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[Article]

Evaluating the Power Output of the Smith-Root GPP 5.0 Electrofisher to Promote Electrofishing Fleet Standardization

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Abstract.—The Smith-Root (S-R) series of GPP (gas-powered pulsator) electrofishers are widely used in boat-mounted electrofishing systems. Sampling in waters having different conductivities requires adjustment of the electrofisher controls to maintain consistent output power. However, the current meter supplied on GPP electrofishers provides an average rather than a peak measurement, and because no voltmeter is included, determining peak power output is not possible. As part of an overall effort to promote standardization of electrofishing operations, we used static electrical loads to measure the output characteristics of the commonly used S-R GPP 5.0 electrofishers under simulated electrofishing conditions. The range of resistance values to be simulated with static loads was extrapolated from in-water measurements of five electrode configurations consisting of paired, half-submerged, spherical anodes in combination with a 5.5-m-long flat-bottom aluminum-hull boat serving as the cathode. We measured the power output of GPP 5.0 electrofishers while they were connected to static loads of 114, 19, 9.5, and 5.7 Ω to simulate a wide range of ambient water conductivity values (approximately 100–1,000 μS/cm). These measurements of GPP 5.0 power output will provide electrofishing fleets with an improved understanding of electrofisher operational controls and performance and allow for a more consistent method of selecting electrofisher settings.

Electrofishing is an accepted and effective method of sampling freshwater fish (Dolan and Miranda 2004). Standardization of electrofishing in waters having different conductivities is now viewed as essential when monitoring temporal and spatial differences in fish assemblages (Miranda and Dolan 2003; Miranda 2005). The benefits of standardization for fisheries programs include minimizing variation in catchability, maximizing catch, and reducing injury to fish (Burkhardt and Gutreuter 1995; Bonar and Hubert 2002; Miranda 2005). Standardization of an electrofishing fleet involves three basic aspects: (1) using similar electrical configurations for electrofishing boats and their electrodes; (2) controlling the waveform and power output of the electrofisher; and (3) adopting a set of operational procedures that are applied consistently.

Kolz (1989) proposed a theorem to explain how electrical power is transferred from the water into the fish. This model makes it feasible to calculate and adjust the output power from an electrofisher so that constant electric power is delivered to fish in waters with differing conductivities. Miranda and Dolan (2003) substantiated this model over a range of conductivities (12–1,030 μS/cm) for an effective fish conductivity of 115 μS/cm. The power transfer model is fundamental in standardizing electrofishing operations and requires that field personnel measure the ambient conductivity of the water and understand electrofisher output characteristics.

Smith-Root (S-R), Inc. (Vancouver, Washington), is at present the dominant manufacturer of electrofishing components in the USA; their GPP (gas-powered pulsator) series of electrofishers are widely used in boat-mounted electrofishing systems (Miranda and Spencer 2005). These electrofishers are considered robust, but they are not supplied with a voltmeter, and the ammeter does not provide a reliable indication of current (Pope et al. 2001). The setup raises concern that users may not fully understand how adjustments to GPP settings control important electrical properties potentially affecting fish capture or causing injury (Miranda and Dolan 2004; Miranda and Spencer 2005).

Consequently, additional instrumentation is required to be able to calculate the power being delivered to the water. One option utilizes a portable oscilloscope, standardizing the point in the electrical circuit and the electrofisher control settings at which electrical measurements are taken (Miranda and Spencer 2005). Such electrical measurements require extreme caution because they expose workers to high voltage or high current. An alternative to making electrical circuit measurements to overcome the metering limitations of

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GPP electrofishers would be to better understand GPP performance over a range of water conductivities to aid selection of appropriate control settings.

In this evaluation we measured the voltage and current output of the GPP 5.0 by using four static resistance loads selected to simulate the total resistance of an aluminum-hulled electrofishing boat over a range of commonly encountered water conductivities. Using static loads eliminated the variability that would exist if such measurements were attempted with the boat in the water. The purpose was to provide fishery biologists with guidance for selecting GPP 5.0 settings on the basis of local water conductivity without the need for onboard electrical measurements.

