The Bureau of Commercial Fisheries Type IV Electrofishing Shocker--Its Characteristics and Operation

by Benjamin G. Patten and Charles C. Gillaspie

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ABSTRACT

A fish shocker which is effective, dependable, light weight, and economical to purchase and operate is described. The output energy of this shocker is 450 volts direct current at 150 milliamperes, pulsed into square waves at frequencies controllable from 20 to 100 per second with a fixed duration of 6 milliseconds.

This output energy produces a good galvanotaxis reaction in fish in the field. Our experimentation and information from the literature indicates the output energy of the described shocker to be of a favorable range.

Methods of operation of electric shockers are given. The recommended sizes of the electrodes are about 40 cm. square for the anode and 2.3 m. square for the cathode. The electrodes should be operated close together, especially in resistive waters. In suitable waters a wading technique is used, but a floating electrofishing operation is necessary if waters are deep or swift.

The effectiveness of a shocker is often reduced by environmental factors, but in most situations little can be done to compensate for this. The effects of water resistivity, variations in fish size or species, temperature, and fish mortality factors are discussed in relation to the success of electrofishing operations.

INTRODUCTION

In recent years electrical methods of collecting fish in fresh-water shallows have been developed because they are more convenient and efficient compared with nets or traps. Little is known, however, of the basic relations between fish and electricity, or how environment affects the amount of electrical energy that reaches the fish. Quantitative evaluations and comparisons of electrofishing research by different authors are almost impossible because varied shocks and shock-producing equipment have been used in waters of varying resistivities on different species and sizes of fish. The interrelations of these factors are not commonly known or understood.

Because it is difficult to evaluate electrofishing operations, most shockers do not produce the optimum stimulative electrical energy for fish, or the methods of introducing electricity into water may not fully utilize the power potential. As a contribution to knowledge of electrofishing, we describe the design and operations of the Bureau of Commercial Fisheries Type IV shocker, which has proven to be effective and dependable for electrofishing. Also, we attempt to delineate the preferred type of electric shock and the effects of environment on electrical energy gradients in the water.

THE TYPE IV SHOCKER

The Type IV shocker is the fourth of a series of shockers constructed by the Bureau of Commercial Fisheries technicians at the Seattle Biological Laboratory for the collection of fish. The Type I shocker produced a wave shape that was relatively ineffective in comparison with the wave shape produced by Types II, III, and IV. Shockers of Types I, II, and III require a heavy, cumbersome, portable generator for power, and the initial cost of these generator-shocker sets is much greater than for Type IV. The Type IV shocker is also more dependable and more economically maintained than its predecessors.

DESCRIPTION OF THE SHOCKER

The Bureau of Commercial Fisheries Type IV shocker[1] weighs 9 kg., excluding a battery, and measures 15 by 30 by 20 cm. (fig. 1). The schematic diagram of the Type IV shocker is shown in figure 2. The 12 volt (v.)/400-v. dynamotor output is connected in parallel with a 100 microfarad (μf.), 600-v. capacitor bank to provide power for the shocker. In operation, this supply is connected on one set of normally open contacts of a mercury-wetted relay, capable of operating up to 100 pulses per second. The other side of the normally open contacts of the relay is connected to the 2-ampere (a.) fuse, power output plug, and cable to the anode. The mercury-wetted relay is driven with an OA4G relaxation oscillator which, when fired, energizes the coil of the relay. Duration of the output pulse is fixed by the size of the capacitor in the power supply side of the mercury-wetted relay coil. Frequency is determined by the time constant of the selected capacitance and fixed resistance in the trigger anode circuit of the OA4G thyratron. Frequencies of 20 to 75 pulses per second with a duration of 6 milliseconds (msecs.) are easily obtained with this circuit.

A power switch located on the front panel, when in the "on" position, connects the dynamotor to a 12-v. battery. With the local-remote switch in the local position, the unit operates continuously. With the switch in the remote position, the dynamotor operates only when the strip-switch on the anode handle is closed. The strip-switch energizes the coil

