Comparison of In-Water Voltage Gradients Produced by Electrofishing Boats

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Abstract: The voltage gradients of electric fields produced by electrofishing boats are important in determining sampling efficiency and the potential for injuring fish. We evaluated 10 electrofishing boats and found that 3 boats had malfunctions that could impact sampling or operator safety. The in-water voltage gradients were measured for the remaining 7 boats to make comparisons among boats and to determine the voltage gradients present during electrofishing. For all boats evaluated, the cathode was the aluminum boat hull, and the 2 anode arrays each consisted of 3–11 droppers (cables, chains, or rods; 0.6–1.2 m long) suspended from a boom in front of the boat. A grid (1.5 x 2.0 m) was attached to the anode support booms between the anodes and the bow of the boat; this grid facilitated measurements of voltage gradients in the portion of the electric field where most fish are captured. For 9 locations defined by the grid and for 3 water depths (0.1, 0.5, and 1.0 m), a voltage gradient vector was calculated from the horizontal and vertical voltage gradients measured with a probe connected to an oscilloscope. With applied voltages of 900–1000 V, the mean voltage gradient for sampling locations within 1 m of the bow was 2.6 V/cm (SE, 0.1); means for individual boats ranged from 2.1 to 3.4 V/cm. In addition to measurements at locations defined by the grid, maximum voltage gradients of 16-20 V/cm were measured within 5 cm of anode droppers. Despite differences in equipment, the electrofishing boats produced electric fields with similar voltage gradients when measured at similar locations relative to the electrodes.

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Electrofishing boats are commonly used to capture fish from rivers and lakes, and the susceptibility of fish to capture is dependent on the electric field intensity and type of electric current (Bohlin et al. 1989). Differences in the electric fields among boats can lead to biased catch rates (Heidinger 1983), and if some boats have electric fields of abnormally high intensity, higher rates of fish injury are possible. Comparison of the electric field intensity among different electrofishing boats is important to assure quality of data. However, we are not aware of any published studies conducted to evaluate and compare intensity of in-water voltage gradients among various electrofishing boats.

Measurement of the electric field generated by an electrofishing boat requires in-water determination of voltage gradients (V/cm) at specific locations in the water (Kolz 1993). A control unit (pulsator) is typically used on electrofishing boats to regulate voltage and current; however, the switches and meters on pulsators indicate the electric output rather than information about the in-water electric field. The waterborne electric field can not be determined simply from the pulsator settings because the electric field is affected by several variables, including water conductivity and the size and shape of electrodes (Novotny and Priegel 1974, Kolz 1993). The electric field is never homogeneous around the boat, and in-water voltage gradients decrease as distance from electrodes increases (Bohlin et al. 1989, Kolz 1993).

Although the arrangement of electrodes used on electrofishing boats can vary, the cathode is usually located close to the boat or the aluminum boat hull itself acts as the cathode, and electrode support booms are used to suspend the anode in front of the boat (Reynolds 1996). A 60-Hz, 110- or 220-volt alternating current (AC) generator is typically used, and selection of generator capacity is dependent on the water conductivity range where electrofishing is to be conducted [i.e., high or low conductivity requires more power (Reynolds 1996)].

Our objective was to evaluate the voltage gradients, generated in a defined region between the electrodes, produced by electrofishing boats. Our approach was to determine the voltage gradient produced by each boat to enable comparison among different boats and electrode configurations. In addition, tests were conducted to determine if electrofishing equipment on each boat was operating correctly, particularly regarding safety of the operator.

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Methods

Ten electrofishing boats (4.5–5.5 m length) were considered in this study: 5 boats were evaluated at the Auburn University Fisheries Research Station (Auburn, Ala.), and 5 boats were evaluated at the Walton Fish Hatchery (Ga.). All of the boats had the aluminum boat hull as the cathode and suspended anode droppers from rings or umbrella arrays (Smith-Root Inc., Vancouver, Wash.) attached to paired electrode support booms extending in front of the boat (Table 1). Boats used either model VI-A or model GPP Smith Root pulsators (Smith-Root, Vancouver, Wash.).

Table 1. Anode characteristics of the electrofishing boats used for comparison of in-water voltage gradients.