Methods

Aluminum-hulled electrofishing boats are commonly equipped with paired anodes. Spherical anodes offer favorable electrical properties, including lower electrical intensity at the anode surface, a more extended effective electrical field than in other anode styles, and decreased importance of anode spacing in maintaining an effective electrical field for fish capture (Novotny and Priegel 1974; Novotny 1990; Kolz 1993).

This study measured the electrical output characteristics of the GPP 5.0 while powering the equivalent resistance of paired stainless steel spherical anodes (Martinez and Tiffan 1992) suspended half-submerged from fiberglass booms extending in front of a flat-bottom aluminum boat. A FLUKE model 99B digital oscilloscope equipped with a model 80i-1000-s current probe measured peak volts and peak amps.

By measuring peak voltage and peak current applied to the electrical system, we could calculate electrical resistance, using Ohm's Law. The total electrical resistance (R_1 = peak voltage divided by peak current) of a 5.5-m-long aluminum-hulled, flat-bottom boat (cathode), and two half-submerged stainless spheres (anodes) was measured at a local lake having an ambient conductivity of 741 μS/cm (C_1). Measurements made for two anodes of each of five diameters—20, 23, 25, 28, or 30 cm—were found to have corresponding total resistance values of 14.5, 10.2, 9.7, 9.1, and 7.7 Ω. These five in-water measurements of total electrical resistance were extrapolated to obtain the theoretical resistance (R_2) of this range of sphere diameters that might be used to standardize electrofishing operations in ambient water conductivities (C_2) between 100 and 1,000 μS/cm (Figure 1):

$$R_2 = (R_1 \times C_1)/C_2.$$

Total resistance values ranged from about 107 Ω for 30-cm anodes at 100 μS/cm to 6 Ω with 20-cm anodes at 1,000 μS/cm (Figure 2). We selected four levels of electrical resistance encompassing this range—114, 19, 9.5, and 5.7 Ω—as the static loads to simulate the approximate in-water resistances for ambient water conductivities of 100, 400, 700, and 1,000 μS/cm, respectively. CADET model 4F1000W (Part 09954) 4.2-amp, 240-V, 1000-W electric baseboard heaters, 122 cm × 17 cm × 9.5 cm, each with a measured resistance of about 57 Ω, were wired in parallel or series to achieve the approximate levels of the four simulation resistances (Table 1).

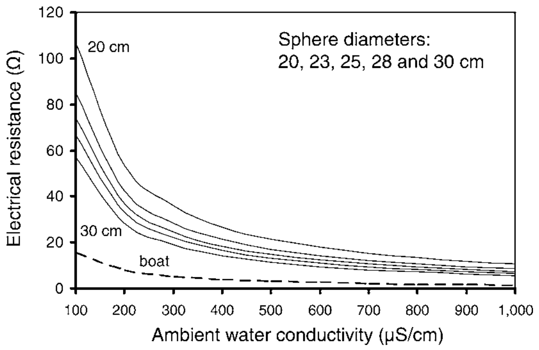

FIGURE 1.—Extrapolated electrofishing system resistance, including a 5.5-m aluminum-hulled, flat-bottom boat used as the cathode and two half-submerged pairs of stainless steel spherical anodes 20, 23, 25, 28, and 30 cm in diameter, at water conductivities ranging from 100 to 1,000 μS/cm. The dotted line denotes the estimated resistance of the boat hull.

Two or three GPP 5.0 electrofishers were tested at each resistance level (Table 1). Measurements were performed with the boat in which the GPPs were operated positioned on its trailer in a parking lot with the hull grounded to the soil as a safety precaution. The booms (anodes) and hull (cathode) were wired to an isolation strip to facilitate interconnections for the number of electrical loads needed to simulate the four static loads. The electrofishers were powered by the proprietary S-R 5-kW generator and operated in the pulsed direct current mode. Peak voltage and peak current were measured with the oscilloscope described above. For each range, 500 or 1,000 V, the peak power output was calculated at percent of range settings of 10, 20, 40, 60, 80, and 100% in combination with the pulse frequency settings of 7.5, 15, 30, 60, and 120 Hz. Although the shape of the pulsed direct current waveform from the GPP 5.0 changed with different electrical loads and electrofisher settings, only the peak voltage and current were recorded. The product of these measurements determined the peak power output for the individual electrofishers. These power calculations from the individual units were averaged to develop the relationships between the various combinations of electrofisher settings and the four static loads.