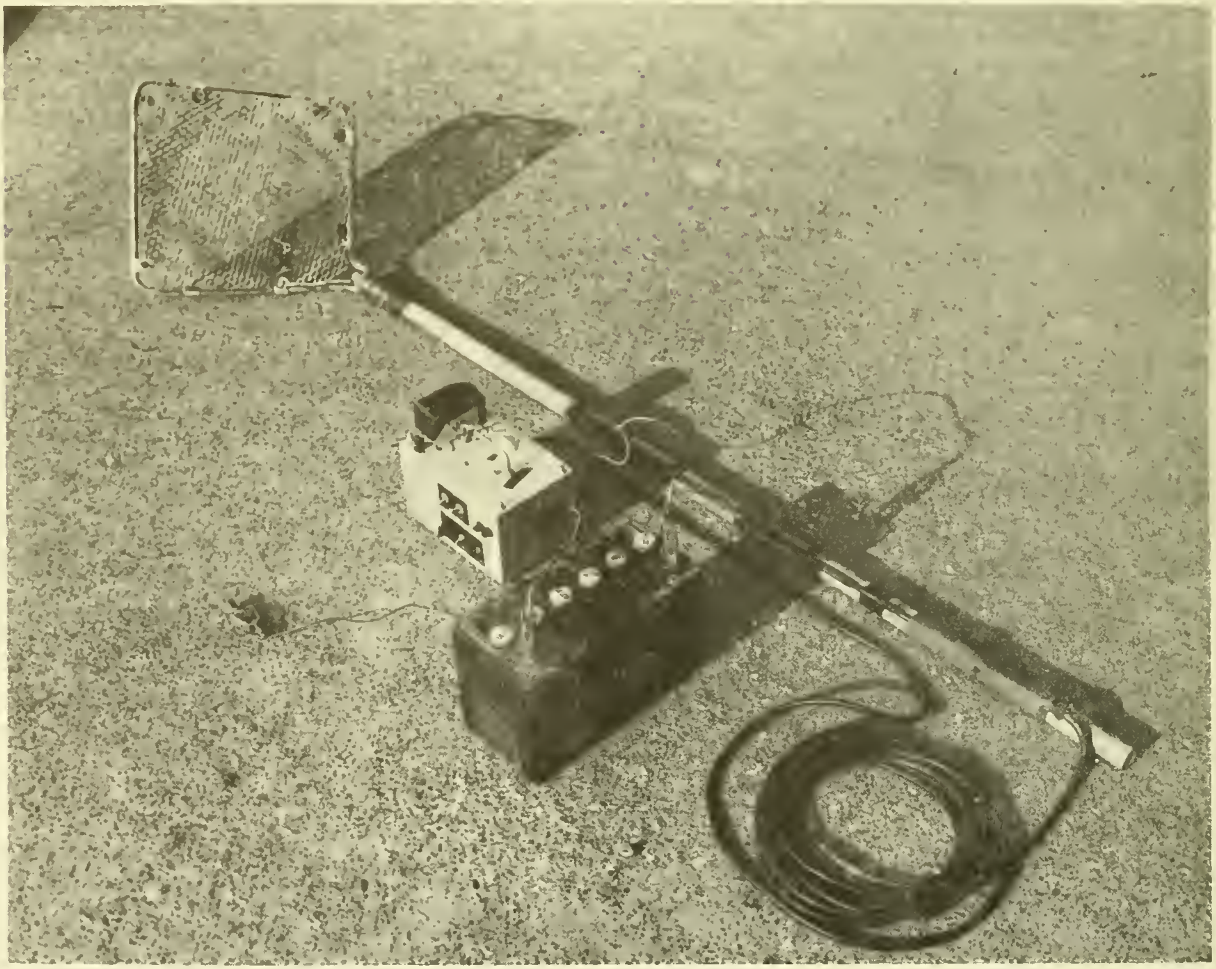

Figure I.--The Type IV shocker in operational condition, less the cathode. The strip-switch mounting is on the anode handle. The small black box on the shocker is the running-time meter.

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[1] Some of the materials and methods described here, we credit to Richard B. Thompson, Fishery Biologist, Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash. His foresight led to the development of the Bureau of Commercial Fisheries shockers to Type I, II, and III, which provided the basis for development of the Type IV shocker.

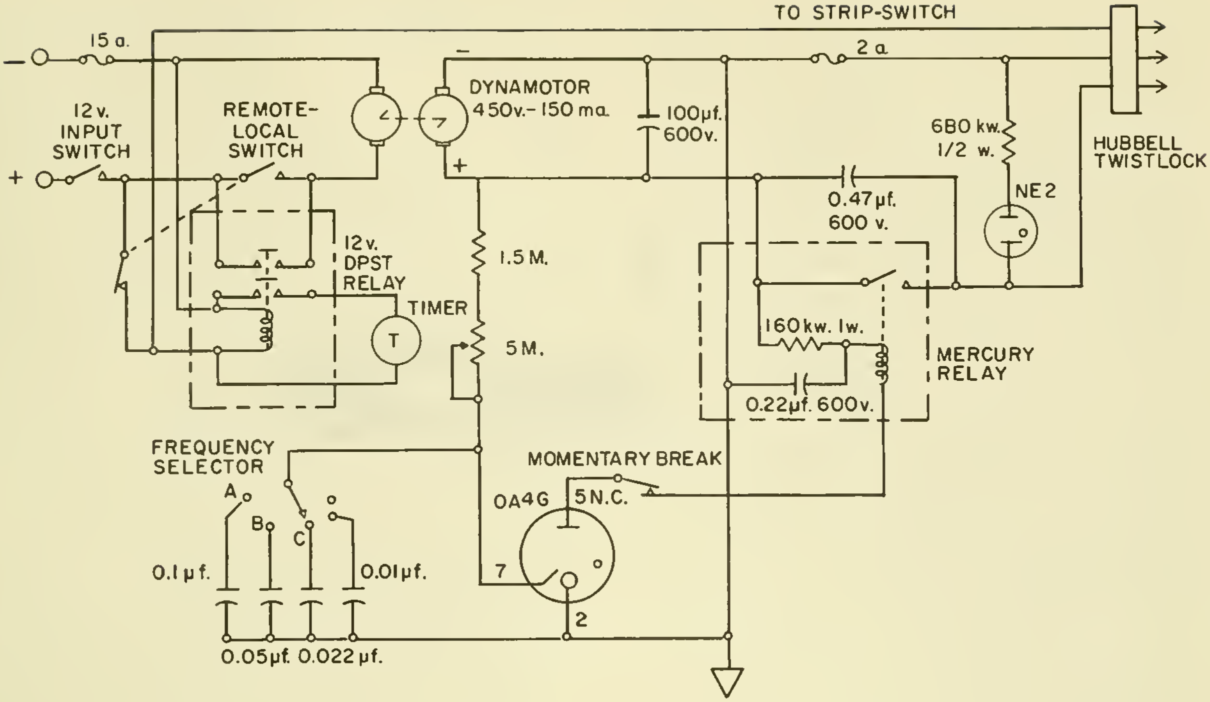

Figure 2.--Schematic diagram of the Type IV shocker.

of the 12-v., double-pole, single-throw relay. One set of contacts on this relay also controls the running of the timer motor.

A normally closed momentary switch located on the front panel, is used to open the plate lead of the OA4G to allow for deionization of the tube and to restore normal pulsing operation after a misfire. A misfire can be caused by accidental shorting of the electrodes in the water.

A four-position selector switch connects different values of capacitance into the trigger anode circuit to vary the frequency of the oscillator.

A running-time meter and a small neon indicator lamp are installed on top of the unit. The lamp is wired directly across the output of the unit and gives visual indication of the output pulse. The running-time meter records cumulative time that the unit runs, to assist in determining catch per unit of effort.

A 12-v. battery with a 50-ampere-hour rating is generally sufficient as a power source for 4 to 5 hours of use. (If intermittent automobile trips are made, the battery can be recharged en route by a connection to the 12-v. car system.)

CHARACTERISTICS AND EFFECTIVENESS OF THE ENERGY OUTPUT

The more desirable forms of electrical energy for electrofishing have not been carefully determined, although some research on various neurological phenomena resulting from electric shock do suggest the optimum energy output for electrofishing. These findings are used here to establish a basis for evaluating the shock produced by the Type IV instrument.

Effects of Basic Electric Currents

The three types of electrical energy considered here are alternating current (a.c.--usually 60-cycle), direct current (d.c.), and pulsed d.c. The continuous reversal of fields in a.c. current in equal magnitudes along a sine curve eliminates unidirectional physiological response in animals. In electrofishing with a.c., the voltage gradient decreases with distance from the electrode (fig. 3), and a typical set of fish reactions occurs within the graduated intensities. The weaker voltage gradients along the periphery of the field invoke fright and flight, resulting in escape;

