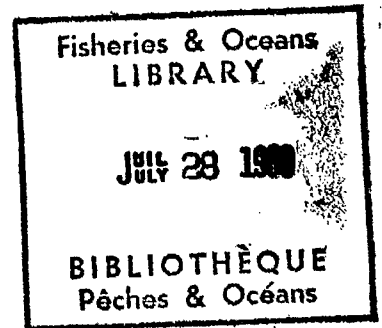


Canadian Translation of Fisheries and Aquatic Sciences

No. 5048

Electrofishing
(a working translation)

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Original title: Die Electrofischerei

In: (Publisher) - Heenemann VBH, Bessemer Strasse 83, Postfach 420320,
D - 1000, Berlin 42, Germany (Price 32.80 DM), 1975

Original language: German

- * The translation should be used with the original text for illustrations, references and the useful multilingual glossary of terms used in electro-fishing. The translator (R.W. McCauley, Wilfred Laurier University, Dept. of Biology, Waterloo, Ontario, Canada phone (519) 884-1970), will answer any questions that the reader may have on particular passages.

Available from:

Canada Institute for Scientific and Technical Information
National Research Council
Ottawa, Ontario, Canada K1A 0S2

1984

235 typescript pages

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Chapter 1. Some Historical Origins of Electrofishing

The idea of influencing the behaviour of fish and other forms of life by electricity is really self evident. Nature herself demonstrates this completely through electric fishes. However, as it often happens, the inventive genius of Man often overlooks Nature's example and, with great pains, Man over a long period of time developed electrical methods of controlling the movements of fish. The development and application of electric pulses which simulated those of electric fish did not even occur until after the second world war.

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Fish equipped with compact electrical organs have been well known for thousands of years. It was even recognized early in history that these species have the ability to paralyze and kill their prey; they were even used in medicine as a kind of shock therapy in which the impulses from the fish were carefully applied. The nature of these shocks was not even understood at the time. It is recorded, for example, that the Roman physician Scriborius Larsus recommended that his patients to place their feet on an electric torpedo fish and to keep their feet long enough until "the foot and leg became rigid up to the knee". A moslem physician prescribed shocks from an electric torpedo fish for epileptic ^{fits.} seizures. Even in Aristotle's writings and in his contemporaries there are numerous examples of directions in the use of electric fish for therapeutic purposes. Today the word "narcosis" is a reminder of the medicinal application of these fishes by the Greeks and Romans. This word has its origin in the root "narce" which is the name for this fish in the Mediterranean sea used for this purpose.

Fig. 1 Speckled electric torpedo (Torpedo torpedo)

Fig. 2 Dorsal view of Torpedo marmorata with the electric organs exposed (O) together with the nervous system (N).
(after Fritsch)

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The electric organs in large, heavy fish constitute not less than $1/4$ to $1/3$ of the total weight (fig. 2) and are composed partially of a million cell columns (electroplaques^{qucs}) connected in series. (fig. 3) Each of these elements (as in the electric eel) is capable of generating a voltage of 0.1 volts. Since these cells are arranged in series considerably high potentials may be produced either acting over a brief interval or for long periods of time. For example the electric eel of the gymnotid family (fig. 4) can generate a voltage of 300-600 volts up to a rate of 400 impulses per second and the electric catfish (family Siluridae) can produce a potential of 350 volts delivered in impulses up to 280 times per second.

It is worth noting that the shape of this impulse is almost identical which that used today in many devices to repel fish. This is good support for the thesis that technology approaches the ideal form without any inspiration from Nature.

Fig. 3 Cell columns (Electroplaques) which make up an electrical organ. (after Fritsch)

The general significance of the electrical organs of fish is fairly well known. They serve not only to aid the orientation of fish in space, to detect and paralyze prey but also to protect it from enemies. The electric eel is the prototype of an electric fish and its responses in water are relatively easy to demonstrate; it produces the type of impulse required for the particular purpose at hand. These impulses are generated and controlled by particular organs. When lying inactive and peaceful on the bottom it sends out no electrical discharges. (Coates and Cox) As soon as it starts to move, swimming leisurely, pulses of 50 volts are sent out. The number of these pulses may

vary considerably. The form is such that the peak voltage is gradually built up (i.e. a leading edge which has a slight slope) in contrast to that of the paralyzing impulse which has a steeper leading edge. The eel wishes to detect prey without frightening it away. If the impulses encounter an object in the water they are reflected and perceived by sense organs of the eel. In this way the fish uses a kind of radar system. This type of orientation is necessary since the eel's eyes are covered by a layer of skin rendering it blind. The skin over the eyes apparently protects the fish from the electrical impulses produced by its own body.

If the electric eel perceives an object in the water as prey the impulses become stronger. In this instance the source of energy has its origin in the large electrical organ which surrounds the body almost throughout its entire length. These shocks having a potential of 600 volts paralyze the prey so that it can be seized and devoured.

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According to the studies of C.Kreutzer the impulses are differential according to the purpose they serve. They may be associated with rest, exploratory, predatory and protective impulses.

Fig. 4 The pulse of an electric eel as measured with an oscilloscope maximum value: 410 volts.

Recharging time increases from 4 to 21 ms. (after Wasmus)

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Fig. 5 Electric catfish (Malapterurus electricus)

***** An inhabitant of the Nile and other African rivers.

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If the eel is hungry, for instance, it transmits continuous, regular impulses of low potential and of two milliseconds duration. (Fig. 7) When prey is found this is turned off and replaced with high voltage shocks. (Fig.8) This involves a series of impulses 0.6-2.0 seconds long at a frequency of 50-100 times per second. The smaller the prey animal, the higher the frequency sent out. The pulse which the eel generates to defend itself against enemies or in response to a stick thrust into its aquarium are composed of similar groups of impulses. Here two impulses of high potential regularly alternate with three exploratory impulses with low potential (Fig. 9) The number of defensive and exploratory impulses may be variable. For defense the eel discharges only 1-7 impulses in total.

The impulses used to capture prey have a steep leading edge, are flat on the top and a trailing edge of gentle slope. The frequency of these impulses is relatively high since the eel only captures small fish. Fairly large pauses separate the impulses since the eel has stunned one of several fish it waits until the fish recovers before sending the next pulse. In this way the eel is economical in its use of energy.

Man knew in classical times about electrical fish and experimented with them to the extent that their electrical shocks could be utilized. However, it was many years after the discovery of electricity that it occurred to people that it could be used to influence water plants and animals. A pioneer in this field was Unger who established that single-celled organisms (Stentor niger) could be attracted to the negative pole of a field of direct current and that the swarming spores of the alga Vaucheria clavata was rendered immobile in the region of both poles, not distinguishing one pole from the other.

Figure 6. Curve form of the voltage shocks delivered by the electric eel (after C. Kretzer...)

Figure 7. Resting condition - exploring pulses of the electric eel.

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Mach in 1875 showed that the sculpin (Cottus gobio) could be stunned by putting it in a vessel between two platinum electrodes and in so doing it lay on its back in the direction of the positive pole. Experiments conducted by Hermann on frog larvae and fish embryos in 1885 as well as of Verworn in 1889 on higher plants were the first time that the stimulating effect of the galvanic current was recognized. Both investigators referred to this as "galvanotropism". Blasius and Schweitzer (1893) were the first to demonstrate the narcotizing effects of a galvanic current on fish. They also recognized the importance of the current density as a characteristic of the strength of an electric field. It was one year later that Hermann and ~~Matthias~~ ^{Matthias} defined this new concept as δ (delta) which is equivalent to microamperes per square millimetre i.e. 10^{-6} amperes per square millimeter of the liquid conductor. The current density is related, however, only to the conducting medium. The distortion of the electrical field caused by the presence of the experimental object is not taken into consideration.

After experimenting with direct and alternating current, Engelen, a physician from Duesseldorf, first applied in 1912 an interrupted direct electrical current of the type discovered by LEDUC in 1900. Today we understand LEDUC's current as a series of variable impulses, 100 cycles per second, consisting of ^{one} ms. long pulse followed by a delay of 9 ms. (Fig. 11a)

Because of its well known physiological effects and good experimental characteristics LEDUC's current was highly prized in scientific investigations. Engeln^e conducted local anesthetics for the first time of fish under water. In the 1920's and 30's Fe. and Fr. Schemin~~sky~~ systematically studied all the details of the behaviour of fish and other aquatic animals in electrical fields consisting of various types of electrical currents. (i.e. direct, alternating, and interrupted currents) They uncovered a considerable number of basic electrophysiological

principles which they defined and mathematically analyzed; these principles are still valid today.

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From this point on we can truly speak of electrobiological research. Fe. and Fr. Schemin~~sky~~ky along with F. Bukatsch published their text; Basic Electrobiology in 1941 on the effect of electrical currents on whole organisms such as plants, animals and humans. In addition to pharmaceutical effects, the investigations of the Schemin~~sky~~ys were concerned with a detailed description of the behaviour of aquatic animals in direct and alternating current fields and the determination of the relationship between body size and sensitivity to the electrical current. The two workers were aware of the essential difference between the narcosis induced by direct current (galvanonarcosis) and that by alternating current which caused numerous consecutive muscle contractions. The concepts of oscillotaxis and oscillotropism had their origin in their work.

They conducted experiments, moreover, with LEDUC's current in which they utilized not the classic 100 cycle but 10, 25 and 50 cycles. (page 27) They also ^{altered} ~~altered~~ the relationship of the duration of the pause to the cycle. (i.e. the "duty cycle")

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They ingeniously conceived simple experiments which permitted the demonstration of the effects of pulses having duty cycles of 10/10, 7/10 etc. down to 1/10 of the classic LEDUC's current.

The Schemin~~sky~~ky's and other investigations ^{or's} ~~investigations~~ who followed used this experimental approach and ^{gained} ~~obtained~~ some remarkable perceptive information. They were able to demonstrate, among other things, that the reactions of fish were not changed when the duty cycle was decreased from 10/10 down to 9/10, 8/10 etc., and even to 1/10 a fact which would later prove to be of fundamental importance in marine electrofishing.

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If you calculate the "snout-tail" voltage (or side to side, depending on the orientation of the fish in the electric field) for fish in sea water, you find that the amount of energy necessary to maintain this field is too high to be practical, being of the order of several hundred kilowatts. The same voltages may be attained, however, with savings in the ratio of the duration of the pulse to the rest period and this economy permits economical electrofishing in seawater.

Holzer supplemented the Scheminaky's scientific work in the 1930's by numerous mathematical equations. He was first to coin the expression "Gestaltspannung" - snout-to-tail voltage and also the first to demonstrate the repelling effect of the electric field on fish, making it a subject of research. Experiments on the effects of LEDUC's current on fish were also conducted by the physiologists Nicolai, (1930) and Ivy and Barry (1932).

Although in England a patent was obtained already in 1895 for an electrical harpoon to catch wales and in Japan an electrofishing device in 1895, (basic research only began in 1924) in Germany all efforts in electrofishing research were confined to pure scientific questions.) The practical application of electricity was the result of an accidental happening. In 1910 an electrical transmission line broke in the power generating station in Einhardt - Hohenzollern and fell into the Ostrach, a tributary of the Danube. The owner, Neher, observed that the fish in the stream, after some jerky movements floated on the surface seemingly lifeless and could be easily retrieved. This chance happening gave the miller the idea of suspending two cables conducting direct current (110 volts) and attaching two metal {copper plates on the ends}. The experiment demonstrated that it was possible to catch fish with electricity.

The results of this demonstration became quickly known. Several years later (around 1916-17) it is reported that already in southern Germany a dynamo driven by a portable gasoline engine was used to collect fish (see page 117). This, however, was something before its time. Perhaps too much was promised or perhaps the attempts to catch fish were carried out in waters of unfavourable electrical conductivity - something quite possible in Bavaria. Another possibility for the lack of success was ignorance of other factors which influence electrofishing to the extent that the operation could be rendered unsuccessful.

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A Schönfelder, chief fisheries supervisor of Hohenzollern, published the accounts of his experience with electrofishing gear. His article "Catching fish with electricity" published in the "Sportangler" was followed by an article of the same title written with F. Schiemenz. Holzer made contributions from the practical results of his own research. He secured a patent March 5, 1932 under the number Kl. 45h. Gr. 27/30 - German patent No. 596 074

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1. A device to catch fish electrically by means of electrodes arranged in the water more-or-less horizontally. A direct current field of varying potential gradients is produced between the electrodes. The positive electrodes are either bent or small in relation to the cathode such the electrical field intensifies ^{because of} in the direction of the positive electrodes.
2. A device described as in (1) such that surfaces facing downwards are screened.

After further experiments over many years a committee was formed. The following took part: master fish culturist A. Ripfel, Ottobeuren, the mechanic J. Zimmerman (Sigmaringen), master fish culturist Marx (Bregenz). Dr. K. Smolian, the head of the institute of electrical machines of the technical university in Hannover, Prof. Dr. Humburg and government fisheries consultant Dr. F. Schiemenz (Hannover). Up to 1943 development was left to private initiative but after this date efforts were coordinated by SMOLIAN and fisheries master HAGER in a committee on the then Union of German Fisheries of the Reich " SMOLIAN took over the chairmanship. Members were H. SCHMIDT, K. HAGEMAN, both engineers of the Siemens-Schuckert, Stuttgart, A. Oberholzer contractor(Dornbirn) fishery master E. KAEFER and master fish culturist A. SCHILLINGER (Munich).

This committee had, according to the words of SMOLIAN, the task of "determining if and in which way electricity could be employed to catch fish without injuring fish, other water inhabitants and, without endangering humans."

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Also the committee was to recommend "which methods could be applied to achieve certain practical results." In addition they had to work out the theoretical background necessary to solve practical questions- "to discover the limits of success and possible dangers." The committee, in spite of the useful things it produced during its short existence could not avoid "that fishery literature wrote articles which elicited unfulfilled hopes resulting in many types of gear which were unsuitable for the fishing industry; the confusion and disorder increased with time.

SMOLIAN'S final report of this committee indicates, surprisingly, that there was disagreement on the use of interrupted (chopped up) direct current. He writes: "Interrupted direct current (short intervals) has a considerable physiological effect on fish.... stimulation and shock occur when the current is turned off and on."

Even then different conductivities of water bottom and the fishes' body were considered, ~~The~~ proper conclusion was drawn in that the most efficient electrofishing is achieved in water of moderate conductivity over a bottom of poor conductivity. "In very poorly conductive water the intensity of current is so low that the applied voltage is not great enough to induce narcosis." In highly conductive water, however, the fuses in the generator are blown or short circuits are caused.

In SMOLIAN'S report damage to young fish and food organisms was also considered. He concluded that electrofishing was harmless to these. (page 97).

In all the experiments described in the report, the anodic or stunning effect of the electric current was described exclusively.

Repelling and lethal effects while recognized were not desired and were avoided as much as possible. Its use in fisheries and water diversion was not yet anticipated. SMOLIAN only once mentioned that fish could be repelled with alternating current and dispersed in a desirable direction. This possibility was already considered in Denmark in 1912. At the same time German Imperial patent No. 260161 class 45h. Gr. 20 was granted to the Dane Niels Dueholm LARSEN from Copenhagen for a device "to confine or direct fish and other aquatic animals in fiords, sounds, rivers and other water bodies. The barriers were planned not only for stationary structures but also for moving devices and were to be powered by either alternating or direct current to drive fish in the same or opposite directions. It was conceived that these devices would be supplied directly or indirectly by a source of electricity. In the construction of the main electrical cable provisions were made for numerous uncovered wires hanging downwards in the water; the cable was either stretched above the waters or allowed to float on the surface. One is not sure if ever his patent was applied. At any rate it is worth noting that the idea of repelling fish by electricity appeared more than fifty years ago. It was not realized, likely, because of the lack of suitable equipment. Nowadays we know that such devices must have an electronic basis.

