6.55	1.62	48	11.872[b]	8.463[b]
Rainbow Trout Control 0.5 h	68.3	5.9	72.3	6.4	24	4.92	1.16	5.90	1.72	46	10.686[b]	6.276[b]
Rainbow Trout Test 3 h	66.6	5.7	71.7	5.9	25	4.44	1.33	5.80	1.65	48	12.845[b]	10.588[b]
Rainbow Trout Control 3 h	69.1	5.7	80.4	6.5	25	5.15	1.64	6.19	2.49	48	9.049[b]	4.663[b]

[a]Comparison of mean standard length and weight to determine if a significant growth change occurred within each group.

[b]Significant at .001. S_D = standard deviation. N = sample size. M = mean.

Table A8. Growth changes.[a]

	Δ Standard Length (mm)			Δ Weight (gm)		
	Test	Control	t-value	Test	Control	t-value
Channel Catfish 0.5 h						
	3.5(15)	3.9(18)	0.356	0.22(15)	0.27(18)	0.371
S_D	2.8	2.9		0.36	0.36	
df	31			31		
Channel Catfish 3 h						
	7.6(17)	4.8(21)	3.836[c]	0.54(17)	0.10(21)	3.053[b]
S_D	3.1	1.9		0.47	0.41	
df	36			36		
Rainbow Trout 0.5 h						
	4.3(25)	4.0(24)	0.531	1.24(25)	0.98(24)	1.216
S_D	1.8	1.9		0.73	0.77	
df	47			47		
Rainbow Trout 3 h						
	5.1(25)	4.6(25)	0.680	1.35(25)	1.04(25)	1.232
S_D	2.0	2.6		0.64	1.11	
df	48			48		

[a]Comparison of mean changes in standard length and weight between test and control groups.

[b]Significant at .01. [c]Significant at .001. S_D = standard deviation.

( ) = sample size.

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