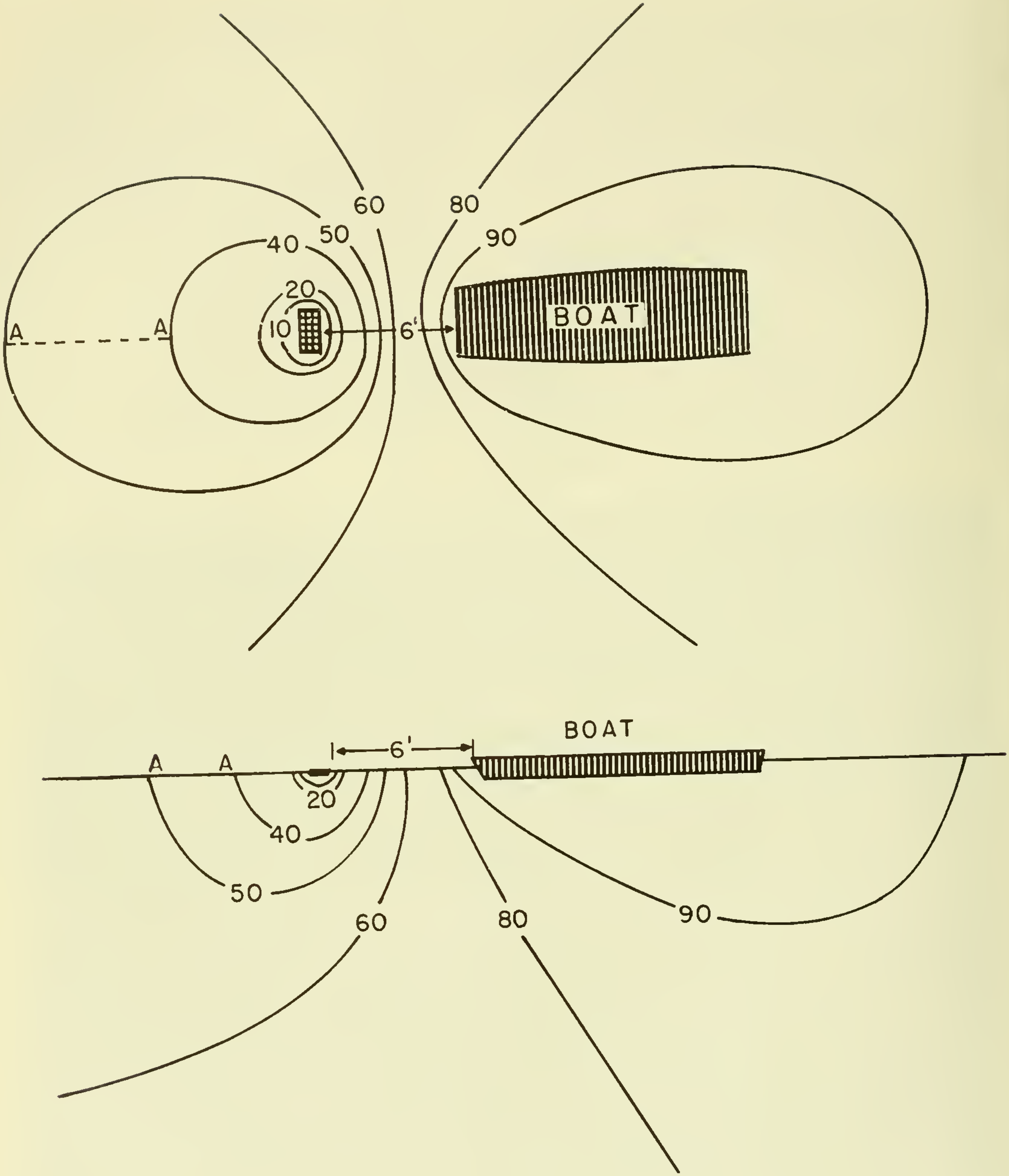

Figure 3.--Teledeltos analog plots illustrating the decrease of voltage gradient in fresh water between the small or hand-operated electrode (the anode in d.c. electrofishing), and a 4.2-m. aluminum pram electrode from top and side views. The percentages of the given output voltage found within the lined boundaries are shown by their corresponding numbers. The voltage gradient at any one point can be estimated by dividing the voltage differences of the encompassing lines by the number of units of distance along perpendicular intercepts of these lines. For example, if the output voltage was 100 v. and the distance AA was 1 m., then the average intensity between these points would be 10 v. per meter.

closer to the electrode, oscillotaxis (Van Harreveld, 1938) occurs; and the strong voltage gradient surrounding the electrode produces electronarcosis.

The typical set of fish reactions to increasing strength of d.c. (Vibert, 1963) differs from those caused by a.c., primarily in the replacement of oscillotaxis by galvanotaxis (Van Harreveld, 1938). The alternating directional response to the a.c. is replaced by a unidirectional one that causes the fish to move progressively toward the anode. This directional response is of primary importance in electrofishing as the fish can be attracted out of swift or turbid water or from heavy underwater cover to a predictable point. Although d.c. produces the desired galvanotropic effect, it still leaves much to be desired because of refractoriness of the fish.

Extensive, strong, directional swimming does not occur unless the d.c. is pulsed. The reactions of fish to pulsed d.c. of increasing strength are similar to those reported for d.c.--except that before directional swimming commences, the pulsations set up a series of movements which are probably galvanotropic reflexes of a spinal origin (Van Harreveld, 1938). We believe that locomotion may be a voluntary escape reaction at this time but that galvanotropic reflexes produced by pulsed d.c. inhibit the fish from turning away from the anode. The result is violent milling movements; some fish escape and others succumb to galvanotaxis.

Optimum Pulsed D. C. for Electrofishing

Complexity of the problem becomes manifold in determining the optimum pulsed d.c. for electrofishing. The voltage, frequency, duration, wave shape, and amperage all must now be considered and combined in such a way that they supplement each other to produce a strong swimming motion of fish toward the anode. The least electrical energy required to induce repetitive galvanotropic reflexes is of prime importance in electrofishing because the electric power in water disperses as the reciprocal of the square of distance from the anode. Within a given distance from the anode, the electric energy is at the threshold strength for continuous galvanotropic reflexes. This is the area of greatest concern, for it determines the effective range of a shocking unit. The following sections summarize the type of pulsed d.c. which has the greatest threshold for galvanotaxic stimulation of fish.

Effect of voltage on fishes.--Adelman and Haskell (1957) and Vibert (1963) have demonstrated separate stimulating intensities for muscle and nerve tissue in fish. They found that direct stimulation of muscle requires considerably greater voltage than is needed for neural reaction. Neural stimulation, therefore, is unquestionably the most useful stimulus in electrofishing because it occurs at lower electric intensities than muscle stimulation but achieves similar results.

If a fish neuron is subjected to voltage that increases gradually from zero, an initial reaction occurs at a certain intensity, termed the threshold voltage (Haskell, MacDougal, and Geduldig, 1954). Voltage increments above the threshold do not increase the strength of the neural reaction. Thus, the reaction is of the all-or-nothing type (Prosser and Brown, 1961).

Effect of repetition rate and duration of a pulse.--A single pulse of electric energy of subthreshold strength does not leave the nervous system unaltered since a series of pulses of the same value may elicit response (Cooper and Eccles, 1930; Prosser and Brown, 1961). This phenomenon, termed summation (of inadequate stimuli), has been studied by Haskell and Adelman (1955) in hatchery brown trout. In their experiments the optimum frequency for summation was close to 180 pulses per second. Their comparisons of the threshold response of pulsed and unpulsed d.c. showed that the threshold stimulus occurred at 20 percent less voltage with pulsed d.c. Pulsed electricity of "summation strength" is probably insufficient to produce a significant galvanotropic response and is assumed to cause a fright reaction.