Apart from the suggestions of SMOLIAN and LARSEN there is, to our knowledge, no further information on the application interrupted direct current in electrofishing before the second world war. Electrofishing was confined to brooks and small bodies of water. The time was apparently not ripe for the use of interrupted current. At that time technical means of producing impulses electronically were non existent thus it was

not possible to develop effective repelling effects. Just after the recent war electrofishing received the benefits of modern pulse generating techniques and electrical technology. Further impetus was provided by the physiologist H.W. DENZER and the physicist C. KREUTZER. At a meeting of the fisheries science working group (22.1. 1948) formed in Hamburg after the war, H.W. DENZER recommended the use of pulsed current but pointed out at the same time that physiological, electrical and physical background knowledge was lacking. C. KREUTZER developed the first pulsed gear "Salmo" and later "Salmo-Super." Together with the Siemens-Schuckert factory he constructed the first pulse generator for marine fisheries; in addition he developed electrical Tuna hooks and an electrofishing repelling device to combat the Chinese mitten crab. The firm SOMMER and MEISTER and F. SCHIEMENZ had already attempted this (page 184). At the meeting called by P.F. MEYER-WAARDEN in 8.7.1949 to which fishermen, fish tug captains, shipowners, representatives of the government and scientists were invited, C. KREUTZER and his collaborator, engineer H. PEGLOW, outlined their plans. After a detailed discussion physiologists and physicists declared that these plans could be successfully carried out. The construction of a pulsing generator for marine electrofishing was begun with the financial support.

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of the german fishing industry and with the co-operation of the Siemens-Schuckert works, the AEG and the federal fisheries research institute. Two years later when this work was reaching a conclusion the American occupational forces provided the use of the german minesweeper R 96 for the first experiments. This vessel had already been used by C. KREUTZER in testing his electrified tuna hooks on the North Sea. The pulse generator had a capacity from 180 to 200 kW and produced pulses of current of at least 10,000 A. With this gear 20 cm herrings could be fished anodically up to 10 m away, codfish 40 cm long from up to a distance of 25 m. This was undoubtedly a great triumph of german science and technology which was recognized everywhere.

Following the success of C. KREUTZER in the USA, the firm Dethloff electronics (Hamburg) in the german federal republic began the development of electrical catching, confining and killing gear for marine fisheries. The generator construction works AG Fulda, the firm "Sabo" Dieringhausen and, in addition the firm F. Ploeger and H. Peglow both of Hamburg, dedicated themselves to the building of electrofishing devices for inland waters. AG Fulda was already involved in the construction of this gear. Some of them built had already pulsing gear. AG Fulda and some took on the construction of these devices. In 1951 the electrical machine works of AG Fulda and F. Ploeger of Hamburg joined the electrofishing co-operative which was represented by the firm E. Doebler (Hamburg).

Scientific studies begun in 1954 by P.F. MEYER-WAARDEN in the laboratory founded by C. KREUTZER was continued by E. Halsband. This laboratory was in the Institute for Coastal and Inland Waters.

In contrast to earlier work, experiments were designed to answer basic questions in electrofishing - questions which were ignored because of lack of time and facilities. Of prime importance were those processes occurring in the body of a fish under the influence of an electric field. E. Halsband also applied himself to solving technical problems. Valuable tips were given electrical firms building electrofishing gear - how they could improve the gear to make it more effective. Methods of preserving the freshness of fish were developed in 1963 with Fr. BRAMSTEDT and K. TRAUTNER. The fisheries institute in Albaum, Nordrhein-Westfalen under the direction of H.W. DENZER, as well as the institute for colloidal chemistry (Poppenhuse/^{hansen / Rhön}Rhön) were concerned with electrofishing, ^{especially} problems especially those in the field of electrical conductivity of water. The role of geological formations and polyions in the water was also investigated.

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To bring electrofishing under some kind of control, the german fisheries association was formed in 1952 and was the successor of the imperial german fisheries association; K. BAHR was the director from 1959 onwards. The committee was under the chairmanship of G. BUHSE. The association of german electrical engineers concerned itself with the drawing up of construction and safety regulations (page 21).

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Chapter 2

Significance and Scope of Electrofishing Concepts

1. Significance and Scope of Electrofishing:

The concept of electrofishing has changed in the course of time.

In the beginning when Smolian and his group were developing the practice, direct and alternating current were used to achieve the desired effects. With the physiological effective pulsed current, it was possible to improve electrofishing in sea water and to overcome the problem of the high electrical conductivity of sea water (about 500 times as conductive as fresh water). This made electrofishing practical in the oceans. Almost at the same time attention was directed to the repelling effects of pulsed current. Later there was interest in the lethal effects of the electrical current and its use in the humane killing of fish and in preserving the quality of fish flesh.

Electrofishing had therefore experienced a not inconsiderable enlargement of its concepts. Originally a method of catching fish it is now an important method of managing our natural waters and their fish stocks as well as euthanasia and preserving the quality of fish flesh.

Experiments were begun at the end of the war in Germany to incorporate pulsing techniques in the catching of fish and evoked enthusiasm. At the time the effects were explained using fictional and exaggerated reports which proclaimed that the effective range was large in water. Later high expectations were not realized and people did not want to hear anymore about the subject. Today the judgment is more objective and based on facts. We now know what can be expected from electrofishing. We know, in which waters, the form of electrical current and the dimensions

of the operation for effective electrofishing. The reactions to the electrical current of various species of fish and other forms of aquatic life are now known. The technical and biological limits of electrofishing are also recognized.

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We have to come to terms with the kind of commercially available electrofishing gear in common use. These have an effective range in fresh water (anodic effect) of 4 to 6 m for average water conductivities, and 10 to 12 m for very conductive waters. When large areas of water are being fished electrified nets or guiding weirs must supplement this gear.

Small electrofishing gear is only suited for the fishing of small brooks, shallow reaches of a river and likewise lakes, ponds and small ~~bodies~~ ^{bodies} of water. Rarely will the fish harvest on such bodies of water be increased using electrofishing techniques. These methods serve the more valuable goal of allowing the fisheries biologist, fish culturist and the angler to estimate and manage the fish stocks, thus the number of fish, their size and age composition, the species as well as estimates of growth can be determined. In addition fish ready for market may be removed in desired numbers. Predatory and diseased fish can also be taken out. In brief, one can obtain a very good idea about the commercial value of the waters and the regulations which are necessary to improve the fish stock. All these measures may be taken without influencing the survival of the fish. Even food organisms can be evaluated within certain limits.

In large bodies of water (lakes, rivers, etc.) the application of such gear to check fish stocks poses problems. Since only small stretches of this water can be fished at one time one loses the general control of effectiveness of the electrofishing. It is difficult to ascertain the range of the effective field ~~especially~~ ^{especially} with sensitive fish which are stunned in deep and murky waters. Fish are frequently already narcotized before having reaching the anode and are therefore removed from the catch and escape observation. Others in the fringe of the effective field of the anode hide on the bottom or flee to the yet unfished water before they can be sighted. Electrofishing still can be of use in such waters. It is customary in Steinhuder Meer to catch eels and pike at those times of the year when other kinds of gear are not successful because of the response of the fish to the anode. The fish are removed from the reed beds. Carp can be removed from ponds which either cannot be drained nor have wet pockets in the mud. Finally catching and repelling effects may be combined (page 169)

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Electrofishing is of little interest to oceanic fisheries. Large ships are used on the open sea to catch large masses of fish and the electric field has an effective area of 20 to 30 m diameter (for 20 to 40 cm fish) and 50 to 70 m (for 1 m to 2.5 m fish). This field can be produced today with a 40 kW generator. It is possible, however, by using the anode effect to concentrate great quantities of commercially valuable fish and to harvest them. Installing relatively expensive gear can be very profitable. Under certain conditions the electrical guiding of schooling fish as menhaden, sardines, tuna, etc. can be

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successful. KREUTZER was able to remove menhaden from a circular weir with a suction pump in which the intake pipe served as an anode. This was accomplished within a time shorter than previously with a greatly reduced damage to the fish. This expensive equipment also saved human labour. In this instance the relatively small effective electric field did not affect the operation. The essential result was the saving of time and labour, and the preservation of the net material; the menhaden fishery was placed on a profitable basis. Electrodes may be combined with the power of light to attract schools of valuable sardines or to bring tuna from the depths to surface waters where they can be caught by traditional gear (weirs, hooks, etc.) supplemented by fish pumps. C. KREUTZER also assembled an electrified trawl in which the repelling effect of the trawl on fish was eliminated. An electotrawl^T for pelagic fish can be used to catch fish from fishing grounds which could otherwise not be fished; fish are anodically attracted to the catching area of the net. These few examples illustrate that the anodic effect of the electric field may also be used in ocean fisheries. ^{They also} ~~These examples~~ emphasize that electrofishing is not generally applicable to the sea and is only practical under certain conditions.

Incidentally, it should be noted that, from a technical standpoint, it is not always easy to combine the electrical current in the right dimensions and the proper pulse frequency. The success of catching fish with electricity is very dependent on its field of effectiveness.

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Somewhat favourable are the conditions when fish or other aquatic animals are to be repelled. Here the extent of the electric field of a certain shape is not as important as that used to catch fish anodically. It is necessary to apply pulsed current to the water and, by means of an electrode chain, build up the largest and broadest field possible. It is also important that the pulses of current are separated by a sufficiently long interval of time. Enough time is required for the fish when it swims into the electrical field to be affected by the shock and to turn around leaving the electrical field to swim upstream.

Fields produced in freshwater by hanging chains of electrodes at normal values of water conductivity and for electronically controlled pulsing devices, are 20 to 30 m broad. Most fish cannot penetrate this barrier. A provision of course, is the construction of the electrode chain where the fish can swim easily against the current. If the current is too swift it is hardly possible for the fish to swim out of the danger zone. Since the strength of the electrical field increases in the direction of the electrode chain the effect of the field is more reliable than that used when fish are caught by the anodic effect.

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Today it is no longer technically difficult to stop the migrations of fish in small brooks by means of electrical barriers of electrodes in a chain. There are now pulsing gear perfected which, when connected to an electrode chain, can block up to 90% ^{of} ~~pf~~ the migrants. The provision,

of course, that the local conditions are carefully taken into account when the barrier is constructed. Using this blocking effect fish, especially eels, salmon and other migratory fish can be prevented from swimming into turbines or to lead them around obstructions in the river. A reach of the river may be sealed up and downstream and, even with movable barriers, one can work in large areas of water. The barrier is fastened to two motor boats and the pulsing gear mounted in one of the boats. The breadth of field corresponds to the extension of the electrode chain and fish are driven by it into a catching gear. Using the shocking effect it is not possible to fish out the entire population since a large proportion of the fish seek to escape through the region widely separated from the barrier chain. In the instance of lakes so deep that the bottom does not come under the influence of the electrical field the shocking effect is even less. From experience we have found that the greatest proportion of the fish dive downwards and remain beyond the influence of the field until the boat has passed over the region and the field is no longer detectable.

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Electrical shocking in the ocean is also technically possible. Its profitability depends upon certain conditions: considerable investment of capital is involved. Shocking gear will only pay when it aids in the catching of valuable fish which cannot be caught with conventional fishing gear or gear having a restricted effective area. Large schools of gravid red tunas on the north coast of Spain and the north coast of Africa are susceptible ^{to} ~~for~~ electrofishing techniques. Because of unusually cold water temperatures and unfavourable water currents the fish do not swim into the effective range of the stationary nets.

Here these valuable fish can be herded electrically into the weirs. Since 1000 tunas are caught nightly during the months of migration the application of electrical means, although costly, is profitable. It was once thought that a fiord could be blocked from the ocean by a chain of electrically charged electrodes and living fish could be held in this enclosed body of water until fisheries operations could be conducted. Again it is a matter of the value of the fish which determines whether the practice is economically feasible.

At the beginning of the chapter it was suggested that attempts were made to stun chinese mitten crabs with electricity and to kill them. Already the electrical stunning and killing of other aquatic pests, predatory fish for example, have been established. Even warmblooded animals such as muskrats have been combatted by electrical means. Muskrats spend most of their time out of the water in their lodges and are therefore beyond the range of the electrical field in the water. Crocodiles also react to electricity, according to our experiments in the Wuppertal zoo. On the basis of field experiments it is possible that people can be protected from these dangerous animals either by the anodic effects or by a repelling effect. They can be captured and killed electrically without damaging their valuable hides.

It has long been known that the electrical stunning and killing of warm-blooded animals is quick and humane. A similar effect occurs in poikilothermic and cold-blooded animals. Because of this the electrical stunning and killing of fish has significance for the animal care regulations.

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According to the regulations the slaughter and preservation of living fish and other cold-blooded animals of 14.1.1936 (RGB1 I page 13) and that of 13.11.1936 (RGB1 I page 941), both based on the animal protection law of 24.11.1933 (RGB1 I page 987), the following was decreed: fish intended to be consumed by humans should be stunned before slaughtering. Stunning and slaughter can be carried out using a reliable electrical gear. Also in the opinion of the german fisheries associations to fulfill their requirements (Federal copy IV/85) an electrical device was developed to stun and kill eels which are smoked on a large scale.

A role which is not yet fully appreciated is the preservation of quality in fish flesh through stunning and killing. Preliminary experiments of MEYER-WARREN conducted already in Larache (Morocco) in 1956 showed that electrical killing favoured the maintenance of quality. F. BRAMSTEDT and K. TRÄUTNER noted that fish killed by electricity had not used up their supply of glycogen. Fish caught by ordinary means struggled a long time before death occurred. Bacterial decomposition was also much slower in fish killed by electricity. Even when it is only a matter of hours the enhancing of flesh quality by electronarcosis is pronounced in easily spoiled quality fish as tunas, sardines and sprats.

Up to now the importance of electrofishing in practical fishing and water management has been outlined; it is also useful to zoologists and ecologists. It is possible, for instance, to estimate fish populations by electrical methods of fishing out a body of water. All aquatic species can be removed. Shy and fast-swimming forms can be captured and removed with catching gear. It is often surprising the variety of species

and number of fish when a body of water well known to anglers is fished out electrically.

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Up to quite recently anglers were critical of electrofishing. Their objections were based on the belief that it was an unsportsmanlike attack on ~~the~~ nature, destroying aquatic life indiscriminately.

The aquatic community is not harmed by conventional electrofishing operations; this is thoroughly discussed on page 93. Certainly there can be a risk but then risk is minimized by following directions and obeying laws. Electrofishing may only be carried out with the permission of the appropriate local authorities. This is, however, difficult to obtain and is given only to reliable and trustworthy persons.

2 Concepts of Electrofishing

With the increase of the importance of electrofishing it is necessary to establish some termini technici. The 0136 electrical catching commission, the Society of German Electrical Technologists (VDE) made these the highest priority. Regulations for the establishment and operation of electrofishing devices in freshwater as well as coastal and on the high seas were worked out. These deliberations, naturally were confined to the practical operation of these types of devices.

We agree with the commission that these concepts henceforth should apply everywhere in the german speaking countries and are therefore relevant to our book.

We speak about electrofishing devices in the general sense of the VDE regulations and these include gear to catch, herd, block, lead, repel, stun or kill fish or other aquatic organisms. The devices may be fixed or movable and may consist of one or more types of gear.

Fixed devices are such structures which are, either because of their mechanical function or construction, tied to one place. This also includes devices on board ships.

Movable devices are either portable or movable and voltage is applied while they are moving.

We differentiate among electrofishing catching, electrofishing repulsion and electrofishing killing devices. An eletrofishing catching device catches fish or other animals in the aquatic world with the aid of electric energy.

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An electrofishing repulsion device is that arrangement by which fish and other aquatic animals are kept away from waters used by hydroelectric stations and other plants which draw in water.

An electrofishing killing device uses electrical energy to kill fish or other aquatic animals. This killing is done either for humane reasons or to improve the quality of the flesh and to prolong shelf life.