Boat	Boom length (m)	Diameter of ring (m)	Dropper number	Dropper length (m)	Type of dropper	Distance to grid[a] (m)
1	3.0	0.8	4	1.2	cable	0.7
2	3.2	0.9	6	1.0	cable	0.8
3	3.3	0.6	8	0.6	cable	1.1
4	2.6	0.6	3	0.9	chain	0.8
5	2.2	0.9	10	1.0	rod	0.3
6	1.7	0.9	11	1.0	rod	0.5
7	2.0	1.0	8–10	1.0	rod	0.9

a. Distance from the nearest dropper to the grid locations nearest the anodes.

Each boat was evaluated for malfunctions in electric current output. An oscilloscope (Tektronix, Model 720 A, Wilsonville, Ore.) was used to determine if the pulse frequency of the output current was consistent with the pulsator setting, and to determine if the shapes of the output pulses were consistent with half and full wave, rectified AC as specified by the manufacturer (Smith-Root, Vancouver, Wash.). To determine if the anode array on each electrode support boom received the same electrical energy from the pulsator, the oscilloscope was connected to the boat hull and each anode array individually, and the voltage was measured. At the same time anode arrays were tested, the foot pedal was checked to determine if a voltage was present when the pedal was not depressed. Three boats had malfunctioning electrofishing equipment and were not further evaluated.

Boat electric fields were measured in ponds with ambient water conductivity of 45 µS/cm and temperature at 15–17 C (Yellow Springs Instruments, Yellow Springs, Ohio). Pulsator settings were: pulse frequency, 60- or 120-Hz PDC; voltage level, 900–1000 V; and pulsator current meter indication, 4–6 amps. Water depth was 3–4 m during measurements. An oscilloscope was connected to a probe used to measure the in-water voltage gradient. The sampling probe consisted of 2 wires separated by 1 cm in the horizontal plane, and 2 wires separated by 1 cm in the vertical plane. Each wire was insulated except for the terminus of the wire. Two electrically isolated channels of the oscilloscope allowed simultaneous measurement of the peak voltage potential between the 2 wires in each plane. At each location and depth, mean horizontal (H) and vertical (V) voltage gradients were determined from 2 or 3 replicate measurements, and then a peak voltage gradient vector (E) was calculated as follows:

$$E = (H^2 + V^2)^{1/2}$$

Because the intensity of the voltage gradient measured in the water is dependent on the orientation of the sampling probe, we conducted preliminary measurements to determine the optimum electrode orientation for sampling the maximum horizontal component of the voltage gradient. We determined that the measured horizontal voltage gradient was within 10% of the maximum when the gap between the 2 wires measuring the horizontal field gradient was oriented parallel to the centerline of the

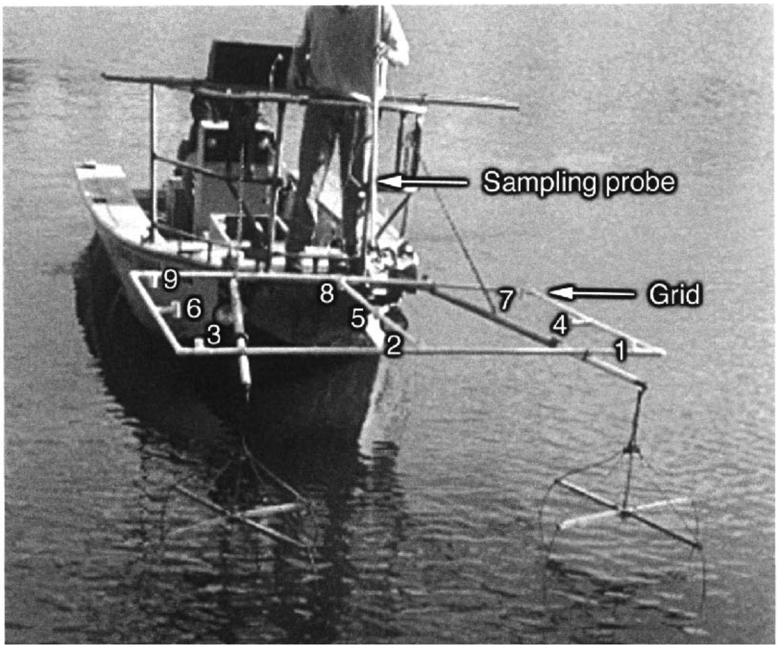

Figure 1. Electrofishing boat with sampling grid (1.5 x 2.0 m) attached to the electrode support booms. Numbers (1–9) on the grid indicate sampling locations for most boats. The sampling probe measured the voltage gradient at each sampling location at 3 depths (0.1, 0.5, and 1.0 m).

boat; therefore, this orientation of the probe was used for all electric field measurements recorded.