When electric energy of constant voltage (somewhat greater than that required for summation) is pulsed with increasing frequency, the neurally induced muscle flexures strengthen from isolated twitches to sporadic volleys and finally to strong unified contractions. This phenomenon is termed facilitation (Prosser and Brown, 1961). For example, Gray (1936) noted that a cycle of 50 electrical pulses per second was required to elicit one undulation per second from eels with the spinal column transected behind the medulla. This finding nullifies implications (Burnet, 1959), probably born of the German theory (Halsband, 1956), that frequencies should approximate the natural undulation rate of fish.

Optimum frequencies for electrofishing have not been demonstrated adequately in fishes, but our experience with varied sizes and species has indicated a general "favorable" range. Pulsations below 50 per second attract fish poorly. The most desirable fish reactions are at 50 to 90 pulses per second except in resistive waters. Here, frequencies as high as 100 pulses per second are necessary to produce similar reactions. Rates from 90 to 140 pulses per second cause very rapid swimming undulations, but frequencies above 140 tend to narcotize. Excessively high frequencies have no apparent effect upon fish.

McMillan (1928) observed no reaction when salmon were subjected to 500,000 cycle a.c.

Although pulsations can set up the strong rhythmical flexures required for galvanotaxis, a certain minimal amount of electrical energy must reach the fish. If the time (duration) of the electrical impulses is extended, the fish experiences prolonged exposure at given voltages and hence is subjected to increased power. An example of the profound effect of duration of exposure of electricity on fish for the threshold summation stimulus has been demonstrated by Adelman and Haskell (1957). As the frequency and duration are electronically set and remain stable, their optimum combination is one of the most important considerations of electrofishing. The "preferred" frequency-duration combinations that have been determined by others for a variety of fish species and conditions with different types of shocks have varied widely (fig. 4).

Evaluations made in the laboratory and field by us and our associates have indicated the optimum frequency-duration relations shown in figure 5 for waters of 5,000 to 30,000 ohm cm.^{3} resistivity.

As the frequency increases from 50 to 90 pulses per second, the maximum duration can decrease from 12 to 6 msecs. Greater durations would produce fish "fatigue" and constrained movement which may represent refractoriness in the nerves and muscles. Lesser durations do not generally provide the needed energy. We recommend that the minimal duration for 50 to 90 pulses per second be 8 msecs. at the lower frequencies and 6 msecs. at frequencies of 70 and over. Shorter durations may be effective, especially in more conductive waters, but in most situations they do not produce the desired effect, and the rate of escape of the fish may be high. The greater power requirements to compensate more resistive waters can be met by extending the duration and increasing the frequency. Thompson's (1960) area of optimum response (fig. 4), determined in waters of 41,000 ohm cm.^{3} resistivity, is excellent for describing frequency-duration relations in resistive waters.

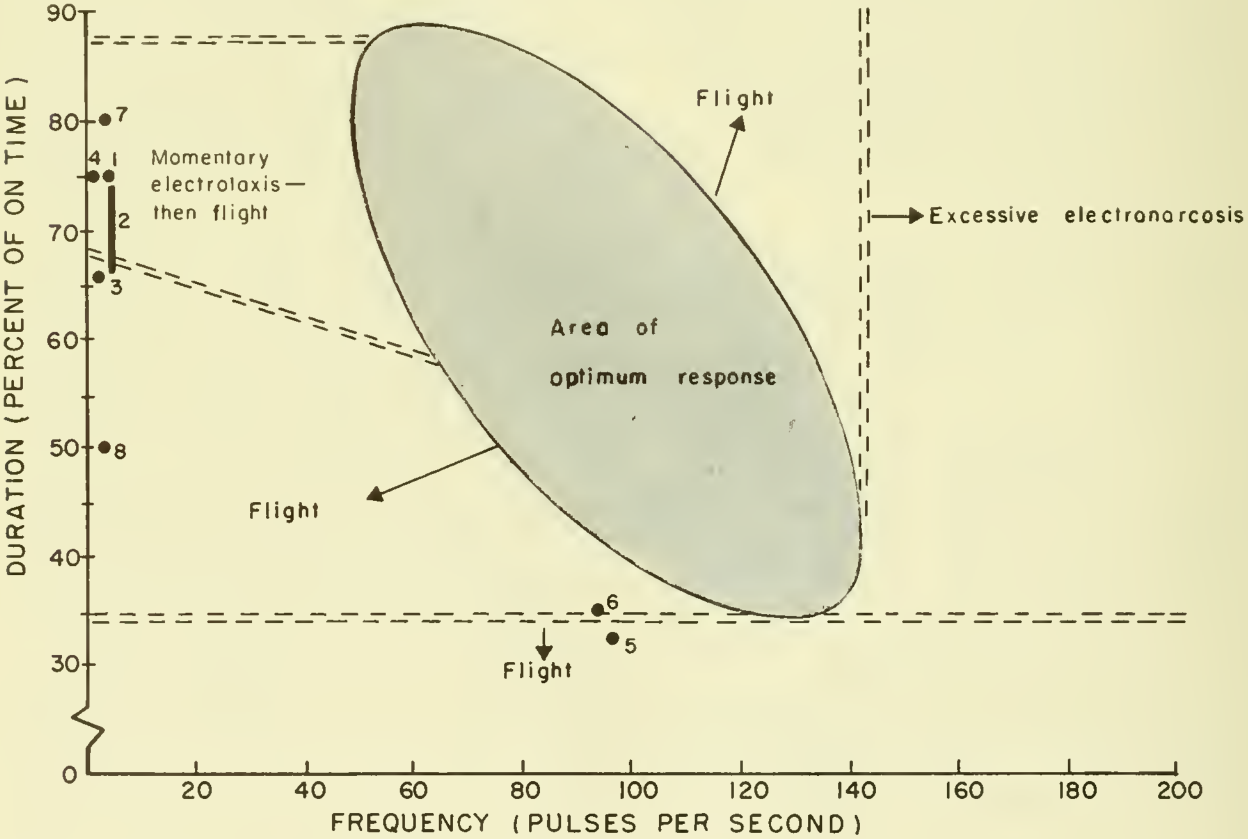

Figure 4.--Optimum frequency-duration combinations for electrofishing, as reported by various authors, shown with Thompson's (1960) "area of optimum response"(shaded). Numbers preceding each citation refer to numbers (1 to 8) shown in graph. 1--California Marine Research Committee (1950); 2--Groody, Loukashkin, and Grant (1952); 3--McLain and Nielsen (1953); 4--Haskell and Adelman (1955); 5--Taylor, Cole, and Sigler (1957); 6--Rollefson (1958); 7--Burnet (1959); 8--Smith, Franklin, and Kramer (1959).