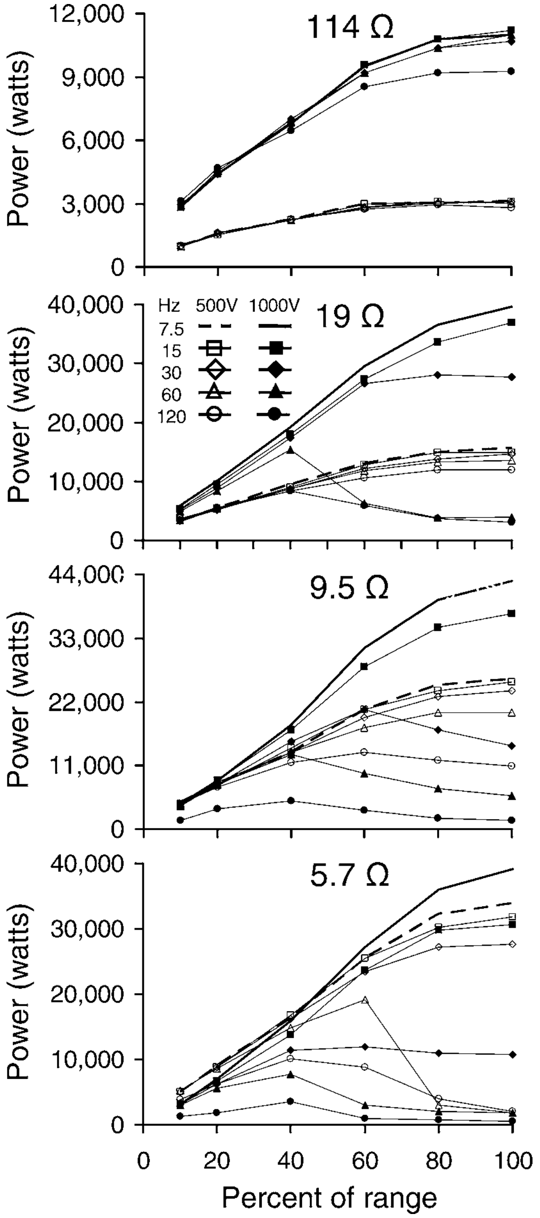

FIGURE 2.—Peak power output for Smith-Root GPP 5.0 electrofishers connected to static loads to simulate electrofishing electrodes in ambient water conductivities of 100, 400, 700, and 1,000 μS/cm.

The percent of range control on GPP electrofishers adjusts the amplitude of the output waveform to a maximum of 500 or 1,000 V and also the width of the pulse from 1 to 5 ms (Smith-Root 2004; Miranda and Spencer 2005). Therefore, the duty cycle and amplitude of the pulsed direct current waveform are simultaneously affected by this single control in a manner that is not obvious to the operator. Miranda and Spencer (2005) provided interpolated pulse widths for a GPP 7.5 correlated with percent of range settings that were used to estimate duty cycles for the GPP 5.0 operated at pulse frequency setting options of 7.5, 15, 30, 60, and 120 Hz. Duty cycle was calculated as the product of pulse width (ms) and pulse frequency (Hz) divided by 1,000, expressed as a percentage.

An effective fish conductivity (C_f) of 115 μS/cm (Miranda and Dolan 2003) was used to calculate the multiplier for constant power (M_{cp}; Kolz 1989; Miranda and Dolan 2003) for the four simulated resistance levels (114, 19, 9.5, and 5.7 Ω) and their associated ambient water conductivities (C_w; 100, 400, 700, and 1,000 μS/cm).

$$M_{\mathrm{cp}} = (1 + C_f/C_w)^2/(4 \cdot C_f/C_w).$$

Results

Peak power calculated at the low (50–500 V) and high (50–1,000 V) range settings resulting from the combined adjustments of percent of range and pulse frequency at each of the four resistance levels ranged from 500 W to over 40,000 W (Figure 2). In general, the results showed performance trends that can be expected for any electrofisher that is operated near or beyond its design limitations. For example, when less power was required (114 Ω, high resistance) the data for both voltage ranges are tightly grouped. However, as the power requirement was increased, the output of the 5 kW generator approached its power limit, and the high duty cycle waveforms (i.e., higher frequencies) exhibited a reduction in available power output.