The maximum intensity of the electric field was measured for 5 boats by approaching an anode dropper (closest to boat) with the sampling probe until the maximum voltage gradient was recorded. Measurements at different depths at specific locations were facilitated by a grid (1.5 x 2.0 m) mounted on the electrode support booms between the anodes and the boat hull (Fig. 1). Measurements were taken at 3 depths (0.1, 0.5, and 1.0 m) at each of the sampling locations, and voltage gradient vectors were calculated for each depth at each location. For 7 of the electrofishing boats, the grid defined 9 sampling locations between the anode and the cathode; only 6 sampling locations were used for 2 boats because the booms supporting the anodes were short. The grid was set on the electrode support booms 10 cm in front of the prow of the boat, and sampling locations were oriented in rows that were 0.75 m apart (Fig. 1). The distance from sampling locations to the anode droppers differed among boats (Table 1) because of the variation in length of electrode support booms. Analysis of variance was used to determine if there were significant differences in voltage gradients among boats or at different depths (SAS Vers. 6 software, SAS Institute, Inc., Cary, N.C.).

Results

Malfunctions in electrofishing equipment were detected in 3 of the boats tested. One boat produced an electric field (<1.0 V/cm) when the foot pedal was not engaged. In another boat, the 120-Hz PDC setting generated a waveform consisting of 1 normal pulse followed by a pulse that was lower in intensity (50%) with an abnormal and inconsistent shape. Unequal delivery of electric energy between anode arrays was observed in the third boat.

The maximum voltage gradient vector was determined near the anode for 5 boats and was 16–20 V/cm in all cases. For electric field locations defined by the sampling grid, voltage gradients were highest and most variable at grid locations 1–3, which were the locations nearest the anodes (Table 2). Because of the short electrode support booms on boats 6 and 7, measurements were collected at only 6 grid locations for these boats (Table 2). The differences among boats for measured voltage gradients at the grid locations closest to the anodes (locations 1–3) appeared to be primarily related to the variation in distance between the sample location and the nearest anode dropper. At grid locations further from the anode (locations 4–9), all boats had similar voltage gradients (Table 2); means for boats ranged from 2.1 to 3.4 V/cm. For the relatively uniform voltage gradient at grid locations 4–9, the mean for all boats for the 3 depths combined was 2.6 V/cm (SE, 0.1). Overall, there was no statistically significant difference for voltage gradient measurements among boats.

Voltage gradients at 0.1 and 0.5 m were similar but there was a small, but statistically significant, decrease at 1.0 m. The relative contribution of the horizontal and vertical components to the voltage gradient also varied with depth. The horizontal voltage gradient was higher than the vertical voltage gradient for all grid locations when measured at 0.1 m depth, but at 1.0 m the vertical voltage gradient was higher than the horizontal gradient at grid locations 1–3 (Fig. 2).

Discussion

Although electrofishing has been widely used for collection of fish, no previous studies have compared the in-water voltage gradients produced by various electrofishing boats. For the boats in our study, most measured voltage gradients were similar among boats for the region between the anodes and cathode. The variation in measured voltage gradients at grid locations near anodes was probably related to differences in electrode support boom length, which affected the position of sampling locations in relation to anodes. The region of the electric field measured in our study was small relative to the total electric field area of electrofishing boats, and evaluation of other portions of the electric field is warranted. We measured the voltage gradients in the most intense portion of the electric field because of the potential for fish to be injured by high voltage gradients.

The highest voltage gradients we measured were recorded within 5 cm of anode droppers, but limitations of the measurement technique prevented measurement of a true maximum voltage gradient. Theoretically, the maximum voltage gradient is next

Table 2. In-water voltage gradients (V/cm) measured at a water depth of 0.5 m. The numbered locations were defined by a grid (Fig. 1). Voltage gradients for each boat were measured 2–3 times at each location and SD is given in parentheses.