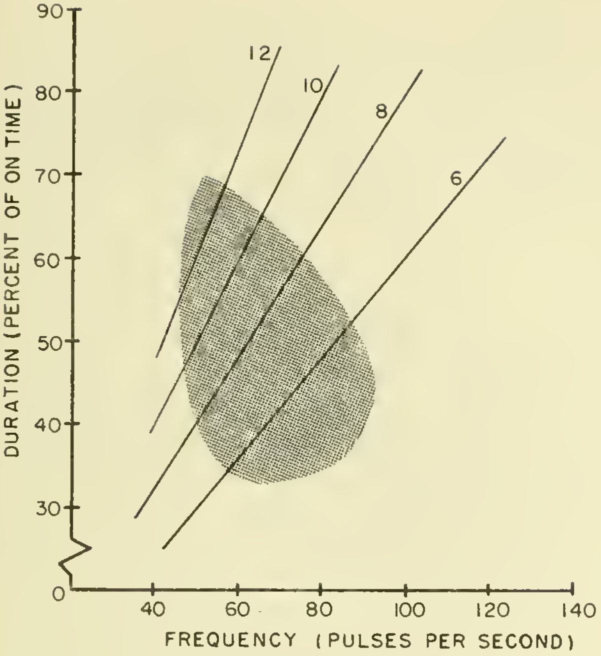

Figure 5.--The optimum frequency-duration combinations for electrofishing in waters of 5,000 to 30,000 ohm cm.^{3} resistivity. The lines show the "on" time relation in msecs.

Wave shape.--The square wave is considered superior for electrofishing because the maximum voltage is produced throughout its duration. Other wave shapes have a lower efficiency. For example, the triangular wave shown in figure 6 has one-fourth the electric energy of a square wave of the same duration and peak voltage. Condenser discharge waves (fig. 7, A) have low efficiency and require high frequency rates for moderate effectiveness.

The leading edge of a wave is apparently critical in eliciting the neural response. Haskell, MacDougal, and Geduldig (1954) observed that stimulation occurred on the "make" of the impulse. Abe (1935) was able to stimulate catfish more effectively with fast ascending and slowly descending pulses than with the inverse. An almost instantaneous pulse rise is probably the most desirable.

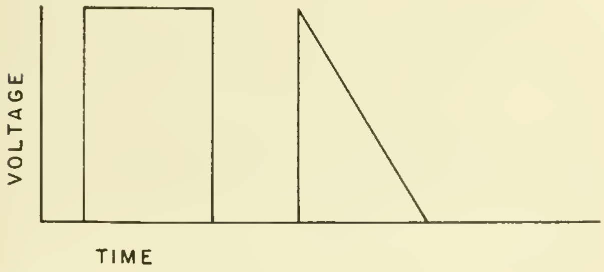

Figure 6.--Square and "triangular" waves of identical peak voltage and duration: the "triangular" wave is capable of producing only one-fourth the power of the square wave into a given load.

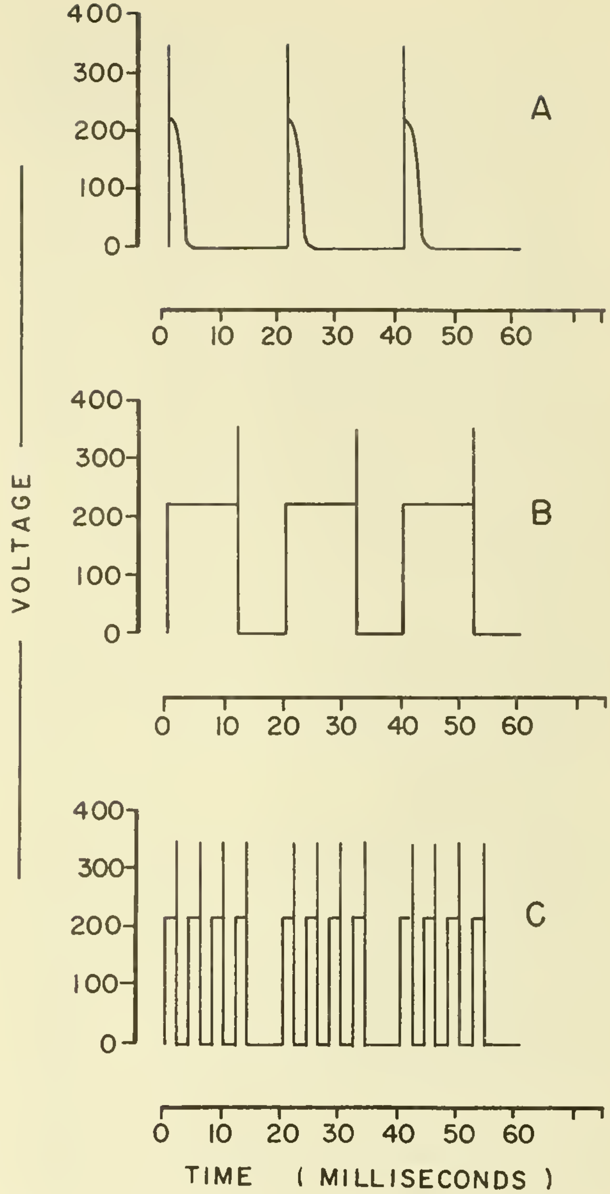

Figure 7.--Wave shapes of Bureau of Commercial Fisheries shockers: A--the triangular condenser wave with a controllable frequency and an uncontrollable short duration, produced by the Type I shocker; B--the square wave with controllable frequency and duration produced by the Types II and III shockers; C--the basic square wave, B, which can be subdivided into groups of pulses with frequency and duration controllable, produced by the Type III shocker.

Variations of the basic square wave may be considered. The wave is most easily controlled by allowing it to drop to zero volts between impulses. Groups of pulses, or subdivision of the duty cycle (fig. 7, C), appear to be about as effective as an uninterrupted pulse cycle. Groups of pulses produced by the Type III shocker are of no proven advantage to date. All of the Bureau of Commercial Fisheries shockers produce a characteristic voltage discharge "spike" (fig. 7) which probably has a duration too short to produce a pronounced stimulating effect on the fish.

Output voltage.--The voltage potential of the d.c. shocker should be appreciable to provide a strong stimulative gradient at a distance from the anode; yet practical limits must be set for the safety of the operators and in consideration of the physics of water conduction of electricity. An output of 150 v. approaches the desirable minimum in more conductive fresh waters that characteristically have resistivities of 1,000 to 15,000 ohm cm.[3]. Greater voltages are recommended for general-purpose shockers, especially if work is to be done in highly resistive waters. The curvilinear relation, however, between output voltage and the waterborn voltage gradient at various distances from the anode (fig. 3) suggests that there is a practical upper limit. Considering all factors, we feel that output voltages above 400 are hardly justifiable even in the most resistive waters, providing optimum-sized electrodes are used.