Further concepts will be examined in the chapters on physical, technical and physiological bases of electrofishing. These are suitably presented in the relevant chapters and in the appendix (page 237).

CHAPTER 3

BASIC PRINCIPLES OF ELECTROFISHING

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The electrophysical and electrophysiological processes which play a role in influencing fish by electricity in the water and in the body of the animal itself are complicated and require considerable knowledge to understand them. Anyone who is concerned with electrofishing requires some background knowledge to understand the basic principles. This is also necessary if one wishes to know the possible applications and principles of electrofishing and the limit imposed by natural and technical boundaries.

Before we turn to the practical section of electrofishing the basic principles as they are applicable will be discussed. If electrophysiology is something more than electrophysics, then it would follow that the book has been written by a biologist to whom the physiological processes were more familiar than the physical. This book is written for the person interested in fishery biology and not for specialists versed in technical matters.

1. Physical and Technical Principles

As mentioned above it is necessary to explain some of the basic principles in electricity, for those readers who so far have not much to do with electricity. Additional explanations are found in footnotes and in the glossary at the end of this book.

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1.1 Basic laws of the direct current circuit

1.1.1 Electrical current

The important variables and their relationships may be learned by studying the electrical circuit.

In every electrical circuit a generator of current causes the current to flow. For currents of small magnitude galvanic cells (i.e. dry cells) and storage batteries are used. In electrical generating stations dynamos are exclusively used.

Another important component of the circuit is the load or appliance through which the current flows to produce a desired effect such as light or heat. Loads include - lamps, motor, cooking and heating appliances. The ability of the current to perform work is utilized in these devices. In order to bring the current to the appliance, some system of conduction is necessary, and this forms the third component of the electrical circuit. Thus connections between electrical produce and load are necessary. We know that a motor can only be driven when two wires are used. This illustrates the most important fact - the electric current must flow to the load and back to the electrical generator. Often the return part of the circuit may be provided by the ground or by masses of metal, as for example, the hull of a ship.

The necessity of two wires shows that the current flows in a circuit - generator - load - and then back to the generator to complete the circuit. The current continuously flows in this manner.

The movement of the current is produced by the current generator and the load converts this form of energy into another. The flow of the current may be compared with the flow of water through pipes since there are many similarities.

According to present day concepts it is assumed that current flowing in an electric conductor consists of a large number of negatively charged particles known as electrons. Electrons are more or less mobile depending

on the particular substance - i.e. some materials conduct electricity better than others.

As mentioned above the electric current represents a definite number of free electrons whose number in metals is $10^{23}/\text{cm}^3$. Each electron carries a specific electric charge which is termed e . Since each metal contains n unit charges, the total quantity in the metal when no current is flowing is $n \times e$.

When current is flowing in a conductor the total number of electrons is set in motion. In a metallic conductor, for instance, having a length ℓ and a cross-section A , the quantity of electrical charges moved is $Q = n e A \ell$. In the time interval 't' the quantity of charges moved through the cross-section A is really the electric current and its magnitude may be mathematically defined as.

$$I = \frac{Q}{t} = n e A \frac{\ell}{t} \quad (1)$$

We now introduce the concept specific current density which is defined by:

$$S = \frac{I}{A} = n e \frac{\ell}{t} \quad (2)$$

If it is remembered that velocity in physics is defined as distance over time, then from equation (2) the quotient, $\frac{\ell}{t}$ may be considered to be the speed of the electrons.

Equation (1) may be further explained by introducing some values. It is necessary also to present a new unit of current strength. The quantity Q is not used for practical reasons but the larger unit - the Coulomb (C) is chosen. The charge on an electron is calculated to be $e = 1.6 \times 10^{-19}$ coulombs. From this it follows that one coulomb is the

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equivalent of 6.24×10^{18} unit of current; expressed as coulombs per second (C/s) or amperes (A). When substituting coulombs for Q in (1) the equation is simplified as $I = \text{Amperes per second (A/s)}$. $\longrightarrow$ (A/s)

Other quantities derived from amperes are milliamperes

(1mA = $\frac{1}{1000}$ A) microampers ($1\mu\text{A} = 10^{-6}\text{A}$) or kiloamperes ($1\text{kA} = 1000\text{A} = 10^3\text{A}$)

1.1.2. Direct, alternating and pulsed current.

Various types of currents are distinguished in electric technology - direct currents having a constant direction of flow and alternating currents in which the direction of flow reverses several times a second. A graph of direct current of constant strength consists of a horizontal line parallel to the time axis (Fig. 10a).

A graph of alternating current illustrates the periodic reversal of direction and is represented by a sine curve (Fig. 10b). The instantaneous value varies between zero and the maximum value (I_m) and also $-I_m$. Since the current during a specific interval of time, continuously reverses its polarity with a corresponding change in current, it is necessary only to express the period of the cycle. The period is understood to be that interval of time (T) measured in seconds, after which the cycle of fluctuation of the current repeats itself (Fig. 10b, 11a, b, c).

$f = 1/T$ The reciprocal of the period ($\frac{1}{T}$), that is the number of periods in a second, is known as the frequency, the unit of which is Hertz. Alternating current from the ^{household} ~~household~~ circuit has a frequency of 50 Hz.

A special form of alternating or fluctuating current is pulsed current which consists of continuously interrupted direct or alternating current, or is produced by periodic discharges from a condenser. All types of fluctuating current are employed in electrofishing and each type has a specific use.

(Fig. 11 - Various types of pulsed current a: square wave b: section of sine wave. c: exponential die-away, pulsed current).



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(a) Square wave (Fig. 11a)

Square wave pulses are rarely used in electrofishing since capacitive resistance elements in the load form exponential die-away curves following the surge of current resulting from making ^{the} the circuit. (Fig. 11c)

(b) Parts of the wave of a sinusiodal current (Fig. 11b)

Periodic interruptions of sinusiodal current which forms pulsed current are well suited for frightening fish. Its effectiveness is determined by changes in the angle of the flow of current $\int$. The effect depends on the I (Fig. 11c) size of the fish, water boundaries, etc.

(c) Exponential die-away current (Fig. 11c)

The shape of pulsed current is often used, since especially good physiological effects (frightening and lethal) are observed. Also since the pulse is produced by discharging condensers, a practically unlimited supply of energy is available.

S. 27 A pulsed current which is to be used in electrofishing must fulfill the following conditions:

1. It must consist of brief but very effective pulses. This is especially essential for electrofishing operations conducted in the sea where the high electrical conductivity of sea water must be taken into account. ~~/~~

Ⓒ Kreutzer and J. Delhloff, for example, employed currents with peak strengths of 10000 amperes and peak voltages of 500 volts. In freshwater, because of its favourable electrical conductivity, essentially less current strengths are required. Because of its variability and the different sizes of water bodies the conductivity of the water must always be determined before electrofishing is begun. It would be pointless to use a pulsing device for a range of resistivity 30 ohm·cm (sea water) to 10000 ohms·cm (springwater)

when the waters being fished are in the range 800 to 3000 ohm-cm.

2. The duration of the pulse - i.e. the time required for the pulse to rise from 0 to the peak and then back to 0, should not exceed one millisecond.

It is important that this ^{time} ~~time~~ be chosen so that a minimum of power is required. The types as mentioned above are provided by either the discharge of a condensor or by means of electronic circuit breakers (transistors and thyristors).

3. The time required for the pulse to rise from 0 to peak must be extremely short as possible. This is achieved if the curve is made to rise as steeply as possible. The steeper the leading edge of the curve the more effective is the pulse on fish. If the pulse slowly rises to the maximum, the fish displays no motor reaction even when high levels of current are used. In catching fish with electricity pulses with a steep leading edge and a trailing edge of shallow slope should be used.

4. The number of pulses applied per unit of time must, if at all possible, be determined by the species and the size of fish. The frequency of pulses characteristic of the species is determined by the shape of its body, but the sensory physiological properties of the species are also important. Apart from these features, reactions to the pulses by large fish are slower than those displayed by small fish, since a larger mass of muscle must be moved in the former. For large fish, therefore, fewer pulses per unit time are necessary to produce a muscle cramp than in small fish. Obviously small fish can be stunned with low frequency of pulses, but the duration of the pulse must be essentially longer and the voltage higher. This last strategy

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is not feasible in practical electrofishing since one tries to get the maximum effect with a minimum of power. Those differences which exist in relation to the frequency of pulses, required to produce a given reaction in the various species of fish of various sizes and various conditions are discussed on Page 71.

The pulse frequency, ^(f) i.e., the number of pulses per second may be calculated from the duration of a pulse t_d and the duration of the pause R (Fig. 11a).

$$f = \frac{1000}{T} = \frac{1000}{t_d + R} \text{ (Hz)} \quad (3)$$

Each of the factors enumerated here (1-4) is to be taken into account when an optimum effect on fish and other aquatic animals is to be achieved. Each variation of these four parameters will give rise to a significant alterations in the nature of the stimulating current and therefore its effect. Increases in the rate of increase in voltage on the leading edge of the pulse, for example, will have a more pronounced effect according

the more as ~~the~~ the increase of current is ~~quicker~~ sudden.

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to the Dubois-Raymond law. Furthermore a stimulus must act over a minimum time at a minimum time to elicit a response (Horweg-Weiss law).

1.1.3. Electrical Potential

The electric current arises, as previously mentioned, from the flow of electrically charged particles. To understand the reason for this motion it must be remembered that the producer of the current is an essential component of the circuit. Without this component no current would flow. This force which moves electrons is designated the electrical potential and has the symbol U . Within the source of current the potential is such that free electrons drain away to the negative terminal. The potential difference in the current source is traditionally called the electromotive force (EMK).

29 The unit of potential is the volt (V). Smaller units are millivolts $= 1/1000 \text{ V} = 10^{-3}\text{V}$; microvolts (μV) $= 10^{-6}\text{V}$. The large unit is the kilovolt $\text{kV} = 10^3\text{V}$.

1.1.4. Ohm's Law

It is self evident that not only the potential (voltage) but also the current can have various values. Since the potential moves the electrons at a speed according to its magnitude, the current should increase in a closed circuit, with increased voltage. Current varies directly with voltage.

$$I \sim U$$

If various electrical circuits are tested with small and large incandescent lamps it will be found that different current strengths can exist at the same voltage. This demonstrates that the nature of the circuit can influence the number of electrons which flow through it. The conductivity of the circuit

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is designated as G

$$I = GU \quad (4)$$

The better the connecting wires conduct, the greater is the conductivity and I at a constant voltage is correspondingly more (Equation 4). In electrical technology, conductivity is not usually employed. The reciprocal called resistance to flow or briefly "resistance" is used.

$$R = \frac{1}{G} \quad (5)$$

or
$$I = \frac{U}{R} \quad (6)$$

Equation (6) is the most general form of Ohm's Law and states that current strength increases with increasing voltage and decreases with increasing resistance. The law is the most basic for the flow of electric currents in conductors.

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If the units amperes and volts are inserted in equation (4) you obtain, from $G = I/U$, a unit of conductivity (A/V) which is abridged as 'Siemens' (S). Accordingly from $R = U/I$ the unit V/A is derived, i.e., the ohm (Ω). One kilohm ($k\Omega$) = 1000 ohm; one megohm ($M\Omega$) = 10^6 ohms.

1.1.5. Electrical Resistance

The resistance depends on the nature of the electrical circuit - i.e. dependant upon the conductor itself. It can be shown experimentally that, in a long conductor, resistance varies directly with length and inversely with the area of cross-section. The nature of the material composing the conductor also affects the resistance. The current flowing encounters a greater resistance the longer the thinner a wire, and the poorer its conductance. The last feature is known as the specific conductivity σ and the greater it is the more current can be conducted. The reciprocal

of the conductivity is the specific resistance, and smaller it is the more current can flow. Conductivity and specific resistance are used in practice.

If the length of the conductor is 'l' and its cross-section is 'A' then the resistance is

$$R = \frac{\rho l}{A} = \cancel{\frac{\rho l}{A}} \frac{1}{\cancel{\rho l}} \quad (7)$$

Equation (7) permits the calculation of resistance of a conductor, using the variables length (cm), cross-section A (cm²) and the nature of the material. If ρ (Ω) and κ are inserted in this equation with the appropriate units ~~then~~ ^{then}:

$$\rho (\Omega) = \left(\frac{\Omega \text{ cm}^2}{\text{cm}} \right) = (\Omega \text{ cm}) \quad (8)$$

and $\kappa = \left(\frac{\text{S cm}}{\text{cm}^2} \right) = \left(\frac{\text{S}}{\text{cm}} \right) \quad (9)$

Equations (8) and (9) provide numerically the resistance of a cube, of one cm edge. If you are working with elongated conductors, i.e., wires, the length in meters and the cross-section in mm² would be used. In this case the unit for the specific resistance from equation (7) is:

$$\rho = \left(\frac{\Omega \text{ mm}^2}{\text{m}} \right)$$

and $\kappa = \left(\frac{\text{S m}}{\text{mm}^2} \right)$

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Table 1

Specific resistance and specific conductivity of various conductors
i.e., silver, copper, gold, aluminum, wolfram zinc, brass, nickel, iron,
(tin, platinum, lead.

For various electrodes of different shapes in water, the following
resistances are given according to Hoesl.

a) Wire or band of one metre long $R = \frac{2\rho}{\ell}$

b) Rod, one metre long $R = \frac{\rho}{\ell}$

c) Square plate of side, one metre $R = \frac{\rho}{2\ell}$

Conductive Material

$$\left[\Omega \frac{\text{mm}^2}{\text{m}} \right]$$

$$\left[S \frac{\text{m}}{\text{mm}^2} \right]$$

The following values for resistance of electrodes of various shapes
have been found by Hoesl:

(a) Wire or strip of 1 m length: $R = \frac{2\rho}{\ell}$

(b) Rod of 1 m length $R = \frac{\rho}{\ell}$

(c) Square plate (1x1m) $R = \frac{\rho}{2\ell}$

(d) Hemisphere having a
diameter $d(m)$ $R = \frac{\rho}{3d}$

ρ is the specific resistivity of the water in ohms. m.

(e) Sphere: $R = \frac{K}{\sqrt{A}}$

where A is the surface area and K is a constant in which the conductivity
of the water is contained (Kreutzer).

The following example should clarify the relationships indicated above.

Question: What current flows when the potential difference is 300 V, between two electrodes, one consisting of a rod ~~immersed~~ ^{immersed} 0.5 m, and the other a square plate (0.5 × 0.5 m). The water has a resistivity of 150 ohms m

Solution: According to the relationships introduced here and Ohm's law, the following may be calculated:

$$I = \frac{U}{R} = \frac{300}{\frac{150}{0.5} + \frac{150}{1}} = \frac{300}{450} = \frac{2}{3} \text{ Ampere}$$

1.1.6 Electrical Work

If electrons are moved under the influence of potential difference, work is performed which is proportional to the potential and charge moved.

From equation 1: $W = U \cdot Q = U \cdot I \cdot t$ (10)

Using the units amperes (A) volts (V) and seconds (s) work is expressed in the units Volts. Amperes. seconds. ^(VAs) The product of voltage and ampere ^(VA) has its own unit, i.e., watt (W), and the unit of work - Watt-second ^(Ws) is known as a Joule (J). Normally electrical work is measured by a wattmeter and expressed as kilowatt hours (kWh). Interesting in this connection is the work which can be performed within a given interval of time. This is termed "power" (P) and from equation (10) it follows that

$$P = \frac{W}{t} = UI \quad (11)$$

where U is again an arbitrary voltage - for example, the voltage across the terminals of a generator. The unit of work becomes volt-ampere or Watt (VA). Larger units are usually preferred - i.e., 1000W = a kilowatt, 1000kW = a megawatt.

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To calculate the work performed when a current of I flows through a resistance R , simply substitute IR for (Ohm's law) and obtain the more convenient formulae: $P = I^2R$ (12)

$$\text{or } P = \frac{U^2}{R}$$

1.1.7. Electrical Currents in Liquids

There are two categories of conduction of electricity through materials.