		Boat						
Location[a]		1	2	3	4	5	6[b]	7[b]
1	H	2.8 (1.9)	3.7 (2.1)	3.5 (0.1)	5.12 (0.1)	12.2 (1.1)	5.1 (0.4)	3.8 (0)
	V	5.0 (0.3)	3.0 (1.4)	3.0 (0)	4.4 (0.1)	11.3 (0.5)	5.1 (0.1)	3.5 (0)
	E	5.8	4.7	4.7	6.8	16.6	7.2	5.2
2	H	4.2 (0.5)	2.3 (0.4)	3.6 (0)	2.0 (0)	4.4 (0)	4.3 0.4)	2.6 (0)
	V	4.3 (0.2)	2.2 (0.5)	2.8 (0.3)	2.1 (0.1)	4.9 (0.3)	4.0 (0.4)	2.5(0.1)
	E	6.0	3.2	4.6	2.9	6.6	5.9	3.6
3	H	8.2 (4.0)	8.1 (1.8)	4.3 (0)	6.6 (0.3)	5.3 (0.1)	3.9 (0.1)	2.2 (0.3)
	V	5.5 (4.6)	5.4 (0)	3.5 (0)	5.8 (0.3)	5.2 (0.1)	3.7 (0.1)	2.3 (0.2)
	E	9.9	9.7	5.6	8.76	7.5	5.4	3.2
4	H	3.3 (1.3)	3.2 (0.3)	2.0 (0.2)	2.2 (0.3)	3.0 (0)		
	V	2.5 (0.6)	2.4 (0)	1.4 (0.2)	1.7 (0.1)	2.6 (0.2)		
	E	4.1	4.0	2.4	2.8	3.9		
5	H	3.2 (0.6)	2.5 (0.4)	2.4 (0.2)	2.0 (0)	2.8 (0.3)		
	V	2.3 (0.6)	2.2 (0.1)	1.7 (0.2)	1.6 (0)	2.4 (0)		
	E	3.9	3.3	3.0	2.6	3.7		
6	H	3.6 (0.2)	2.5 (0.1)	2.4 (0.1)	2.4 (0)	2.0 (0)		
	V	2.5 (0.10)	2.0 (0.1)	1.7 (0.1)	2.0 (0.1)	1.9 (0)		
	E	4.4	3.2	2.9	3.1	2.8		
7	H	2.4 (0.3)	1.7 (0.4)	1.6 (0.2)	1.4 (0)	1.4 (0)	2.0 (0)	1.8 (0)
	V	1.4 (0.2)	1.3 (0.6)	0.9 (0.2)	0.9 (0)	1.1 (0)	1.8 (0)	1.4 (0.2)
	E	2.8	2.1	1.81	1.7	1.8	2.7	2.3
8	H	2.8 (0.2)	2.0 (0)	2.4 (0.2)	1.9 (0.1)	2.0 (0)	2.9 (0.4)	2.0 (0)
	V	1.4 (0.1)	1.4 (0.2)	1.1 (0.3)	1.1 (0.1)	1.4 (0.1)	2.1 (0.1)	1.3 (0.1)
	E	3.1	2.4	2.7	2.2	2.4	3.6	2.4
9	H	2.32 (0)	1.6 (0.3)	1.8 (0.1)	1.8 (0)	1.4 (0)	2.0 (0)	1.4 (0)
	V	1.3 (0.1)	1.0 (0.2)	0.8 (0.1)	1.0 (0)	1.0 (0.1)	1.6 (0.3)	1.2 (0.2)
	E	2.6	1.9	2.0	2.1	1.7	2.6	1.8

a. H = horizontal gradient, V = vertical gradient, E = combined vector.

b. Measurements were made at only 6 locations because of the short booms used to support the anodes. The 2 rows in this shortened grid were separated by 0.75 m.

to the anode dropper (Novotny and Priegel 1974, Kolz 1993); thus, our highest measurements were probably less than the maximum. Measurement of the maximum voltage gradient was difficult because small changes (1 cm) in the position of the sampling probe near the anode resulted in pronounced changes in the voltage gradient. Maximum in-water voltage gradients measured within 5 cm of anode droppers have not previously been reported for electrofishing boats.