Amperage.--The amperage in electrofishing provides the quantitative effect of a stimulating current. Because the power that can be transmitted through water is a function of resistivity, the optimum amperage varies with the water. It is most convenient, however, to use maximum possible amperage.

Our experience with different dynamotor power sources for the Type IV shocker indicates that a current of 60 milliamperes (ma.) is inadequate but that one of 150 to 180 ma. is adequate in waters over 5,000 ohm cm.[3] resistivity; a shocker capable of producing 1 to 2 a. is adequate in all fresh waters. General-purpose shockers should be able to produce 2 to 3 a. for sampling in less resistive waters.

Output Energy of the Shocker

The Type IV shocker has a potential output of 450 v. pulsed at frequencies from 20 to 100 per second into square waves having durations fixed at 6 msecs. The frequency ranges commonly used in all waters are 50 to 70 pulses per second, which result in a 30- to 40-percent duty cycle. Decreasing water resistivity distorts the wave shape primarily by diminishing the output voltage (fig. 8).

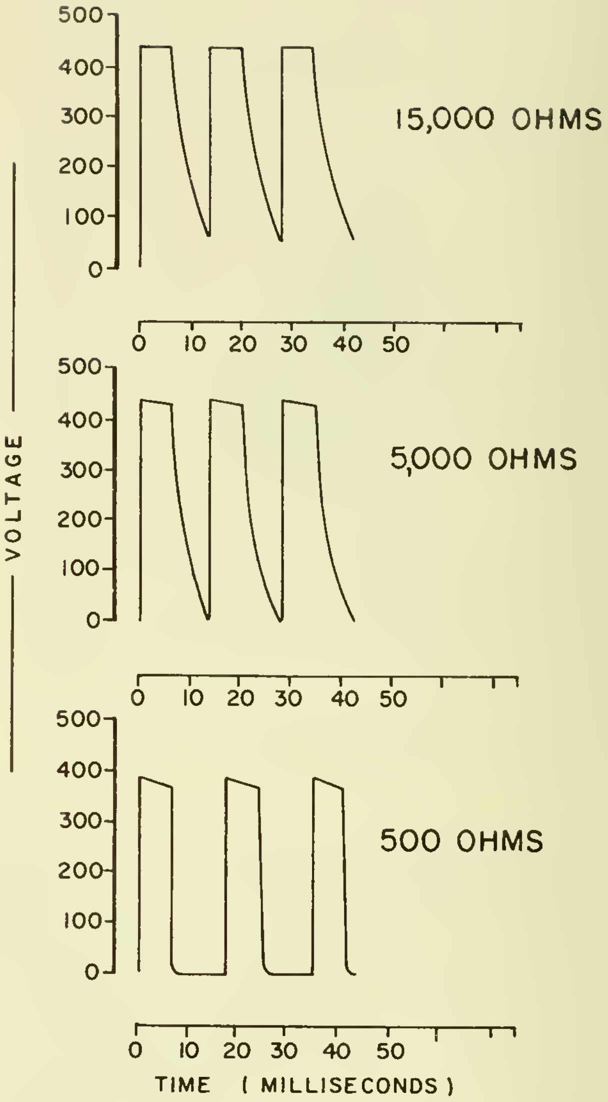

Figure 8.--Distortion of wave shape of Type IV shocker caused by a 15-, 5-, and a 0.5-thousand ohm load.

The Type IV shocker has proven highly successful in attracting fish from distances, and they often forcibly collide with the anode through galvanotaxis. The frequency-duration possibilities are just within the optimum range for moderately resistive waters, but the high voltage potential produces additional requisite energy for strong galvanotaxis. The additional stimulative energy desirable in highly resistive waters is partially attained through a rise in output voltage.

METHODS OF OPERATION OF ELECTRIC SHOCKERS

The size and construction of the electrodes, the methods of "fishing" the anode, and the abilities and experience of the operators can be as important in electrofishing as the use of an optimum output current. In the following section we discuss equipment and procedures that we have found to be successful in the field.

ELECTRODES

The electric energy in water can be increased by the use of "optimum-sized" electrodes. The maximum surface area of the electrode is governed by the practicality in manipulating it--especially the anode, or fish-attracting pole, which should be highly mobile and of a size that can be passed through swift waters without excessive difficulty. The conductive grid of the anode is best when about 40 cm. square. This size of grid actually hinders conduction in most waters, but the increased current densities immediately surrounding the anode (fig. 3) facilitate electronarcosis which eases problems of capturing fish.

The electrical resistance inherent with small anodes can be overcome with the use of enlarged cathodes in practical stream operations because the cathode can be stationary. The optimum size for the cathode is dependent upon the water resistivity. The suggested minimum cathode surface area for waters less than 30,000 ohm cm.^{3} is 2.3 m. square, but for more resistive waters the cathode size should be increased.

The most satisfactory cathode is an aluminum boat, since it can also be used to transport the shocker and fish-holding tubs. Some caution must be used with a boat cathode. The operators can receive shocks by placing one hand on the boat and the other in the water simultaneously, and gear-damaging short circuits can result if the anode touches the boat. Weighted-down metal hardware cloth serves as a good cathode in small streams where mobility is not required. Galvanized washtubs are often used as cathodes for convenience, but are not highly recommended, especially if the stream is resistive. Because electrical resistance increases with distance between the electrodes, the anode is usually fished within 15 feet of the cathode.

ELECTROFISHING TECHNIQUES

One engaged in electrofishing must wade or float, depending upon the depth or swiftness of the water. In suitable waters, the operators wade and can probe the anode into likely fish habitat (fig. 9). Wading upstream eliminates effects of turbidity caused by bottom sediment. Furthermore, if collections are for a food-habit study, stunned prey are not swept downstream and consumed by predators. If turbidity and predation are unimportant, however, collections can be made more efficiently and less strenuously when moving downstream. The fish are normally oriented upstream, or toward the descending electrical field, and the shocked fish initially induced into flight bolt upstream into higher voltage densities, where they are held. Fish that manage to escape are often captured a short distance downstream. The size of the fish captured by wading operations in large streams is usually less than 150 mm., whereas larger fish are taken in deep waters by the floating method.

The floating method of electrofishing is used when the stream is too deep or swift to wade (fig. 10). The anode is clamped rigidly ahead of the boat, extending into the water. One man guides the boat with oars while one or two operators dip fish as the boat drifts with the river.