- (a) Metallic or electron conduction
- (b) Electrolytic or ion conduction

The first is found predominantly in solid and liquids metals, metallic alloys and intermediary metallic compounds. The second occurs chiefly in salts, in the solid, liquid and dissolved state. Metals conduct, as a rule, electricity much better than electrolytes. As mentioned previously this is due to the presence of free or loosely bound electrons. Conduction in electrolytes is accomplished by ions, i.e., electrically charged molecules.

If a potential difference is set up between two electrodes in an electrolyte, a boundary layer exists between the metallic electrodes and the electrolyte. The point of entrance of the current into the solution is called the anode; the point of exit is known as the cathode. Here it must be considered that the circuit has to be completed in order that a flow of ions occurs between the two electrodes. The carrier of the electrical charges are, as mentioned previously, ions which, according to the nature of their charge move to the anode or cathode. Positive ions which move to the negative pole are called cations whereas negative ions (moving toward the positive pole) are known as anions. At the electrodes all ions lose

their charge, i.e., the cathode releases as many ions as the anode receives. The direction of current flow correspond, i.e. from the negative to the positive pole.

If two metallic electrodes are placed in a weak solution of copper sulfate, they are surrounded by positive copper (Cu^{2+}) and negative sulfate ions (SO_4^{2-}). If a voltage is applied between the electrodes the ions under the driving force of the potential move to the oppositely charged electrode. Positively charged copper ions move to the negative electrode where they pick up the electrons which lack. Now neutral copper metal is separated on the kathode. Negative ions migrate to the anode and give up their electrons.

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The movement of electrons (electrical current) through the electrolyte is achieved by their transport in ions.

1.1.3. The Electrical Field

Coulomb's law states that two point charges Q_1 and Q_2 exert a force on each other in an airless space which is directly proportional to their product and inversely proportional to the square of the distance r .

$$\vec{K} = k \frac{Q_1 \cdot Q_2}{r^2} \quad (13)$$

k = constant of proportionality.

In the same way, the force can be calculated which is exerted by a point charge $Q(Q_1 = Q)$ from a distance to the unit charge ($Q_2 = 1$)

According to equation 13,

$$\vec{K} = \frac{Q}{r^2} = \vec{E} \quad (14)$$

A value may be assigned to each point in the space around the charge Q indicating the amount and direction as well as the force acting on the unit charge particles. This defines the electrical field. Magnitudes which contain both quantity and direction are known as vectors and are indicated by an arrow in the direction of the vector.

The vector $\vec{E}$ of equation (14) defines the electrical field and may be expressed in the form (equation 14) as

$$\vec{E} = \frac{\vec{K}}{Q} \quad (15)$$

Equation (15) states that charge of the acting force $\vec{K}$ is the same as the charge Q multiplied by the field intensity $\vec{E}$.

Using equation (10) and the relationship that force is equivalent to work acting over a distance it follows that $\left(\vec{K} = \frac{U}{l} \right)$

or
$$\vec{E} = \frac{U}{l} \quad (16)$$

The unit of field strength from equation (16) is expressed as volts per centimeter (V/cm) or volts per meter (V/m). Instead of describing the points in the field of force in the vicinity of the electric charge as vectors, it may be mapped by curved lines which indicate the strength and shape of the field. These are called current lines. The strength of the field expressed by the respective size of the vector may be represented by the density of the current lines, i.e., the number of field lines divided by a surface perpendicular to them. This value, which has also a vectorial component is expressed as current density $\vec{S}$ (Equation 2).

The relationship between current density S and the strength of the

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electric field $\vec{E}$ is revealed when Ohm's law is applied and in this equation the resistance R is inserted ^{by} equation 7:

$$I = \frac{U}{R} = \frac{U \chi A}{\ell} = \frac{UA}{\rho \ell} \quad (17)$$

from which $\frac{I}{A} = \chi \frac{U}{\ell} = \frac{U}{\rho \ell}$ (18)

combining equations 2 and 16 we get

$$\vec{S} = \chi \vec{E} = \frac{1}{\rho} \vec{E} \quad (19)$$

or $\vec{E} = \rho \vec{S} = \frac{\vec{S}}{\chi}$ (20)

The current density is therefore equal to the product of conductivity and electrical field strength. Equation (20) is really the basic Ohm's law. If the basic Ohm's law is applied to electrofishing, then it is evident that the electrical field strength will vary with various water conductivities. If for example, a certain field strength is required to induce narcosis in a fish then in poor conducting mountain streams a smaller current density can be used than in good conducting waters. Good conducting water however, provides strong stable electric fields in comparison to those of poorly conducting waters.

Since current density and electrical field strength are bound together by Ohm's law, the representation of the electrical field by current density agrees with electrical field strength in quantity and direction as long as χ with respect to Q has the same values throughout the entire field.

By solving equation (16), with the potential U , it turns out that the potential U is equivalent to the electrical field strength $\vec{E}$ multiplied by the distance of separation ℓ of the two measuring electrodes ($U = \vec{E} \ell$).

The various points in the vicinity of the charge may be arranged in the place of the vectors $\vec{E}$ voltage - value U . If points of the same potential are joined, then equipotential lines are formed which defines the shape of the field.

Various types of electrical fields are shown in figures 12 to 14. In Figure 12, the field about a point charge is represented radially symmetrical, i.e., the line of current spreads out radially from the point source euqlly on all sides. In this instance the equipotential lines are concentric circles.

Fig. 12 The electrical field surrounding a point electrode. Lines of current are shown by solid lines and equipotential lines are dotted.

In Fig. 13, the electrical field (lines of current as well as equipotential lines) between two plate electrodes are shown. Figure 13 shows four equipotential lines separated by equal distances. The potential between any two lines especially the outermost lines and the surface of the electrode is one-fifth of the entire potential. If we assume, for example, that the total voltage between the two electrodes is 6 kV then, between any two of the lines ($6 \text{ kV}/5 = 1.2 \text{ kV}$) ^{can be measured.} In relation to the negative electrode, the designated equipotential lines one after the other have voltages 1.2, 2.4, 3.6 and 4.8 kV respectively. Notice that the lines of current and equipotential lines always intersect at right angles.

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Fig. 14: Current and equipotential lines between two spherical electrodes of different charges

Fig. 13 ~~Current and equipotential lines between two plate electrodes. Lines of current - solid lines. Equipotential lines - dotted lines.~~

Since the surface of the electrode is also an equipotential surface, the lines of current leave perpendicular from it. The electrical field is strongest where lines of current and equipotential lines are the most concentrated which according to Figures 12-14 occurs at the electrode.

The flow of electric current may be compared with the flow of water. It flows down the mountain always in the direction of the greatest slope. On a map, equipotential lines are analogues to contours. The electrical current will flow in the direction of the greatest potential drop.

It should be mentioned at this point that the information given by depicting an electrical field by equipotential lines, or by lines of current flow, is the same since both are directly related to each other.

It may be shown graphically by calculating the equipotential lines between two concentric spherical electrodes, one with a radius r_1 and the other with a radius r_2 ($r_2 > r_1$).



$$\Delta \phi = I \frac{P}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \quad (21)$$

in which I is current strength and P is the resistivity of the water.

Equation (21) permits the plotting of equipotential lines surrounding spherical electrodes. It can also be used, however, for all other forms of electrodes used in electrofishing which, although a crude approximation of

values — is sufficiently accurate for practical work.

Fig. 14 Current and equipotential lines between two spherical electrodes of different charges

Equation (21) illustrates furthermore that the shape of the electrical field is dependent on the current strength I , on resistivity of the water and or that of the surrounding bank, the geometric measurement of the water being fished and the dimensions of the electrodes.

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If a current flows from the positive pole of a current source over a uniform metal conductor back to a negative pole, the potential difference between the two poles falls more or less uniformly according to the resistance of the conductor. The relationship in the electrical field is different since the equipotential lines are compressed near the electrodes and farther apart as the distance from them increases. If the field is explored with two probes maintained at a constant distance it will be found that the greatest potential gradient lies in the immediate vicinity of the electrode. Figure 15 shows a typical plot of the gradients existing between two electrodes separated by 10 m and having a total potential difference of 300 V. The water has a resistivity of 150 Ω .m.

Fig. 15 Voltage as a function of distance from two electrodes of opposite charges.

From Figure 15 it is deduced that the voltage at the positive electrode is high whereas at a distance of one metre it has dropped to 1/10 of this value. Between distances 1.7 and 2.4 metres, the value is only 2 V. In the midpoint between the two electrodes (5 m) the voltage falls to zero

(44) (21) 2.

and changes over to negative values; 10 m from the positive pole the voltage reaches the greatest negative value.

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A fish which has a snout-to-tail voltage of about 2 V, i.e., this is required to elicit a certain response to the field, would be stunned at distances 1.7 to 2.4 metres from the electrode. Small fish would not be influenced significantly in this instance because they are affected only by ⁴ greater voltage gradients charges at the electrodes.

At a distance of 1 m from the electrode the body voltage of 2 V can only be attained in fish 8 cm long. A fish 70 cm long would "tap off" a significantly higher voltage.

In summary we can say that the potential difference is large only in the immediate vicinity of the electrodes, dropping off significantly as the distance from the electrode increases.

From this we may formulate a fundamental rule of electrofishing. The current density required to narcotize, paralyze or kill fish is found only in the immediate vicinity of the electrode. Increase of the input voltage cannot alter this relationship. This fact is also applicable to electrofishing in the ocean.

1.1.9. Sources of Electric Current

The electric current necessary for electrofishing operations is usually supplied by batteries or generators, eg. direct and alternating current generators.

Batteries are composed of a more or less large number of wet or dry cells. A wet cell is a vessel with acid containing, for example, zinc and copper plates are connected by a conducting wire. The potential difference across the electrodes of such a cell is about 1.4 volts.

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Most cells used in industry are storage cells containing lead plates in sulfuric acid; each cell has 2 volts across the plates.

A dry cell is a battery having no liquid acid but acid-saturated sawdust instead. The number of cells placed in service, depends on the potential difference desired. Batteries used in industry have potentials of 6, 12 and 24 V. Once spent, dry batteries are discarded and, unlike wet cells, cannot be recharged. For this reason dry batteries are seldom used in electrofishing, because they are uneconomical. Batteries are only used when small bodies of freshwater are to be fished with apparatus producing pulses. Since the production of short pulses require relatively little current, fishing operations can be carried out 8-12 hours before the batteries have to be recharged.

S 41

Before the use of pulsing devices, dynamos were exclusively used or gasoline generators. The latter were used to supply power for pulsing devices when current from batteries was not sufficient because of the unfavourable conductivity of the water (p 125).

If electrofishing is to be carried out in the ocean the sources of current described above are not adequate since the conductivity of sea water is 500 times as great as that of freshwater. In such instances gasoline or diesel generators are used. In experiments conducted on 96, a generator of 200 kW was available, capable of providing 10,000 A. In recent years 40 kW or less have been used which can be produced with large automobile engines. (p 134).

In many situations currents for electrofishing gear is provided by the circuit used for electric lighting. Thus current is obtained for electrofishing devices installed in front of the intake screens from the

(46) (11/3)

electricity produced by the plant - an arrangement not only ^{more} practical but also economical (p 146).

1.1.10 The Importance of the Shape and Arrangement of Electrodes in Establishing an Electric Field in Water

As mentioned previously the form and density of the lines of electrical current and consequently the efficiency of capturing fish depends upon the form and arrangement of electrodes. Schiemenz and Humburg in 1939 explored the various possibilities of placing electrodes in various configurations. From their work the following results emerged:

The greater the distance the electrodes are separated, the greater is the dispersion of the lines of force ~~between the electrodes~~ ^{between the electrodes} resulting in a decrease of the current density ~~in this region~~. At the electrodes the lines are concentrated. According to equation (20) there is also an increase in current density. A fish in the region of an electrode

^{greater} experiences a snout-to-tail voltage than a longer fish in the middle of the array of electrodes. ~~The result of this~~ This means that the electrical influence of the field can cause great differences in lethal and repelling effects.

S42 It is therefore desirable to produce an electrical field between the electrodes consisting of parallel lines.

S.42

For plate electrodes

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(47)

$$V = E_{\min.} \cdot \frac{r}{2} \ln \frac{2\pi r}{h} \quad (22)$$

$$I = E_{\min.} \cdot \frac{1}{\rho} \cdot \frac{\pi}{2} r \cdot l \quad (23)$$

$$R = \rho \cdot \frac{1}{\pi \cdot l} \cdot \ln \frac{2\pi r}{h} \quad (24)$$

where V = voltage between the two electrodes (V)

I = the total current (A)

R = the electrical resistance (Ω)

$E_{\min.}$ = least field strength (V/m)

ρ = specific resistivity of the water ($\Omega \cdot m$)

l = length of the plate electrodes (m)

r = the distance separating the electrodes one from the other

h = the height of the covered surface of the electrodes

The formulae only applies to direct and alternating current.

Humburg found using various arrangements of electrodes in water the following dimensions (breath and depth) of effective fields.

S.43

Long electrodes

1. Both electrodes fully immersed in deep water.

Voltage 220V, Current strength 55A

Extent of the effective field (possible volume of fishable water) 6 m deep and 5 m broad.

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2. Both electrodes floating:
 - (a) Voltage 220V, current, 55A . Extent of the effective field 2.5 metre deep and 10 m broad.
 - (b) Voltage 110V, current 110A, extent of the effective field 1.8 metres deep and 36 metres broad.
3. One electrode floating, the other pole grounded:
Voltage 220V, current 55A, extent of the effective field 2.5 metres deep, 16 metres broad.
4. One electrode floating, the other immersed under it.
 - (a) Voltage 220V, current 55A, extent of the effective field 10 metres deep and 7.5 broad.
 - (b) Voltage 110V, current 110A, extent of the effective field 6 metres deep and 25 metres broad.

For Short Electrodes

1. Both electrodes fully immersed in water:
Voltage 220V, current 20A.
Extent of the effective field 3m deep and 6m broad
2. Both electrodes floating
Voltage 220V, current 14A, effective field 2m deep
7m broad
3. One electrode floating, the other grounded
Voltage 220V, current 20A, effective field up 2m radius
around the anode
4. One electrode floating, the other immersed under it
Voltage 220V, current 14A, effective field up to 3m
in the vicinity and effects up to 5m deep

Schiemenz and Humburg came to the conclusion that, in spite of the large amount of energy used, areas greater than 150 square m. could not be fished.

Denzer writes the following: "When you simulate the energy relations using direct current in a model aquarium test in order to predict practical applications, it is evident that it is impossible to achieve any large effective area (with direct current alone). Physiological experiments have demonstrated that a minimum threshold current density of 0.88 is required to elicit galvanotaxis.

S.44

This means that, for a cross-section of water of one square metre, it would be 0.8×10^6 microamperes = 0.8A. To render a cross-section of water 10 metres square effective a quantity of 8A are required: for 100 square metres - 80A. The calculation of 8A for 10 square metres indicates that, considering the weight of the gear, electrofishing operations can be only carried out in brooks 5m broad and 2 metres deep. The values found from experiments in aquaria are essentially close to those of Schiemenz and Humburg. These may also be deduced from laboratory experiments. In addition from this model the provisions where that the electrodes consisted of flat plates - a condition impossible in flowing water and in narrow, standing waters where too great a disturbance would be caused. When we consider that the heaviest piece of equipment providing 220V and 16A, it would mean that waters with conductivities which allow this current to actually flow would provide an effective field 10m broad and 2m deep. As a result electrofishing, even if it has many practical possibilities, is limited in its ability to remove all the fish from an area.