Direct measurement of in-water voltage gradients with a sampling probe to measure the horizontal gradient was described by Kolz (1993), but our study was the first to measure vertical voltage gradients and calculate a voltage gradient vector that included both the horizontal and vertical components. In our study the vertical voltage gradient measured at locations close to the anode droppers increased with depth,

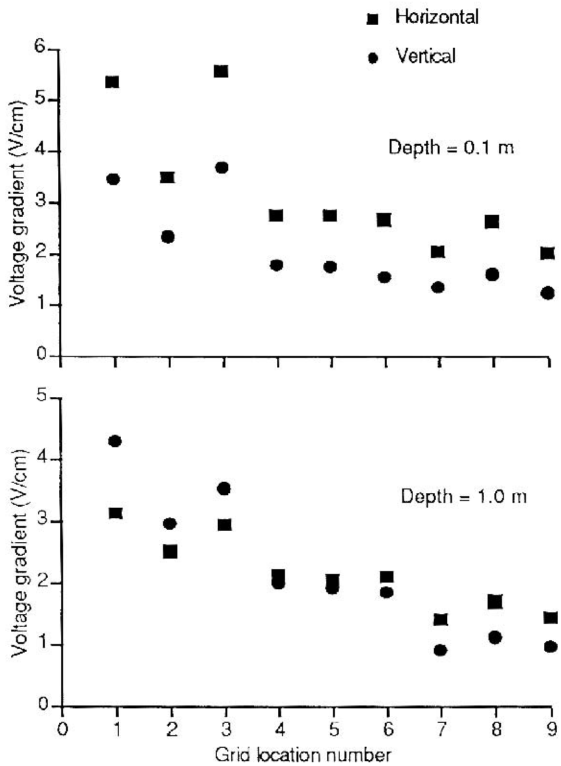

Figure 2. Mean vertical and horizontal voltage gradients at 0.1 and 1.0 m depths for 7 electrofishing boats (Table 1). Grid location number indicates the position on the grid (Fig. 1) where the voltage gradients were measured.

while at locations near the boat, no relation was observed with depth. Anode droppers extended deeper (up to 1.2 m) than the boat hull cathode, which could explain the depth-related difference in relative vertical voltage gradients near each electrode. During boat electrofishing, fish are exposed to electric fields at depths greater than the 1-m depth we measured, and the vertical component of the electric field could be an important factor determining capture of fish.

The intensity of the electric field produced by boats measured in our study was determined in water with 45 µS/cm ambient conductivity, and changes in field characteristics are expected when boats are operated in different conductivities. If an electrofishing boat is operated at the same voltage level in higher conductivity water, current amperage will increase and the electric power load on the generator will increase (Reynolds 1996). When the electric power demand exceeds generator capacity, the voltage level must be reduced to continue operation. Once in-water voltage gradients are determined for an electrofishing boat at a specific voltage level, they can be related to all other voltage levels [i.e., if the total voltage level is half of the original level, each in-water voltage gradient is also half the original (Kolz 1993)].

When electrofishing is used to collect data for management of fish populations, the quality of the data is dependent on proper functioning of the electrofishing equipment. Defective equipment could alter fishing effectiveness and result in biased data. Eventually, electrofishing equipment requires repair or replacement, and changes in electric field intensity among gear types can impact collection of fish and electrofishing efficiency (Heidinger 1983). Electric fields of electrofishing equipment should be evaluated to determine if equipment is operating correctly.

Evaluation of electrofishing boats should include in-water measurements of voltage gradients at defined locations. After the in-water electric field has been evaluated for a specific boat, periodic checks of the electrical system can be made with the boat out of the water if no modifications are made on the boat. In-water measurements can be conducted with a sampling probe, as described in this study. If a sampling grid is used, it should be positioned relative to the anode droppers (where variation in voltage gradients are highest) rather than to the prow of the boat. The in-water field can also be measured without a grid by sampling at locations near the cathode and each of the anodes. Near the anodes, it is especially important to standardize the distance from the sampling location to the anode if boats are to be compared. Once in-water electric field measurements are determined at a specific total voltage output level, changes in the total voltage output will relate directly to the in-water measurements (Kolz 1993). Then routine measurements of electrofishing equipment can test total voltage output at each anode rather than requiring in-water measurements. When checking the electrical system with the boat out of the water, items to evaluate include operation of the foot pedal and the electrical resistance between each anode and the pulse box, the boat hull, and the generator cathode. The waveform of the pulsator output can also be evaluated with the boat out of the water. Periodic testing of electrofishing equipment is important to safeguard data quality and for operator safety.

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