Collecting can be improved further by introducing the element of surprise through intermittent fishing. The intensity of the anode's peripheral electric energies only frightens fish, causing them to bolt or penetrate deeper into cover. In either situation, chances of capture are reduced. It is better not to move through a body of water with the power continuously on, but rather to fish only in likely habitat. Fish can be extracted from areas of heavy cover or from under shore ice by inserting the anode, turning the power on, and withdrawing the anode slowly and smoothly. Fish follow the anode under the influence of galvanotaxis into the open, where they can be netted. If the stream velocity is appreciable, the electrical power can be left on during floating without loss in efficiency.

Night fishing with lights has proven to be exceedingly productive in lakes (Loeb, 1957; Johnson, 1960; and Latta and Meyers, 1961), but it is not so in streams. The reflection and refraction of the spotlight beam caused by the ruffled stream surface greatly impair sighting of the fish. Headlamps are useful for electrofishing by wading.

Figure 9.--Fishing with the Type IV shocker by wading. Note use of polaroid glasses by the biologists for locating fish.

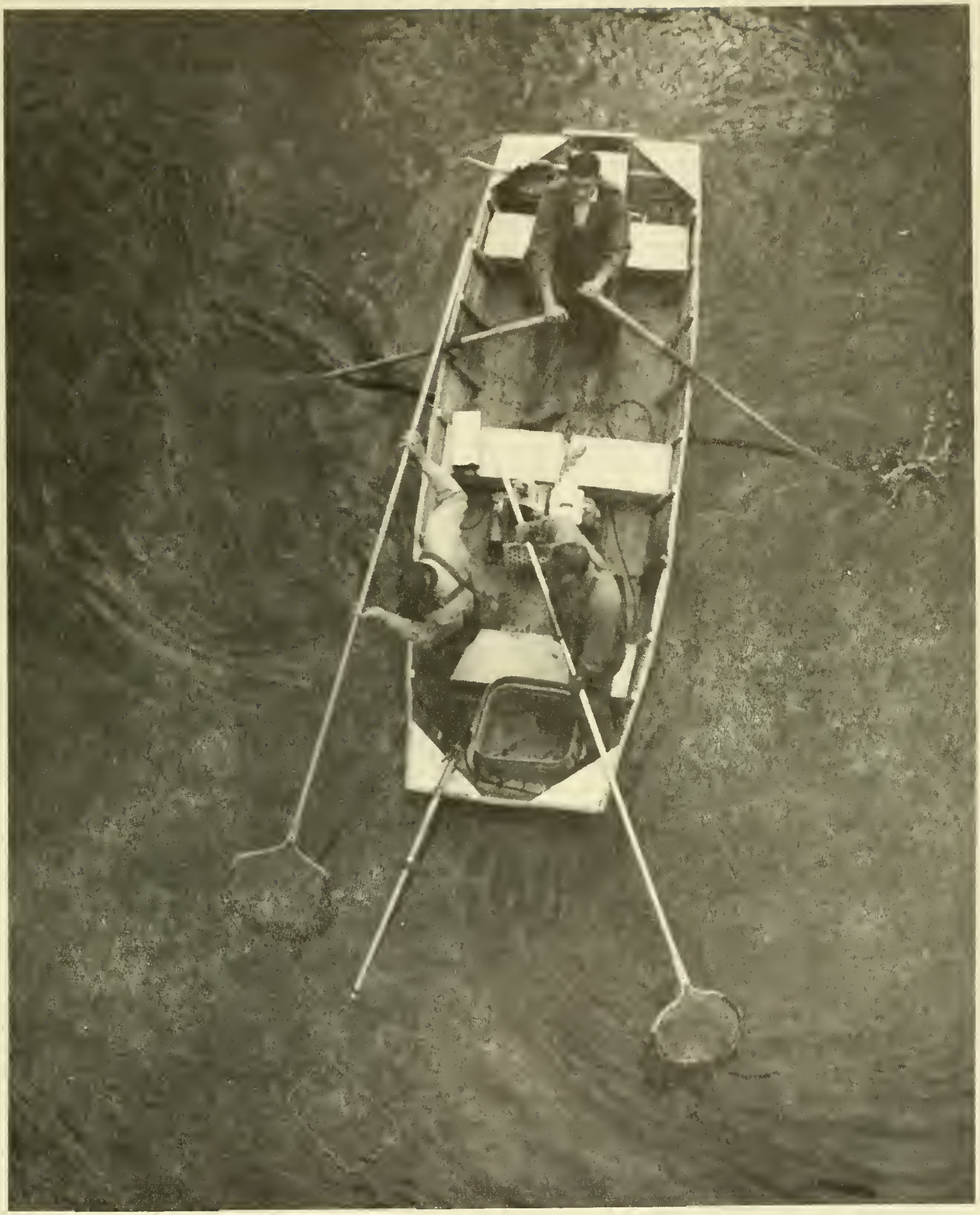

Figure 10.--Floating operation used in deep or swift streams. The Type III shocker can be seen on the middle seat; its power source is the generator.

The effectiveness of the shocker's output energy is sometimes reduced drastically by environmental or biological factors. The resistive effects of water do not alter the pulse frequency or duration but depress the electric energy input. The power that reaches a fish is then modified by the animal's physiological makeup. The following discussion of these phenomena may help to clarify the wide variation of reactions among fish. Some small adjustments in output power can be made to reduce the erratic actions and escape of fish, but this behavior generally has to be accepted.

INFLUENCE OF WATER RESISTIVITY

The resistivity of natural waters depends on the quantity of ionized salts available to carry the electricity. Salts ionize more freely with increase in water temperature, and this is more pronounced in waters of low salt content (McMillan, 1928; figs. 7 and 8).

How rising water resistivity increases the power required to elicit a given response in fish may be demonstrated by the voltages (assuming a constant power supply) required to paralyze sea lampreys at different resistivities (McCauley, 1960). Under his experimental procedure only about 0.8 v. was required in water with resistivities from 400 through 3,000 ohm cm.^{3}, after which the voltage requirements increased, approaching infinity at about 30,000 ohm cm.^{3}.

Practices which reduce the effect of highly resistive waters by delivering more electrical energy to fish include use of high frequencies and durations and use of square waves with peak voltages of 300 to 400 v.; it helps also to maintain large electrodes close together and to take full advantage of the "surprise effect." In some areas water resistivity is so great that electrofishing is generally impractical. Lennon and Parker (1958), who found extreme resistivities in Appalachian mountain streams, attacked this problem by adding salt to the water to improve electrofishing.

INTRASPECIFIC AND INTERSPECIFIC VARIATION IN FISHES

Individual variation is notable among fish even though they are of the same species and have similar lengths. The laboratory experiment of Haskell et al. (1954) on brown trout demonstrates this variability.