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(27)

Electrodes used in the ocean have the following characteristics:
The spreading out of direct current from an electrode is a function of the shape of an electrode and its surface area. For a spherical electrode a diameter - d

$$R_a = \rho(2\pi d) \quad (25)$$

where the resistance of spreading out R_a is, according to equation (25), inversely proportional to the diameter of the sphere, ^{d/}i.e., with increasing diameter, the resistance decreases. For a sphere of diameter 2m and a specific resistance of the medium covering the sphere of 25 Ω cm. (salted fresh water according to table 8 on page 89) there would be a spreading resistance of 0.02 ohms. From equation (16) and (20) V will be $(S\ell)/x$. Accordingly the voltage V for a constant ℓ would decrease with increasing distance from the surface of the electrode. In figure 16 ^{yes see} the experimentally determined field between plate electrodes - one having a surface area of 4 sq metres and the other, fastened to a ship - i.e., a surface of 20 sq. metres. Haier determined that, for this arrangement of electrodes, "within a distance of 2m from the electrode, 60% of the total voltage between the electrodes falls off. If the electrodes are increased threefold only 40% ^{of the voltage is necessary} ~~is lost.~~" It would not be feasible to construct large electrodes because of weight, their resistance to water movement and general awkwardness. The spreading resistance would only be slightly changed if a discontinuous electrode surface instead of a solid surface was used. The discontinuous surface does not have to be rigid since it assumes this property either from the 'lift' or the drag resistance as it is pulled through water.

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Fig. 16 Electric field in seawater as found in an experiment of Haier
(explained in the text)

Fig. 17 Forms of electrodes for electrofishing installations in the ocean
(from Haier).

Explanation of numbers:

- | | | | |
|-------|---------------------------|--------|-------------------|
| left: | 1. lead-in/wire | right: | 1. insulated |
| | 2. tube beam (elliptical) | | lead-in wire |
| | 3. conductive copper net | 2.3 | boards |
| | 4. float | 4. | conducting strips |
| | 5. weights | | |
-

The possibilities of arranging the electrodes are diverse - two forms of electrodes are shown in Fig. 17. When fishing on the high sea, suitable parts of the net frame (page 139) may serve as electrodes of large surface area. If one or several large, flat electrodes have been installed, then the properties of the field can be improved by inserting auxiliary electrodes which produce intermediate potentials. In this way the field strength in this region is not basically changed and the field acquires a preferred direction. This condition is illustrated in Fig. 18. The main electrode 1 produces without the auxiliary electrode, a drop in potential shown along the axis AB. Next to it on the left is shown the drop in potential using auxiliary electrode 2 which is held at 50% of the total voltage. If the stimulating field is designated by a dashed line (showing a value of E_g) then it is evident that the region of influence increases from l_1 to l_2 when the auxiliary electrode is used. The intermediate potential of this extra electrode may be adjusted by a voltage divider or by making the spreading resistance greater than than of the main electrode. Such arrangements are best carried out by using parts of the net frame (Fig. 19). It is known

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from work with alternating currents that very variable currents in a medium through which the conductors run, have the tendency to flow back, if possible, through these conductors. This effect results in a preferred direction of the field and is highly desirable.

Fig. 18: Controlling the drop in potential by means of auxiliary electrodes after Haier). Explanation in the text.

S.47

2. Basics of Electrophysiology

2.1. Typical reactions of the fish in the electrical field.

Fish react in a variety of ways in the electric field. According to the type and density of the electrical current they may swim after the current is switched on, towards the anode, ~~If you~~ place their bodies at right angles to the lines of current flow ~~they are~~ ^{if possible or} narcotized by an increase in current density. They may also be repelled by the electric current and if the field is sufficiently strong they can be killed. The following typical reactions may be distinguished.

2.1.1. Behaviour of fish in fields of direct current.

The first visible reaction of a fish occurs when it is parallel to the lines of force ^{is} ~~shudders~~ ^{is} with its entire body. If its position lies across these lines a movement of the head toward the anode occurs.

When the current density is increased the second reaction is elicited in which the fish - if parallel to the lines of current - swims toward the anode (electrotaxis - called galvanotaxis only when the field is of direct current). If at right angles the fish position ^{is} ~~itself~~ parallel to these

(53)

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lines when the switch is turned on. It does not swim in this instance to the anode but only when a new stimulus is applied. The third reaction occurs when a further increase in the current density occurs. The fish loses its equilibrium and does not display any voluntary movements (electronarcosis).

2.1.2. Behaviour of fish in fields of alternating current.

Again the first reaction consists of a quivering of the head or the entire body but this response is not related to any of the two electrodes. In the second reaction - oscillotaxis, the fish assumes a position across the lines of force so that the potential difference across its body is minimized. No anodic reaction is displayed. In the third reaction the fish are stunned - as with direct current (electronarcosis). In fish narcotized by alternating current the colour of the skin is lightened by contraction of the pigment. In addition when the current is turned on most fishes (trout, carp tench, dwarf, catfish) experience a type of hypnosis (SCHEMINSKY). The fish does not resume its normal swimming pattern as after being exposed to pulsed and direct current - but lies on its side or back for several minutes. After the "hypnosis" has worn off, the fish swims away in the same manner after it had been exposed to direct current.

2.1.3. Behaviour of fish in pulsed current.

Reactions of fishes are dependent upon pulse form, frequency and duty cycle.

S.49

In the first reaction, quivering of the whole body occurs which is more or less in sympathy with the frequency of pulses.

In the second reaction the fish swims according to the shape of the pulse: a rapid rise, gradual or rapid decrease (for example, the form

of a condensor discharge) to the anode. When the pulse form is squared the fish often places itself across the lines of the field. When the pulse has a leading edge of gradual slope which quickly falls off a movement towards the cathode often occurs (p. 63).

The third reaction is again characterized by immobility (electronarcosis). In spite of symptoms which are superficially similar, the physiological processes elicited by the various types of electrical currents are distinctly different.

If fish are exposed to direct current a substance is produced according to Scheminzky and Koellensperger in the spinal cord which initially stimulates or if in a sufficiently high concentration, induces narcosis in the animal. When the current is turned off this substance is again broken down. With galvanonarcosis moreover, a depression of the activity of the central nervous system occurs. In this respect galvanonarcosis may be considered to be similar to chemical narcosis which produces a pure paralysis.

~~Alternating~~ ^{Alf...} current induces a more or less pronounced stimulation of the central nervous system, which is expressed by sustained muscle contraction (twitching). The lack of ability to move - narcosis is a result of muscle cramps occurring at high current densities. These arise from the superimposition of a series of individual contractions. The stunning in this instance is not a true paralysis but rather a muscle cramp of tetanic nature.

2.2. Current density and field strength.

The intensity of the effects of the electrical current is in general

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a function not of the absolute current in the experimental tank but, as mentioned above, is characterized^z by the current flowing through a square cross-section (Equation 2). The unit of current density is the number of amperes flowing through one square millimeter of cross-section. The name of the unit is "Vorsselmann de Heer" or "Poggendorf" and the symbol Δ . For physiological and therapeutic purposes ~~S.O.~~

S. 50

Table 1
Current density values in samples of salt and freshwater fishes
(after Halsband)

Fish species	1 <u>Stickleback</u> <u>Gasterosteus</u> <u>aculeatus</u>	2 <u>Loach</u> <u>Nemachilus</u> <u>barbatulus</u>	3 <u>Plaice</u> <u>Pleuronectes</u> <u>platessa</u>	4 <u>Steinpicker</u> <u>Agonus</u> <u>cataphractus</u>
Length	5-6 cm	10-12 cm	20-22 cm	8-10 cm
Weight	3-4 g	7-9 g	45-100 g	14-16 g
First reaction	0.48	0.08	39.91	18.18
2nd reaction (galvanotaxis)	1.88	1.55	44.34	50.99
3rd reaction (galvanonarcosis)	3.94	2.43	70.95	115.00

It has the value $10^{-6}\Delta$ and is designated as δ . The unit for current density is $10^{-6}\Delta$ per square millimeter.

The threshold values which must be attained to elicit the desired reactions for various species is according to the rules outlined below.

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The threshold values for fish of the same species and size are, within small variations, constant and reproducible. Below the threshold of the first reaction no response is evident.

A simple experiment is described below in which the three reactions are determined in a direct current field.

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Two copper electrodes are attached on the two opposite sides of an aquarium. These electrodes are congruent to these ends. For experiments in sea water, the electrodes are coated to reduce electrolysis. Batteries provide the current and are hooked up in the manner shown in Fig. 20. Voltage is controlled by a variable rheostat and amperes and voltages are measured by the appropriate instruments. A switch in the circuit is used to turn the current off and on.

The experimental fish is placed in the aquarium and allowed 25 to 30 minutes to adapt after which time the determination is begun. A low current density is employed ($0.0586 \frac{S}{cm^2}$) which is slowly increased until the fish convulses either with the head or the entire body. When the first reaction has been achieved the voltage is determined, thus calculating the intensity of field (Equation 16). The voltage is then increased until the fish swims to the anode, indicating the onset of the second phase - galvanotaxis - this value is recorded. Further increase in the voltage eventually leads to complete narcosis, and this value is again recorded.

The intensity of the electrical effect is calculated from the measured current density which is the result of dividing current strength (micro-amperes) by the cross-section of the liquid in the test bath in mm.

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Investigations of Scheminzky and Denzer indicate that Cottus gobio is the most sensitive fish species. An individual 60-70 mm long, undergoes galvanonarcosis at a current density of 1.67δ . In contrast the common minnow (Phoxinun laevis) requires 2.15δ . ^{for the same reaction} Even the interval between the three reactions in Cottus gobio is narrower than that of other fish. If the value of the current causing the first reaction is assigned the value

unity then the galvanotaxis occurs at 6.5 and the galvanonarcosis at 8.8. For the common minnow the ratio is 1:15:24. Denzer used Cottus gobio because it was a responsive fish displaying the first reaction very distinctly. It resembles in its behaviour that of mammals when cramps are ~~induced~~ ^{induced} by oxygen lack. Apparently this similarity is not just superficial but is functional equivalent in the last phase in which the extension of the extremities in mammals corresponds to the spreading out of the fins and the opercula.

S. 51

Figure 20: Experimental arrangement to determine threshold values in fishes (Explanation in text)

A_s - Row of storage cells

R - Variable resistor

A - Ammeter

V - Voltmeter

U - Switch

E_1/E_2 - Electrodes

It is significant that the threshold values decrease with increase of size of the fish.

Table 2

S. 52 Dependence of body size and threshold values for the first reaction,
galvanotaxis and galvanonarcosis in the common minnow Phoxinus laevis
(after Scheminzky)

Length internal	Number of Animals	Average Length	First Reaction	Galvano- taxis	Galvano- narcosis
			δ	δ	δ

The relationship of threshold intensities among each other remains
approximately constant as shown by the following table.

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(cont.)

or $R = \sqrt{\frac{I \cdot L \cdot K}{G \cdot 4\pi}}$

substituting $R = \frac{L}{2}$ ($R = \frac{L}{n}$)

may be also used when it is assumed that the ratio in homogenous and heterogenous corresponds to 3/4 of the length. *Then the*
~~The~~ above formula may be written

$$\frac{L}{2} = \sqrt{\frac{I \cdot L \cdot K}{G \cdot 4\pi}}$$

If this equation is solved for I (by squaring both sides).

$$I = \frac{L \cdot G \cdot \pi}{K}$$

This may be expressed in words in the following manner:

In heterogeneous fields (when the anode is at the head of the fish) the required field strength to stun a fish is, according to Ohm's Law, (Equation 18) proportional to the length of the fish. In other words the longer the fish, the greater the current density (field strength) required to stun it. This is exactly the opposite relation prevailing in homogenous field (Fig. 21).

2.3. Body Voltage

According to Holzer, the body voltage is the voltage between snout and tail necessary to elicit a given reaction in the electric field. In other words the voltage "tapped" across the experimental object is a measure of the strength of the electric ^{influence on fish.} ~~field~~. Since there are often technical difficulties associated with its determination one must be

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Table 3

S. 53 Relative scopes of the three levels of the effect of the electric current in the common minnow Phoxinus laevis (according to Scheminzky)

Average Length mm	1st Reaction	2nd Reaction (Galvanotaxis)	3rd Reaction Galvanonarcosis
Average values			

The position of the fish in the electrical field is also important. Higher values are required to elicit these reactions when the fish is exposed to an ascending current direction ^{than} in the descending current direction. C. Kreutzer has described the relationship between the length of the fish and field strength in homogenous and heterogeneous field in the following way:

In homogenous fields, the longer the fish, the less the field strength which is required to elicit a given reaction. Field strengths are expressed in volts per cm.

When the field is ~~heterogeneous~~ ^{inhomogeneous}, however, for example when a hook in its mouth serves as one of the electrodes, the field strength over the length of the fish is not uniform. In this instance it is greatest near the head, progressively decreasing towards the tail. If it is assumed that the effective strength in this heterogeneous field corresponds to that at the middle of the body in a homogenous field, i.e., the strength required to stun a fish, then the following formula may be used:

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$$R \text{ (Range) } = \sqrt{\frac{\text{current} \times \text{fish length} \times \text{constant (i.e. specific resistivity)}}{\text{body voltage} \cdot 4\pi (=3.14)}}$$

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S 54

satisfied with a statement of current density and ignores the distortion of the field caused by the presence of the fish. The statement of current density must also be supplemented by the size of the animal and the cross-section of the test bath. Distortion of the field increases as the ~~ratio~~ ^{becomes greater and the} of body size ~~to~~ area of cross-section decreases.

Fig. 21 here

A is the field strength required to stun a one meter-long fish. B is the corresponding field strength necessary when distributed evenly along the fish. C is the field strength required to stun a 3 meter fish when the electrode (hook) is placed in the mouth. D is the field strength when the field is homogenous throughout the length of the fish. ~~figure 21~~

It may be seen from the curve and the straight line that short fish require a higher homogenous field strength but a ~~lower~~ ^{lower} hetero-geneous field than long fish. (after Kreutzer)

Only for very large areas of cross-section is the relationship of fish size to size of the test bath practically insignificant.

Concerning the absolute stimulating voltage, Holzer writes:
"The following relationship holds for the equivalent solution".

If you place two electrodes s cms apart in the test bath at a voltage of U (volts/cm), the following formula emerges

$$E = \frac{U}{s} \text{ (volts/cm).}$$

The experimental animal of length L (cm) when placed in a bath is able, because of its extended length, ~~to~~ ^{to} "tap off" a voltage according to its

position in the field.

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According to the length of the experimental object the voltage across the length of the fish is given by

$$U_f = E \cdot L = \frac{U}{s} \cdot L$$

where this voltage is

$$U_f$$

This voltage was named by Holzer, after borrowing a graphic concept of electrical technology, as "body voltage". Extremely more complicated would be the relationship if the conditions of the equivalent solutions were not met. Holzer has given formulae for this condition but they are too difficult to be presented in this book.

The body voltage for trout, as an example, for the first reaction is 0.4 volts, for the second reaction - 1.2 volts and for the third 2 volts. Since large fish "tap off" a larger voltage than small, they are influenced sooner and with relatively small current densities. Fish which tap off voltages less than the body voltage are able to escape the influence of the electric field.

TABLE 4

The dependence of fish length and current density as reflected by body voltage in Leuciscus rutilus, Carassius vulgaris and Alburnus lucidus. 50Hz alternating current (from Holzer)

Length of fish cm	Current strength μA_{eff}	Current density in tank in δ	Voltage at the electrodes V_{eff}	Field strength $V/_{eff}/cm$	Body Voltage
		δ	V_{eff}	V_{eff}/cm	V_{eff}

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The current density at the site of stimulation, i.e. inside the test animal is determined by the following factors: differential conductivity of the body of the fish and the liquid, resistance of the membrane, shape of the experimental animal, spatial dimensions of the region of stimulation and, in the instance where there are several animals in the tank, the number of these.