The GPP 5.0 is purposely designed with two voltage ranges: 1,000 V for low conductivity water and 500 V for high conductivity water. This inherent feature was evident as the electrofisher began to overload when operated at the 1,000 V setting, above 40% of range, and at 60 and 120 Hz with a 19 Ω load simulating 400 μS/cm water (Figure 2). This overload situation for the 1,000 V range became more evident at 9.5 and 5.7 Ω. When set at the 500 V range, the GPP 5.0 continued to function at pulse frequency settings of 60, 30, 15, and 7.5 Hz with a 9.5 Ω load (700 μS/cm water). However, at 5.7 Ω (1,000 μS/cm water), only 30, 15 and 7.5 Hz continued to provide increased power with percent of range settings greater than 60.

Performance among the GPP 5.0 electrofishers became erratic at inflection points where power outputs began to drop (Figure 2). In some situations, when the oscilloscope indicated a drop in power output, the generator's engine continued to run in a manner that may not alert inexperienced operators that a system

TABLE 1.—Number of static loads (baseboard heaters) and circuit configurations used to simulate four levels of electrical resistance approximating ambient conductivities of 100, 400, 700, and 1,000 μS/cm. Two Smith-Root GPP 5.0 electrofishers were measured at three load simulations, 114, 19 and 9.5 Ω, and three were tested with 5.7 Ω.

Simulated resistance (Ω)	Approximate ambient conductivity (μS/cm)	Number of static loads (~ 57 Ω)	Number of GPP 5.0 electrofishers
114	100	2 parallel sets of 4 in series	2
19	400	3 in parallel	2
9.5	700	6 in parallel	2
5.7	1,000	9 in parallel	3

overload existed. Power outputs of individual GPP 5.0 electrofishers operating under sustainable electrical loads, as indicated by increasing power outputs, were more similar (CV = 0.1–29%) at all combinations of settings than at settings producing excessive electrical demand. Power outputs of individual electofishers became more dissimilar at the point where power levels began to drop and the generator was audibly under heavy load (CV = 9–46%).

Estimates of duty cycle ranged from 1% with percent of range set at 10 and a pulse frequency of 7.5 Hz to 50% with percent of range set at 100 and a pulse frequency of 120 (Table 2). Duty cycle was less than 10% for percent of range settings of 50 or less at a pulse frequency of 30 Hz, and for all percent of range settings at 15 Hz and 7.5 Hz. Approximate target power levels were 2,700, 3,942, 5,670, and 7,047 W, based upon the power transfer theory (Kolz 1989), for the four simulated levels of resistance (114, 19, 9.5 and 5.7 Ω) and their associated ambient water conductivities (100, 400, 700 and 1,000 μS/cm).

Discussion

The absence of adequate voltage and current meters for S-R GPP electrofishers requires other means for biologists to estimate power output. The information herein provides insight into the performance of the S-R GPP 5.0 electrofisher and facilitates the selection of initial control settings by field operators, thereby possibly avoiding the need for additional instrumentation or hazardous exposure to electrical circuits. Biologists should begin electrofishing at the target power levels estimated for the existing ambient water conductivities. The initial power target of 2,700 W for an ambient water conductivity of about 100 μS/cm is similar to the target power level of 3,000 W recommended in other studies (Burkhardt and Gutreuter 1995; Miranda 2005).

TABLE 2.—Estimated duty cycles (percent) produced by Smith-Root GPP 5.0 electrofishers at various combinations of percent of range and pulse frequency settings (Hz). Pulse widths (ms) were interpolated from measurements of a GPP 7.5 electrofisher reported in Miranda and Spencer (2005).