The larger the individual of a species, the more sensitive it is to a given electric shock (McMillan, 1928; McLain and Nielsen, 1953; Taylor et al., 1957). Fish absorb power as a function of body surface area and particularly length (Holzer, 1931). Also, the greater resistance of smaller salmonids (Nakatani, 1954), and possibly small fish of other species as well, further reduces their response to shocks.

The senior author's observations (on many fishes in the State of Washington) suggest to him that the degree of galvanotaxis may be related to a fish's benthic or pelagic behavior. For example, the substrate-boring petromyzontids exhibit little galvanotaxis, if any. Fresh-water and euryhaline cottids and the brown and black bullheads move a minimal distance, if at all, and only just before electronarcosis. Starry flounders in brackish water react well in view of their mode of swimming and dependence upon the bottom. In other fishes which do not stringently "adhere" to the bottom, or are pelagic, the galvanotaxis response is generally progressively stronger through the groups Catostomidae, Cyprinidae, and Clupeiformes.

The foregoing information agrees with Vibert's (1963) theory that an internal innate behavioral pattern is of such strength that the stimulating effect of electricity is resisted. Thus, a fish closely associated with the bottom resists galvanotaxis and assumes typical cryptic behavior, whereas the pelagic fishes exhibit a locomotory pattern of escape.

EFFECTS OF TEMPERATURE

Fish flesh has a certain resistivity that decreases with increasing temperature (Whitney and Pierce, 1957). These authors found that electrofishing in highly resistive waters was mildly enhanced because the more conductive fish tend to distort the electric field by the absorption of electricity. Theoretically, success of electrofishing should increase with rise of temperature, but workers in the field have noted differently. Smith and Elson (1950) believed that salmon parr exhibited the best response below 25° C., and suckers at less than 20° C. Webster, Forney, Gibbs, Severns, and Van Woert (1955) had greater success in shocking brown trout at 7.7° C. than at 16.6° C., when both a.c. and d.c. were used. Fisher and Elson (1950) experimentally determined that brook trout and Atlantic salmon acclimatized to 5.5° C. made maximum darts from shocks at 10° C. and 15° C. The curve of relative maximum dart response had roughly the appearance of a normal distribution when plotted against temperature. Other experiments by these authors indicated that maximum shock response was at the temperature preferred by the fish; the work implied that each fish species has a temperature at which it responds most strongly to electrical stimulation.

INJURY TO FISH

Output energies commonly used in electrofishing are capable of killing fish. Death can occur with or without gross physical damage, or by irreversible physiological damage.

Mortalities caused by a.c. electrofishing probably are higher than those caused by d.c. or pulsed d.c. (Taylor et al., 1957), and the gross physical damage from a.c. can be severe (Hauck, 1949).

Harmful effects from pulsed d.c. are usually a result of excessive exposure or intense electrical fields. Pugh (1962) found that two or more of his experimental variables (i.e., high or low voltage; high or low frequencies, with pulse durations of equal time value; square or triangular pulse shapes; and waters of low or high resistivity--where the former was the more severe) were required to produce significant mortalities with pulsed d.c. His work indicates that the quantity of power is a controlling factor of mortalities in pulsed d.c. electrofishing.

The senior author has participated in much electrofishing and has found fish mortalities attributable to pulsed d.c. to be rare. One incident in which fish were electrocuted occurred near the mouth of a stream entering salt water; at this point the resistivity was below 1,000 ohm cm.^{3}. Some of the coho salmon fry subjected to the pulsed d.c. were killed in the estuary, but those 200 yards upstream, in waters of 30,000 ohm cm.^{3}, were not damaged. This mortality from pulsed d.c. is in accord with Whitney and Pierce's (1957) theory that a given electric potential places more energy into a fish in the more conductive waters and with Pugh's (1962) finding that low resistivity is conducive to fish mortality.

Subjecting shocked fish to additional stress commonly causes mortalities. Electric stimulation interferes with or stops respiration in fish for a period of time (Bodrova and Krayukhin, 1958), producing a metabolic deficit. The situation becomes precarious unless the fish are removed quickly from the stimulating currents into water with optimum temperature and dissolved-oxygen concentration.

SUMMARY

Personnel of the Bureau of Commercial Fisheries Biological Laboratory in Seattle, Wash., have developed a series of electrofishing shockers for sampling fish populations in streams. One of the most effective and the most light weight, dependable, and economical is the Type IV shocker. This shocker is described, and its electronic schematic is shown.

The output power capabilities of the Type IV shocker are within the optimum range for electrofishing. The optimum output depends on a combination of a complex of features. Pulsed d.c. is the most effective type of basic power, as unpulsed d.c. does not stimulate as effectively or attract over as great a range. A.c. does not produce galvanotaxis in fish. Pulse frequency and duration are of great importance in electrofishing because they are unaltered by water resistivity. The optimum pulse frequency and duration range for electrofishing in waters less resistive than 30,000 ohm cm.^{3} and the area of optimum response for water of higher resistivity are shown in the figures.

The "square-shaped" wave with a fast rise is the most desirable because the voltage is at its peak throughout the duration. The minimum output voltage for electrofishing in conductive waters is 150 v., but a maximum of 400 v. is more desirable for most usages. An amperage rating of less than 0.2 a. is generally not sufficient for relatively conductive waters, and general purpose shockers should have a 2 to 3 a. rating.

The effectiveness in surrounding a fish in a water-borne electrical field depends upon the capabilities of the electrodes in transmitting electrical energy into water and the methods used to "fish" with the electrodes. The hand-held anode, to which the fish are attracted, should be small--about 40 cm. square. This size permits ease in handling and causes high voltage gradients near the anode. A large cathode is needed to compensate the small anode; and the more resistive the water, the larger the cathode should be. A cathode with a surface area of 2.3 m. square is sufficient for waters up to 30,000 ohm cm.^{3}; the cathode must be larger to be effective in waters of higher resistance.

Electrofishing can be carried on by wading or floating. In waters suitable for wading, the operators probe about with the anode. If the stream is too deep or swift to wade, floating is necessary. Larger fish are caught by floating. Night fishing is not practical in streams.

It is often difficult or impossible to explain variability in electrofishing catches because many factors are involved. Low concentration of ionized salts in a body of water increases resistance and reduces the electrical energy that can be introduced; the stimulating current which reaches a fish is lessened accordingly. A maximal stimulating current of 300 to 400 v. with high values of frequency and duration and a square wave shape help to compensate for highly resistive waters.

The reactions of fish differ among individuals and sizes within a species and among species in their reactions to identical stimulating electrical currents. Although resistivity of fish flesh probably decreases with increasing temperature, the temperature at which a fish makes its maximal response to electrical stimulation may vary among species.

A.c. is more damaging to fish than d.c. or pulsed d.c. In normal fishing with pulsed d.c., fish mortalities are rare, except when a fish is subjected to a prolonged exposure to an intense electric current or placed in water that has a high temperature or low concentration of oxygen.

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