Holzer described the pattern of flow lines of current for a conical object and came to the following conclusion: outer and inner current densities are connected by a linear relation. The relationship of outer to inner current densities falls in three categories. In good conducting solutions the value is very small. For solutions of moderate conductivities the value increases. It is in this region that the equivalent solution falls (i.e. conductivities of fish and the bath are incidental). Low conductivities produce relative values from 3 to 3.2 which is practically independent of the conductivity of the solution. In general the membrane depresses the inner current density. At extremely low conductivities of the bath however, the inner current density, increases when the specific conductivity of the membrane is diminished. The number of objects in the area of stimulus influences the current density in model objects. This influences the current density in model objects. This influence is considerable for objects lacking membranes, but small for those with them.

2.4. The effect of electric current on the metabolism of fish

In spite of the pronounced neuro-physiological effect of pulsed current on fish it was demonstrated by Halsband that the metabolism of fish (basal metabolic rate, ventilation rate and gut temperature) was

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little affected. After effects of exposure to pulsed currents lasted 20 minutes; for direct current however, 70 minutes; and for alternating current, as much as 120 minutes.

In other words -

While pulsed current exerts the greatest neurological effect, it has the least residual effect on the whole animal. It is therefore the most suitable for electro-fishing.

Metabolic intensity is measured by oxygen consumption per hour, frequency of breathing per minute, and gut temperature are conducted in a specially built respirometer. Oxygen concentrations, are determined by the Winkler method. Breathing frequencies are counted by an electrical method devised by Halsband. Gut temperatures are determined by a thermocouple. The electrical stimulus which was applied for a period between 20-60 seconds was applied by wire screen electrodes applied at the end of the respirator tube. The duration of the pulse used in the investigation was 2 milliseconds and the frequency set at the normal rate of 50 per second.

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The following results were obtained from the experiments. After the flow of the electric current a more or less increase ^{or decrease} in metabolism occurred according to the type and duration of the applied stimuli. For example 20 seconds of direct current applied at a current density corresponding to the threshold for galvanotaxis resulted in a maximum increase of 35% over the normal value. This was followed by fluctuating values which fell to the normal value after 70 minutes. When the application was increased to 60 seconds, values of the metabolism were proportionally higher but the return to normal was not longer than previously. A decrease in metabolism was

66

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noted as the threshold for galvanonarcosis was reached. The decrease in metabolism at this value amounted to 52%. The effect of the electrical current influences metabolism not only by an increase in current density but also by the prolongation of the period over which it is applied. In this manner a paralyzing effect is elicited.

Effects of alternating current are greater than those of direct current. The average increase of metabolism at the threshold of electro-taxis for a duration of 20 seconds is 48%. When the current density is increased the initial increase in metabolism falls below normal when the threshold for electronarcosis is attained. On the average the normal value returns two hours after the current is turned off.

Metabolims is least affected by pulsed current. At the electrotaxis threshold it is depressed only 12% and returns to normal after 20 minutes.

Fig. 22 Oxygen consumption and frequency of opercular movements of Trutta iridea, after the effects of direct current (from E. Halsband)

Current density δ = 1.19 (threshold for electrotaxis)
Water temperature ~~15°C~~ 15°C
Time of application = 20 sec
of el. current
Length of fish = 10.5 cm
Weight 11.0 g.

Increase of current density, produces at the level of electronarcosis, a depression in metabolism. The percentual greatest and longest temporal effect on metabolism is achieved therefore by alternating current. The least in magnitude and duration are the effects caused by pulsed current. Figures 22, 23 and 24 show typical experimental procedures.

Presumably the reasons for the change in metabolism lies in the direct effect of the current on the central control of the respiratory movements. High levels of current have an inhibiting effect whereas low

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levels stimulate.

54
for

In the state of excitation and electrotaxis, there occurs as a consequence of the stimulation, an increase in work done by muscles. This produces an increase in the heat generated and is reflected by a higher gut temperature. The calming effect of narcosis in contrast lowers the intensity of the metabolism.

Investigations on warm blooded animals have shown that weak electric currents (A.C. and D.C.) have a vasomotor effect in which the blood vessels are dilated. This vasodilation is not only found on the skin but also in deep sections. This effect may last several hours. Vasoconstriction occurs at higher current intensity which is accompanied by narcosis. It can be assumed that similar effects occur in fish as in warm-blooded animals and that these cause the changes in metabolism observed.

2.5 Migration of Ions induced by electrical currents in fish

It is known from the physiology of warm blooded animals that when direct current is applied to a tissue, electrical charges (borne on ions) are made to migrate. This causes changes in the chemical composition of the animal's body. Those ions responsible for the charges arise from the dissociation of electrolytes into positively and negatively charged particles. Associated with the migration of dissociated ^{salt} ~~salt~~ and water molecules is a movement of the solvent particles. This process is known as electrophoresis. ^{ur} ~~Under~~ dissociated molecules also take part i.e. water and salt molecules as well as colloidal particle suspended in the blood and tissue fluids lipoids, proteins, sugar etc. This migration of ions produces changes in concentration not only in the tissue fluid but also in the cell bodies. The reason for

these alterations in composition may be found in the different, relative permeabilities; at the boundaries of the cell and everywhere where two different media come in contact.

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Figure 23: Oxygen consumption and frequency of opercular movements of Trutta iridea after the application of alternating current (after E. Halsband)
current density $\delta = 0.71$ (threshold for electrotaxis)
water temperature = 15C
length of animal = 9.4 cm
weight = 10.6 g
Duration of application = 20 secs

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Fig. 24 Oxygen consumption and opercular beats of Trutta iridea after exposure to pulsed current (after E. Halsband)
current density $\delta = 0.29$ (threshold for electrotaxis)
water temperature = 15C
duration of application = 20 sec.
length of animal = 10.8 cm
weight of animal = 13.5 g

An activation and mobilization of countless halogen and mineral ions occurs in which an intensive stimulus to all metabolic and life processes is carried out. It is also assumed that the perfusion of fish with direct current elicits similar processes and these exert a profound influence on metabolism.

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Applicable to the stimulating effects of alternating and pulsed current (if one considers these to be a series of current pulses) are the same laws which govern the effects of direct current.

2.6 The Law of Polar Stimulation and its significance in explaining the behaviour of fish in an electrical field.

The behaviour of the whole animal in the electric field corresponds to that of an isolated nerve in response to an electric stimulus. A nerve

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is ^{stim}stimulated when the current is switched on and off. The flow of current itself is ineffective; it is really the change of stimulus intensity which exerts an effect - a condition necessary to stimulate sense organs. For example, the normal position of the head does not stimulate the semicircular canal; only temperature changes fire the thermal receptors. Significant differences exist between the 'make' and 'break' stimulus of the electrical circuit.

1. The threshold value for the 'make' stimulus (the minimum current strength or voltage which elicits a visible response in the nervous system) is less than that of the 'break' stimulus.
2. Stimulation or excitation of the nerves occurs, when completing the circuit at the cathode and, when breaking the circuit at the anode.

The observed phenomenon is known as the law of polar excitation and is explained in the following way. We know from experience the nerve membrane is permeable to ~~cations~~ cations - i.e. (positively charged ions) and ~~impermeable to~~ ^{impermeable to} anions (negatively charged ions). The interior of the axon contains electrolytes, predominantly $K_2 H PO_4$, while outside, in contrast NaCl is an important solute. K^+ can diffuse through the membrane but Na^+ because of its greater diameter is unable to do so. According to the concept of the flow of electrons potassium, which is very mobile, and decreases the resistance and accumulates at the anode. This alteration of the membrane causes an increase of excitability at the cathode - catelectrotonus - and at the anode - a decrease known as anelectrotonus. When the circuit is broken the decline of excitability at the anode returns to its original level. This is expressed by a relative excitation in the vicinity of the anode. The reaction which occurs under the anode also happens by the reversal of polarity

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in tissues which takes place when the circuit is broken.

S 61

This explanation may be peculiar but the breaking of the circuit is less effective than its closing.

The generation of catetectoronus and the disappearance of anelectrotonus has excitatory effects on the nerves.

When these laws which apply to nerves are applied to muscles then Pflügers law of twitch is demonstrated. If the positive electrode is applied to the end of nerve supplying a muscle and the negative electrode on the other end, nothing happens. The anode produces a paralyzing anelectrotonus. When anode and cathode are exchanged a muscle twitch is elicited.

Similar laws apply to the whole animal - fish, for example. When the fish lies with its tail towards the cathods, then this part is strongly stimulated and the resulting movement propel the fish towards the anode. When the fish has the opposite position (head towards the cathode) the current only elicits a slight quiver of the tail. £

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A similar relationship may be shown to apply to the whole animal (i.e. the fish). When the fish lies such that its tail is pointed toward the cathode the caudal end is strongly stimulated driving the fish in the direction of the anode. A faint quivering of the tail is only detected

when the head points toward the cathode. Next the head displays a convulsion towards the anode and the stimulating shock of the cathode spreads gradually over the entire body musculature causing the fish to turn and simultaneously eliciting swimming motion towards the anode. (Fig. 25). The anode reaction is graphically depicted in Fig. 26.

In Fig. 26 strongly magnified body cells are marked to show the excited (light) and paralyzed side (dark).

Fig. 25. The fish of Pflueger's experiment (modified from Denzer)

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The cells are therefore stimulated in the region of the cathode (see the polar stimulation law mentioned above) and paralyzed near the anode. As a consequence the fish turns from the excited to the paralyzed side; it accordingly flees the region of the cathode to that of the anode.

The reaction of the fish in the electric field is influenced by many factors - i.e., type of current, pulse frequency, temperature and the conductivity of the water.

Lamarque interpreted this reaction also as electronus which induced inhibition. The nerve tracts have a double polarity - afferent nerves (receive stimuli) are centripetal, efferent (conduct motor impulse) are centrifugal. The strength of an electric field depends on the length of the nervous elements, the position of the fish, the current density and the

(72) ~~100~~ 49

fish species.

Lamarque also distinguished between anodic movements and anodic bending. These latter occur at low current densities when the fish is perpendicular to the lines of force. Bending toward that anode depends directly on the stimulation of the motor elements of that half of the body which is pointed toward the cathode. In this way the body bends away from the cathode in the direction of the anode.

If the fish lies with its head next to the cathode it will swim at a certain threshold intensity to this electrode. This so-called cathodic galvanotaxis has escaped the notice of many investigators. Cathodic swimming movements are weaker and less pronounced than the forced movement to the anode.

Fig. 26. Graphic presentation of the swimming movements displayed by a fish in reacting anodically to the electric field (explanation in text)

It occurs when the motor nerve tracts are directly stimulated by the current, the shorter afferent nerves not being affected. At stronger voltage values, the fish turns in any case and shows the normal anodic reaction. The movements towards the anode are elicited by reflexes - cerebral and medullary reflexes in direct current, ^{only} medullary reflexes in pulsed current.

2.7 According to E. Halsband, fish when subjected to gradual current increases and decreases, display no reaction up to a certain threshold. At a considerably higher current density some reaction is noticed and only when the current is increased in the direction of the anode ^{by decreasing opposite} or vertically to the

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lines of force. The same observation can be made as mentioned previously on isolated nerves. Also with an isolated nerve gradual increase or decrease in the current elicits no stimulation. The nerve appears to adapt to the stimulus (accomodation). The stimulus results therefore not only from the change in the intensity but also from the rate of change. A further requirement is that the curve describing the increase in current density must attain a certain steepness. The less the steepness the higher is the necessary threshold to elicit a response. The threshold is understood to be the minimum current density which is required to cause a given reaction in the fish.

Beyond a certain time interval for the increase of the current no response will take place. If one combines a gradual increase with a steep decline in current, a distinct convulsive movement of the fish in the direction of the cathode will occur - similar to that phenomenon described in an isolated nerve. When stimuli are applied in rapid succession - closing (make) and opening (break) reactions (stimulation under the anode and stimulation under the cathode) occur simultaneously. There is reciprocal cancellation of reactions in which a reaction to the anode is suppressed. When the current is applied abruptly and the rise in current is steep, the experimental animal shows a pronounced response. The animal is stimulated in the region of the cathode which results in a movement to the anode.

If after the circuit is completed, it is slowly or directly opened, no cathodic "opening" convulsion occurs since the narrow difference of irritability, is not enough to induce stimulation in the vicinity of the anode.

If the circuit is suddenly closed and after a considerable passage of time; (2 minutes maximum) again opened, the animal will display a cathodic opening reaction at a certain current density which is known as the 'cathodic

B

opening convulsion' - also known as the "accomodation convulsion", after such a long application of the stimulus, the fish has accomodated to the slow increase of current such that it responds to another stimulation ^{also} ~~only~~ when it is ^{→ a slow stimulus, but} for sufficient time to affect the fish.

From these results it follows that, when the leading edge of a pulse of current rises slowly and either falls slowly or abruptly, the pulse form is unsuitable for electrofishing. It will not guide the fish to the anode. A series of pulses following each other which have steep leading edges and gradually trailing edges will also produce the desired movement of the fish to the anode. This type of pulse is best for electrofishing and is technically produced by condensor dischargings. It stimulates the type of pulse produced by electric eels and produces the maximum effect for the minimum expenditure of energy.

Fig. 27. Types of electrical pulses (see text for an explanation) left to right: Square wave (A), condensor discharge (B), aperiodic oscillation (C), 1/4 sinus wave (D), 1/2 sinus wave (E).

The various forms of pulses are summarized in figure 27. Curve forms A and B are less suitable for electrofishing than B and D. Curve form D is especially useful when it is required to frighten fish away from installations or to herd them in a desired direction. Its form resembles that produced by electric fish (Fig. 6)

Curve form B is the most ideal type to conduct electrofishing operations. Most fish display the anodic reaction when this form is encountered (page 64).

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The following experiment allows the reader to draw his own conclusion on the validity the description of these curve forms.

The rectangular ^{glass} ~~glass~~ aquarium filled with water is provided with two copper electrodes congruent to and secured on each end. The circuit with a storage battery as a current source is constructed from the diagram shown in fig. 20. Experiments are conducted using steeply rising and falling pulses. Slowly increasing and decreasing pulses are also employed. The ~~first~~ type of pulse is provided by an abrupt turning off and on the current by a tumbler switch and " ^{reversing about switch} ~~large schalter~~ ^{reversing switch?}". Current which slowly builds up and decreases is produced by sliding a glass tube wound with copper wire into a beaker containing an electrolyte (5% common salt, for example). By slowly immersing and taking out the tube the current intensity can be slowly changed. A milliammeter in the circuit registers the current. If a fish is placed in the aquarium (i.e. a trout) the apparatus can be operated in the following manner to study its responses at various current densities. Abrupt increases and decreases of current intensity causes the fish to swim to the anode. No reaction is observed when current changes ^{slowly} ~~are gradual~~. ^{slowly} ~~Gradual~~ ^{ing and decreasing} increase followed by an abrupt decrease results in the cathodic opening reaction mentioned above i.e. the fish displays a movement of its head in the direction of the Cathode. Repetitive experiments with the same fish is to be avoided since continuous stimuli causes fatigue and definite responses to the current no longer occur.

2.8 Analysis of the Anodic Reaction of Fish

Fish respond to stimuli perceived by sensitive nerve endings lying under the skin which in an intact animal leads to a motor reflex. Removal of the spinal cord abolishes the movement to the anode. The anodic response

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is mediated not through certain sense organs which was originally assumed. Decapitated (spinal animals) fish for instance, and fish with severed lateral line organs display the anodic reaction. A convulsion in the direction of the anode is obtained even when the central nervous system is excluded. Kuhn, Schulze and Spiecker conducted numerous such experiments using both surgical and pharmaceutical techniques. The fish was treated with curare in which the neuromuscular synapses were blocked thus innervating the muscles. If such experimental animals are exposed to direct current, convulsions in the direction of the anode occur. The persistence and prolonged effects of this reaction after the exclusion of nervous controls, illustrates that the anodic convulsion is also possible through a direct stimulation of muscle by the electric current. For coordinated movement, however, an intact spinal cord is necessary.