Percent of range	Pulse width	Pulse frequency setting 120	60	30	15	7.5
10	1.3	16	8	4	2	1
20	2.0	24	12	6	3	1.5
30	2.3	28	14	7	3.5	1.7
40	2.7	32	16	8	4	2
50	3.0	36	18	9	4.5	2.3
60	3.2	38	19	10	5	2.5
70	3.5	42	21	10.5	5.3	2.7
80	3.8	47	23	11.5	5.7	2.9
90	4.0	48	24	12	6	3
100	4.2	50	25	13	6.3	3.1

Our findings demonstrated that GPP 5.0 electrofishers are capable of producing extremely high power levels, about 40,000 W, in excess of even the highest power level of about 7,000 W initially suggested for the lowest simulated resistance level (5.7 Ω). Snyder (2003) reported that electrofishing-induced injury and mortality was often associated with excessive power levels. Dolan and Miranda (2004) stressed that biologists must strive to minimize electrofishing injury and mortality from an ethical standpoint, because we now possess the ability to do so. Reasons to avoid injury or mortality to fish also include protecting endangered fish species to minimize disruption of their behavior, to remove sampling induced mortality as a factor in population monitoring, and to preserve evolutionarily sympatric species. By observing fish behavior to detect undesirable fish response to electrofishing (tetany) and monitoring fish condition to avoid signs of electrofishing injury (hemorrhage), adjustments to initial electrofisher settings can be made in the field without making in-water measurements of electrical variables (Dolan and Miranda 2004). The goal remains to induce only that degree of immobilization (narcosis) required to effect the capture of target fishes.

Miranda and Spencer (2005) expressed concern that biologists may be confused about the function of GPP electrofisher controls, particularly the percent of range control. Percent of range settings from 0 to 50% increase power output by simultaneously increasing both peak voltage and pulse width, but any increase in power output from 50% to 100% is achieved by increasing pulse width alone. As a consequence, the rate at which power output increases is generally greatest for range settings from 10% to 60%. The decreased rate of power output and the observed flattening of GPP 5.0 power outputs at percent of range settings from 60% to 100% are attributable to this control feature. This combined function of the percent of range control also directly affects the duty cycle, which has emerged as an important electrical parameter influencing both fish capture efficiency and the potential for injury. Miranda and Dolan (2004) recommended electrofishing at duty cycles of 10–50% to optimize fish capture and minimize fish injury. Our estimates of duty cycle suggest that half of the control setting combinations on GPP 5.0 electrofishers for percent of range and pulse frequency would not be used as they fall below the 10% threshold. This guideline would recommend relying primarily on the higher pulse frequency settings of 60 and 120 Hz. This is consistent with the recommendation by Smith-Root (2004) to begin electrofishing with pulsed direct current at a pulse frequency of 120 Hz if one is uncertain about selecting initial settings.

This use of higher pulse frequencies to achieve optimal duty cycles contrasts with recommendations to electrofish with low-frequency pulsed direct current, preferably 30 Hz or less, to lower the risk of injury in fish captured by electrofishing (Grizzle and Henry 2001; Snyder 2003a, 2003b). However, Snyder (2003a) allowed that the impact of short pulse widths on injury rates of fish was uncertain or might even be more harmful. Short pulse widths and low pulse frequencies combine to reduce the duty cycle and have more recently been shown to require high peak power levels to immobilize fish. Dolan and Miranda (2003) observed that a variety of warmwater fish species subjected to low-frequency pulses with short widths tended to display forced swimming and thrashing rather than immobilization.

Recommending initial GPP 5.0 electrofisher settings to be used by biologists electrofishing from aluminum-hulled, flat-bottom boats advances fleet standardization by promoting the application of more consistent power levels. By avoiding electrofisher settings that result in declining or erratic power output, the performance of individual GPP 5.0 electrofishers is sufficiently similar to accommodate standardization. Preliminary control settings, based on initial power level targets, would be refined in the field by observations of fish capture efficiency, behavior, and injury rate.

Although complete standardization of electrofishing operations is not possible because of differences in habitat, personnel, and electronic variables, standardization of controllable variables remains feasible and advisable. Equipping similarly configured boats with identical equipment and electrode arrays is the simplest way to produce identical electrical fields (Miranda 2005). This evaluation demonstrated that GPP 5.0 electrofishers are capable of supplying the target power output levels for any of the candidate sphere diameters for programs that use paired stainless steel spherical anodes for its aluminum-hulled fleet of boat-mounted electrofishers It may be prudent, however, to select a single diameter to further standardize electrofishing operations.

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