Voluntary and involuntary movements, in the electrically influenced fish may be distinguished. Voluntary movement, normal swimming behaviour - is mediated through the central nervous stsystem. Involuntary movements can be elicited independently of this stsystem. Anodic convulsions fall in this category. Even involuntary movements of bending of the body evoked by the electric current are always followed by a voluntary movement in the opposite direction. The cause of this counter movement is still unclear. It is either some sort of "stepping reflex" in the sense that Sherrington suggested or one of the manifold functions of centres of higher coordination of the spinal cord of fish described by Holst, Dijkgraaf and Lissman.

When a fish is in a direct current field it swims actively to the anode as long as it can voluntarily control its movements. Its nervous system is fully intact. If this voluntary behaviour ceases then the

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swimming movements are transformed into convulsive movements directed towards the anode. The fish body moves in the direction of the anode with each new convulsion. This may be demonstrated using the experimental aquarium described previously. Voltage and amperes are measured by the appropriate instruments from which the current density in the water can be calculated. (See the experiments on page 49).

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(a) A fish is placed in the aquarium and allowed 35 to 40 minutes to attain the relaxed state. After this time the current is turned on. Current is gradually increased from 0 upwards by means of a potentiometer until it swims towards the anode. A current density of 1.4 δ (approx.) is required for a 10cm. long trout. This value is recorded.

(b) A fish is decapitated and then placed in the field of the electric current. At the level recorded in (a) the fish display a consecutive series of convulsions which leads it gradually to the positive pole.

(c) The lateral line is severed with a scalpel and the fish is again subjected to the electric current. At the required setting of the potentiometer the fish moves toward the anode.

(d) The spinal cord is destroyed by pithing and the fish subsequently exposed to the electric current. After this treatment no movement to the anode occurs.

All operations are performed under narcosis (urethane). Reactions for each treatment are compared and the corresponding current densities are recorded.

Scheminsky determined the stage in embryonal development of trout at which galvanotaxis first occurred. While no such response was displayed at 28 days, convulsions were observed when the current was turned off and on. Embryos, 35 days, however, did display a definite

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galvanotaxis.

2.9 Repelling and Blocking Action of the Electric Current.

The electric current exerts not only a narcotizing and attractive influence, but also may repel fish.

The repelling effect occurs:

1. In the vicinity of the cathode and at the fringes of the field when pulsed current is used.
2. When pulsed current is used.
 - (a) i.e. a certain pulse form (Fig. 27)
 - (b) in the application of a pulse duration which is shorter than that necessary to elicit electro taxis.
 - (c) when the frequency of pulses used is less than the normal threshold required for catching fish - for example in trout 50 pulses per second are necessary to catch the fish but only 30-50 per minute to repel them. For some other common species the figures are: carp 30-40 per second (catching) 20 per minute (repulsion); eel 30-40 per second (catching) 15 per minute (repulsion).

The repelling, or, in other words the blocking effect may be explained in the following manner:

The current density in the periphery of the direct current field lies below that required for galvanotaxis or galvanonarcosis. The fish in this region "taps off" a voltage which is below the body voltage necessary for both of these. When pulsed current is used and the pulse duration is shorter than that required to elicit the directed movement of the fish the fish are not attracted to the anode. The fish perceives the electrical stimulus and withdraws from the influence of the electric field. If the pulse frequency is less than that utilized in catching, the fish, after it has sensed the first single pulse with the aid of

* "taps off" is jargon used in electronics where it refers to the voltage delivered by a variable resistor.

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its nervous system and responded by turning toward the anode, has time to swim out of the effective field during the interval between pulses.

2.10 Influence of Electrical Field on Fish in Seawater

Fish may also be influenced by electrical field in the ocean. While the reactions are the same as those in freshwater the body voltage is greater. This is a consequence of the conductivity of the fish being less than the surrounding water. The fish compresses the surrounding equipotential lines and, as a result the current density in its immediate vicinity is greater than that of the surrounding water. The fish "taps off" a higher voltage than that corresponding to its length and the average current density corresponds to that shown in figure 28.

The relationship existing when the fish is surrounded by an equivalent solution (specific conductivity of fish and solution are the same) and that where the solution conductivity is less is shown in figures 29 and 30.

Seawater on the average is about 500 times more conductive than freshwater. This means that when direct current and the appropriate electrodes are used in the ocean a field strength 500 times as great is necessary to maintain the desired field. When pulsed current is utilized, however, the situation is not as unfavourable. Marine fish because of their size tap off a large voltage and the low resistivity of seawater make possible, with special electrodes the application of pulses of short duration - an arrangement which saves considerable power.

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In order that an effective catching effect exists at a distance of R from the electrode the current density must be such that the body voltage for electrotaxis (G) for a fish of body length (G) is produced. The current (I) in the immediate vicinity of the fish may be calculated from fish length L , body voltage G and the specific resistance of the water so that the fish will display the desired reactions. A simple algebraic formula derived from the expression for the area of a sphere has been developed by C. Kreutzer for fish in seawater.

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The propagation of the current is in the form of a sphere in both salt and freshwater.

Figure 31. The formula which can be used to calculate the effective zone of electrofishing in sea water (from Kreutzer)

$$R = \frac{1 \cdot L \cdot K_1}{G \cdot 4 \cdot \pi}$$

where R is the effective zone (distance from the electrode in m.)
I current density in the water (amperes)
L length of the fish in m.
G body voltage in volts
 K_1 specific resistance of seawater (0.3 ohms . m)

5.1) Because of the high conductivity of seawater it is not possible to work with alternating or direct current in this medium. It would be necessary to have an electrical power of about 10,000 kw to catch herring in a "shocking region" consisting of a sphere. (Fig.31) One must use, in such a situation, pulses of short duration (similar to the technique employed to electric fishes.) Leduc in his time employed square wave pulses at a frequency of 100 per second. Each pulse lasted one millisecond and was followed by a pause of nine milliseconds. If the body voltage is determined using this kind of current the value obtained to elicit a response is essentially lower than that corresponding to simple direct current. The peak voltage however of this current is 1.5 to 2.5 as high as that required with pure direct current.

Devices to generate square wave pulses are not commercially available and it is necessary to utilize gear in which condensor discharges are produced. The impulses are controlled by transistors and thyristors. Condensor discharges consisting of a sudden increase in voltage followed by a gradual decay are especially very physiologically effective for fish.

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2.1.1 Threshold pulse frequencies of fish

A measure of the efficiency of a pulsed current is the number of pulses produced per unit time. The minimum pulse frequencies necessary to supply the minimum current to stun freshwater and marine fish depends not only on the species but also on the size of the fish.

Although pulse frequencies greater than the minimum frequency for stunning can immobilize fish in a region surrounding the anode, frequencies less than the threshold influence fish within an area 20% greater. ~~These~~ *can* *reach* *to the anode* *fish swim closer* and are stunned in the immediate vicinity of the anode. At these low frequencies the electrical current is about one half less than that delivered at the optimum frequency.

This fact is significant for electrofishing. Because of the great variability in the responses of various species to different frequencies and the existence of a threshold frequency it is theoretically possible to selectively fish on the basis of species and size.

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In practice, by setting the corresponding pulse frequency you can selectively fish not only a certain species but also a given size range in this species. Such electro-fishing gear is effective provided that, in addition to the pulse duration, the frequency can be smoothly and continuously varied. It has been demonstrated that at a given frequency all fish species and size show a good response (electro-taxis). Selectivity is achieved only when the desired species or size can be removed from the water. As a consequence the gear is uncomplicated for the fisherman to use since ⁱⁿ the small, battery operated devices the pulse duration may be simply set. In large electrofishing gear the pulse duration is itself affected by the resistivity of the water.

The fact that the threshold stunning frequency is dependent on the size of the animal may be explained in the following manner: (Fig.32). Each individual pulse elicits a convulsion in the muscles. If the pulse which follows arrives before the mechanical movement caused by the first has been completed the muscle is continually stimulated and maintained in a state of cramp.

Table 5 Threshold stunning frequencies for some freshwater fishes.

Water temperature 15°C		
Name of the fish and average length in cm	Voltage required for electronarcosis of single pulses volts	Threshold stunning freq. (Condensor discharge of form D.)
according to Halsband (determined in an experimental bath 35 x 22 x 22 cm.)		

Fig. 32. Relationship between electrical stimulation and mechanical movement for small (A) and large (B) fish. (From Kreutzer: explanation in text).

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Table 6: Threshold stunning frequencies for some marine fishes.

Water temperature 15°C (determined in the same bath as in Table 5)		
Species and average weight.	Voltage required for electronarcosis (single pulses)	Threshold stunning frequency

Muscle movement in large fish is slower than those in small since a large muscle mass must be set in motion. Also in large fish a less rapid sequence of impulses is necessary than that required to elicit a cramp in small fish. If the impulses are not supplied at or beyond the threshold stunning frequency, then voltage and amperes must be increased in order to attain the desired effect.

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Small fish may also be electrically stunned with low frequency pulses. The pulse duration, however, must be longer and the voltage higher. This would appear to be a step in the wrong direction away from the minimum expenditure of energy which achieves the required response.

In the experiment which follows the method of determining the threshold stunning voltage in fish is illustrated.

The fish is placed in an aquarium of which the two ends are covered with two congruent electrodes. Electrical current consisting of pulses entering at a rate between 0 and 150 times per second and which can be continuously varied from 0 to 150 times per second, is applied. The pulsed current may be produced by a simple interruptor of the type developed by

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(62)

LeDuc. (Fig.10). Such an apparatus delivers square waves. Condensers can also serve to produce pulses of the shape resulting from condensor discharges (Figs. 33 and 34).

Direct current from a battery is applied via two terminals to a switch (S) the axis of which is driven by a motor (M) supplied with current from the same battery. ^{ery. (30)} The speed of rotation of the motor is controlled by a potentiometer. A number of condensers are charged in parallel across the switch and discharged in series. By this means the charges of the individual condensers can be added together so that, from a two volt battery twelve volts can be built up. The output may be changed by altering the number of condensers. By changing speed of rotation of the motor it is possible to vary the number of condenser ^{or} discharges per second and accordingly the pulse rate.

The switch employed in the experiment described consists of a rotatable round axis which comes in contact with a brush ^(St) for charging the condensor and with a separate brush ^{(Br) X} for discharging. When the axis is rotated the outside makes contact (K) ~~with the~~

↓
~~see contact~~
brushes

X which are interrupted by isolating brushes (75)

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Figs. 33 and 34 show how the switch works. The position of the switch is shown as the condensers are being discharged. All the condensers are in parallel. The contacts (K) are touching positive and negative conducting tracks (St) of the axis which, in this position is supplied by the battery. After all of the condensers have been ~~dis~~charged the contacts separate from the conducting ~~tracks~~^{tracks} and after a brief interruption come in contact with another set of tracks on the axis (Br).

2.1.2 The relationship between the intensity and the time of application of an electrical stimulus.

In order to elicit a response in an isolated nerve the current must not only be of a minimum strength but also of a minimum duration. The minimum current intensity required to evoke a response is known as the rheobase and the minimum time over which it must act is called the useful time. The useful time is a characteristic measure for all excitable objects. The concept "useful time" implies that only a small segment of the time over which a stimulus acts is utilized and further exposure produces no additional effect. If electrical energy is to be conserved in electrofishing and the most efficient technique practised, then the length of this time segment must be determined for each species of fish.

516 In neurophysiology-chronaxie, the concept coined by Lapique, is double the ^{rh/}rheobase. For every current intensity (or voltage) there is a minimum time of application necessary to elicit a response. When these two values are plotted against each other a curve is obtained which approximates a hyperbola. (Fig.35). It may be deduced from this curve that the required voltage becomes less with increasing time of application until a certain threshold value is reached at which there is no change in voltage as the time is increased. The so-called stimulation time-voltage curve continues linearly beyond a certain point. The most economical input of energy occurs at the bend (or elbow) of the hyperbola. At this point the relationship between voltage and corresponding stimulation time is most favourable in producing an electrical stimulus. This value is analogous to chronaxie.

From a biological standpoint, chronaxie is considered to be the most economical stimulus.

The following experiment explains the relationship between intensity and the duration of an electrical stimulus.

A fish is placed in a rectangular aquarium and pulsed currents are applied to the electrodes which cover the broad sides. The electrical impulses are generated by means of a thyatron stimulator. A thyatron has the property to conduct current only when the voltage attains a certain value (ignition voltage). If a thyatron is connected in parallel to a condensor and a voltage is applied which exceeds the ignition voltage, the condensor discharges at a certain rate depending upon its resistance and capacity.

Fig. 37. Schematic diagram of a thyatron stimulator (from Halsband and Ploeger)

As soon as its voltage reaches the ignition voltage of the thyatron the condensor is short circuited and discharged. The discharge proceeds only to that voltage at which the thyatron ceases to conduct current; the condensor begins to become recharged. The process is repeated with the voltage in the system fluctuating between ignition and discharge voltages of the thyatron. Frequency of the cycle depends on the time constant of the system as well as the ignition and discharge voltage, which is dependent from the resistance and the capacity.

The thyatron stimulator used in the experiment can also be connected to the house current which must first pass through a rectifier. Several condensers are wired in parallel to the thyatrons and these may be activated at will through a multi-poled switch. The discharge circuit includes a protective resistance as well as a rheostat. A step-up transformer serves to increase the voltage of the pulses generated. A potentiometer connected between the transformer and the object to be stimulated allows precise regulation of the stimulus voltage. Frequency can be controlled approximately by the choice of condensers or more finely through the potentiometer already in the circuit. Pulse shapes can be traced on the screen of an oscilloscope. Fig. 37 shows the schematic diagram.

The time constant of the pulse is calculated from the product of the

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"useful time" and chronaxie are closely related to the speed of conduction of a nerve - the greater the speed the smaller is the useful time (i.e. chronaxie). Under constant conditions the speed of nerve conduction among individuals of an animal species is the same (i.e. species - constant). It varies, however, with temperature in the same individual. The fibres of various nerves in an animal, however, have different speeds of conduction and chronaxies which according to Lapique and Legendre depends on the diameter of the fibre.

Research of C. Kreutzer and E. Halsband indicates that relations derived from a single nerve may be applied to the whole animal. Experiments using pulsed current show that the shorter the pulse duration the higher is the voltage required to elicit a response. E. Halsband plotted voltages and "useful times" from experiments. Using carp and trout curves were obtained resembling the well known curve of neurophysiology. (See fig. 36).

Fig. 36. Stimulation time-voltage curve obtained using Salmo gairdneri (from Halsband) G = Base voltage; Lm = minimum power; Et = electrotaxis; En = electronarcosis; Volt/cm voltage per cm; ~~R.C.O.~~ ³² = time of a condensor discharge
R. C. O. 37%

In general, times and voltages in the whole animal do not agree with those obtained with an isolated nerve. A point of minimum energy use was obtained. This point, unlike that of the curve resulting from an isolated nerve lies, not at the exact corner of the hyperbola, but slightly above on the ascending limb. The points of the most efficient use of energy should be determined for each species in order to conduct electrofishing operations most economically (especially in the ocean).

According to these studies the half time values of a single pulse (condensor discharge) should not fall below 1 millisecond. Recent experiments of C. Kreutzer, Kuroki and Halsband show, however, that this duration can be shorter. For example 0.2 - 0.3 milliseconds are adequate for a trout. The half time value is the average time over which the current is applied or time constant for a discharging condensor. This is equivalent to the pulse duration of rectangular pulses multiplied by 0.37.

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capacitance μF and total resistance of the circuit $M\Omega$, i.e. $s(\text{secs}) = C.R.$. The number of pulses per second may be measured by a frequency meter and is adjusted to 50 pulses per second. Voltages across the condensor during the experiment are measured and are given as the so-called field strength in volts per cm.

For a maximum half-value time (impulse of 2ms. duration) that threshold voltage which evokes a convulsion in the animal is determined - a value corresponding to the basic voltage. ~~Then at this voltage condensers are~~

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When fish are acclimated to a solution ($MgCl_2$, salt mixture) of substances which depresses metabolism, threshold values for the first reaction and galvanotaxis are significantly increased. The current density, however, required for galvanonarcosis is decreased. If the level of metabolism of the trout is increased, (by KCl) thresholds which elicit the first two reactions are decreased. A higher threshold is necessary to induce narcosis. Active fish having a higher metabolic rate are therefore easier to stimulate by electricity than less active individuals having a lower metabolic rate. They display, on the other hand, a greater resistance to narcosis than the latter. There is a differential threshold of narcosis - fish having a high metabolic rate display a higher threshold than those of a lower rate (Figs. 39, 40).

Fig. 39 Thresholds of narcosis for trout having different metabolic rates
(explanation in text according to Halsband)

~~captions~~ - trout acclimated to a salt mixture

- normal trout

- trout acclimated to a 400 mg/litre KCl

δ = current density

The physiological condition of a fish is therefore very important in determining its reaction to the electric current.

The influence of the intensity of metabolism on the response to electrical currents is illustrated by the following experiment.

For this experiment the following are required:

1. An aquarium with well-aerated water.
2. An aquarium containing a solution of $MgCl_2 \cdot 6H_2O$ ($20 \cdot 10^3$ mg/l.)
3. An aquarium containing a KCl solution (400 mg/l.)

Two experimental fish are placed in each aquarium for 36 hours for acclimation. After this the fish are tested in an aquarium having two electrodes congruent to the ends and filled three quarters full with normal water. (See Fig. 20 for the electrical circuit.) Water temperatures must be kept constant. Fish are allowed several minutes in the aquarium to become calm and the electrical current applied. (See the experiment on page 51).

A comparison of the threshold currents required to elicit the individual reactions (first reaction, electrotaxis and electronarcosis) of various acclimated fish is shown. (See also Fig. 40).

Fig. 40 The threshold for narcosis for trout and carp (from E. Halsband, explanation in the test). Current densities in δ .

2.1.4 Uptake and distribution of electric current in the body of an animal in relation to the resistance of the organism.

It has already been shown on page 69 that only a certain proportion of the current flowing through water (dependant upon conductivity as it controls current density) flows through the body of a fish and only this is available to provide stimulation. When conductivity of fish and water are identical, the fish is in an "equivalent bath" and lines of current flow, without bending, through the fishes' body. In such an instance, the stimulatory effect is small. When conductivity of surrounding water is less than the fishes' body, as it is in freshwater, the great proportion of current lines flow through the fish since it is more conductive than the water. In this case the stimulatory effect is great. In sea water which is more conductive than the fish, only a small portion of the lines of current pass through the fish, the greater amount flowing through the surrounding water, i.e., the lines pass around the fish. In this situation stimulation is small. This fact is very important in electrofishing since it explains why fish are more difficult to stimulate in sea water than in freshwater.

In general the catching effectiveness is greater in water when the electric current flows through a large school since the school, so to say, acts like a large conductive body tapping off a high voltage.

The difference ⁱⁿ ~~that~~ the passage of current through the fish body in sea - and freshwater has been demonstrated in experiments conducted by Scheminzky, working in 1932 on Chinese ~~mitten~~ crabs. In fresh water 81% of the total current flows through the crabs, whereas in seawater the proportion is only 1%.

In order to elicit a desired reaction (i.e. electrotaxis) in the fishes' body, a certain current density is required. This is smaller

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under the same conditions in the equivalent bath than in freshwater and greater than that in seawater. The proportion of current diverted into the fishes body in seawater, ^{= 100% in} freshwater, ^{= 5%} and the equivalent bath ^{= 10%} are ~~100%~~, ~~5%~~ and ~~10%~~ respectively.

The resistance encountered by the electrical current in the fishes body is dependent not only upon the conductivity of the external medium, but also upon the size of the fish, the nature of the surface and the consistency of the body. The current density in the body ^{de} increases with the dimensions of the experimental bath. Under similar conditions the current density in the body of a fish of large surface area is essentially greater than that of a fish having a smaller surface area. Therefore, to elicit a certain effect in a fish of a small surface a correspondingly higher current density must be applied. The condition of the skin in general depresses the internal current density in the body and this is in proportion to the resistivity of the body covering. Trout for example, which have a slimy coating and a thin coat of scales require much less current than Thunas which have a thick body covering.

Not only is the surface of the fish important, but the ^{Cartilage} make up of the body consisting of various cell types ^{cartilage} and bone which offer different resistances. In electrofishing we are interested not only in the resistivity of body parts but of the whole body.

Several methods to measure resistivity are available. Two probes may be inserted into the fish, and the fish is placed on a Wheatstone bridge. One must be careful whether the fish is in or out of water. The following errors can arise in these methods:

When the conductivity of a marine fish is being determined, the moist surface or the surrounding medium has a conductivity greater than the fishes body. As a result, most of the current in seeking the path of least resistance will travel predominantly over the surface and through the more conductive medium; the total resistance measured will be substantially changed. This plays no role when the fish is investigated in the equivalent bath, since line currents pass directly through the fish without being warped by the surrounding solution. When measured out of water, air errors may arise more or less by varying degrees of moistness of the skin.

664 710 57
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Fig. 41 Schematic diagram explaining how the ^{resistance} resistance of a fish is measured.

U = source of voltage 0.5 volts

V = voltmeter

F = fish tube with electrodes

P = potentiometer

O = oscilloscope with Y_1 and Y_2

M = ~~"Massanschluss"~~ (opposite potential C by using an oscilloscope
connection to mass which works with batteries)

Halsband determined the resistance of fish using the arrangement shown in Fig. 41, and in this arrangement, resistance was measured by comparing a voltage drop - i.e., the resistance between the two electrodes determines the drop in the applied voltage (0.5V), which is adjusted to the voltage drop produced by the potentiometer. The resistance across the potentiometer is, under these conditions, identical to that lying between the two electrodes. Frequency of the alternating current uses changes between 50 ^{Hz} and ^{and 4 Hz} 100 ~~Hz~~. No essential difference in resistance values is found when the two frequencies are used.

S85

Next the resistance between the two electrodes when the tube contains fish and water is determined. Simultaneously, the increase in current flowing through the tube containing water and fish is determined with an oscilloscope at a constant voltage of 0.5 volts. This is compared with the current intensity when the tube is filled with water alone. Length, thickness and breadth of the fish are then recorded.

The same determination of resistance and current are subsequently carried on the experimental tube without the fish. The resistance of the fish is calculated by the following means: The fish is assumed to be a parallel elliptical body. The formula for the surface area of an ellipse is $\frac{\pi}{4} D \cdot B$ is adjusted accordingly for the shape of each species, and a factor computed based on the mean thickness and breadth. Conversion factors are shown in the following table.

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<u>Species</u>	<u>Breadth (B)</u>	<u>Thickness (D)</u>
Trout	0.80	0.86
Bass	0.81	0.89
Carp	0.84	0.89
Redeye	0.82	0.87

The ascertained breadth and thickness of the fish are multiplied by these constants before their insertion in the ellipse formula; the values thus obtained are designated as F_F (the surface area of the fish). The water surface in contact with the electrodes - F_W - consists then, of the total surface area of the electrodes $r^2 \pi$ less F_F . The entire surface area of the electrodes F_{ges} . consists of the surface area of the fish and the water boundary in contact with the electrode F_W .

In calculating the resistance of the fish it is assumed that the total resistance lying between the electrodes (R_{ges}) is made up of two parallel resistances $R_W + R_F$. We consider R_{ges} . to consist of two branches of the circuit the ends which have a voltage U .

Fig. 42 Explanation in Text

A current I_{ges} . flows into the junction point and this is distributed in the two branches as I_W and I_F . (Fig. 42).

According to the first of Kirchoff's laws R_W (a series of equations) may be computed now from the length of the fish L (separation of the electrodes) divided by the surface area of the water F_W , the specific resistance of the water.

$$R_W = \frac{L}{F_W} \cdot \rho \cdot W$$

R_F the resistance of the fishes body may be computed by re-arranging the above formula accordingly;

$$R_W - R_{ges} = \frac{R_{ges} \cdot R_W}{R_F} \quad \text{or} \quad R_F = \frac{R_W \cdot R_{ges}}{R_W - R_{ges}}$$

In order to calculate the specific resistance from the measured resistance values, ~~there~~^{their} values must be multiplied by a factor consisting of the surface area of the fish (surface of the fish respectively the surface area of the electrodes immersed in the water) divided by the separation

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(length of the fish and separation of the electrodes respectively).

It follows that:

$$S^W = \frac{F_W}{L} \times \text{measured resistance fish without}$$

$$S^F = \frac{F_F}{L} \times R_F \text{ (computed resistance of the fish)}$$

S87

In determining the resistivity of fish muscle 0.5 cm thick sections are removed from the dorsal musculature. The length of the strips should be about 7 cm. To prevent the narrow strips from folding back on themselves i.e., when pressed by the electrodes and, to also avoid the piece from drying out during the determination, the strips are placed in a trough made of paraffin which has a width of 5 cm and thick walls. The edges of the trough are marked out in centimeters so that the length of the strip can be recorded. On the outer surfaces of the muscle strip, platinum electrodes having a surface area of 0.5 cm^2 are attached and resistance is determined using the method described above.

The resistance determination is based again on measurements employing comparative voltage drops. The resistance indicated by the potentiometer is then identical to that of the muscle. The resistance may be measured directly using a type of Wheatstone bridge and the resistance found multiplied by $\frac{\text{Area of the electrodes}}{\text{Separation of the electrodes}}$

to obtain the specific resistance ρ (ro)

2.15 How the electrical influence of the field on the fish depends on the conductivity of the water.

The effect of the electrical field is profoundly dependent upon the conductivity of the surrounding water. Conductivity of natural water is due to the ionization of the dissolved salts they contain (electrical charged particles; see page 58). Conductivity depends on the concentration of these ions as well as temperature - the higher the temperature and concentration of ions is, greater than the conductivity.

The conductivity, or inversely resistivity of natural water can be very variable. Distilled rainwater, for example, has a resistivity of 5×10^7 ohms per cm. Spring water may have resistivities in the range $10^4 - 10^5$ ohms cms., brook or river water - $1 \times 10^2 - 5 \times 10^4$ and polluted

95 73 62

river waters 100 to 500 ohm cms. Sea or brackish water has a resistivity of 1 to 10 ohm cms.

S88

Table 7

Resistivities of various media (from results of Denzer, Halsband and Hoesl).

1. distilled rainwater
2. precambrian rocks
3. rock salt, anhydrous
4. crystalline rocks
5. sandstone
6. water from various springs
7. water from various brooks and rivers
8. chalk, gypsum
9. slate
10. clay - sand
11. loess - loam
12. ^{Grain} bituminous coal
13. sandy clay tones
14. sand, gravel and freshwater
15. sand, gravel with brackish water
16. sand gravel with seawater
17. clay
18. polluted river water
19. silt
20. salt water
21. steel.

The conductivity of our inland waters lies between 500 and 10,000 ohm cm. There are waters, however, which are out of this range. Water, for example, sampled from a moat near Wilhelmshaven had a resistivity of 41 ohm. cm. This moat had no connection with the ocean but received its high concentration of ions from salty groundwater.

Often the conductivity of natural waters has related to the landscape. In northern Sweden water resistivities of 10-20,000 ohm cm. are found in Switzerland 3000 - 12,500 ohm. cm and in Holland even values of 25 ohm. cm. This last value is a result of a proximity to the sea causing salty groundwater. (Similar to the moat near Wilhemshaven).

Even in limited geographic areas ionic relations can change. Waters of the swiss cantons - Wallis and Tessin are especially soft and have a resistivity of 12,500 ohm. cm. Water in mid-Switzerland, in contrast (Lake Geneva, Lake Zurich) has a resistivity of only 3000 ohm. cm. (Note: the specific resistance (ohm x cm) is the resistance of a cube -(1 x 1 x 1 cm).

S89

Table 8 Resistivity (Ohm. cm) of some foreign and german waters (from results of various authors)

S90

In the same body of water variations of conductivity may occur within a short period of time due to pollution, temperature changes and the effects of thaw etc. intensive changes of conductivity of

(96) 143

The electrofisherman should realize that electric fields in waters lying in geological formations of the first group remain essential within the water itself. In waters of the second group the electrical field extends partially into the bottom. ~~The electrical field in waters of the third group is more or less equally distributed between both media.~~ The possibilities of electroshocking are therefore much better in waters of the first group than those of the second or even in those of the third. In summary it may be said, that to best influence fish with electricity a good to average conductivity in conjunction with a poor conductivity of the bottom and surrounding banks is required.

Water conductivity can be measured with an instrument manufactured by the cooperative ^{fishing association} electrofishing association in Hamburg working in conjunction with the Institute for coastal and inland fisheries.

The Wawista apparatus (water resistance device) functions with transistors based on the principle of the Wheatstone bridge. The measuring electrode consists of 1 cm^2 platinum plates separated from each other by a distance of 1 cm. and which are imbedded in a plastic casing. Resistivities in the range 0.1 to 100.000 ohm cm. can be measured.

2.1.6. Electrical resistivity of water is not always a measure of electrofishing efficiency.

Lauer maintains that the customary method of determining water conductivity is not necessary a reliable method of predicting electrofishing success. Cases may occur - even if rare - in which fish cannot be caught even with a 3 KW device generating pulses. An example is the river Altmühl in Middle Franconia (Bavaria) which has a resistivity of 1300 Ω cm., and in which it

is impossible to electrofish using anodic attraction. Similar observations may be made in the Amazon region and in the Belgian Brook - ^{Lesse} ~~Levre~~. This brook has the same conductivity values as the Lutter and ^{Hardt/Rhon} ~~Hardt/Rhon~~. However, in contrast to poor fishing success in the ^{Lesse} ~~Levre~~, ^{in the} ~~these streams~~ ^{was got} ~~yield~~ an abundant fish harvest when electrofished.

Within the various types of waters there are conductors of the first and second class, in addition semi-conductors or disturbing conductors or combination of all three geological types. While the first which contains ions and cations are ^{and} ~~in geological conductors~~, besides certain divisions of the geological formations; in addition to Ohm's law other laws apply, laws governing capacitance with the result that ordinary resistance bridges are not applicable.

All portions of liquid, gaseous and solid components of mechanical mixtures belong to geological conductors as well as gas bubbles mineral bodies, associations of minerals which are colloidal suspensions, ground ~~for direct current~~ sediments including layers. This capacitive resistance is a nonconductor ^{and for} ~~of~~ ^{a less good conductor} ~~alternating current~~. The conductivity relation for any body of water will be, moreover, quite complex when ions are absorbed on suspended solids - when conducting ions are bound on carrying substances. In these cases the water under these circumstances would be ion free since they are concentrated on the suspended solids. As absorption media are the following: Al_2O_3 , $CaCO_3$, ^{$S.O_2$} ~~SO_2~~ as gel and polysiluric acid as ^{hydrated silicate} ~~hydrous silicate~~. These take up alkaline ions, ^{humanic} materials have other effects in which Ca and Mg ions are bound. When this kind of absorbing material finds its way into water

become poor,
the ion content may be greatly impoverished - a situation common in south German waters (in Altmühl). In this type of absorption normally clusters of ions (polycations and polyanions) are often formed. In compensation ^{solution} ~~compensation~~ H^+ and OH^- ions are converted to neutral H_2O . The water is, in a way, desalinized. The speed of migration of the ions is ^{so} small as a result of the greater friction with water molecules and as a result normal direct current is not sufficient and ohmic resistance is almost infinite. In contrast the polyions ^{function} ~~function~~ as condensor plates of opposing charge and permit the formation of dielectric displacement currents. These appear to be good conductors when measuring bridges or energized by alternating currents are used. The phenomenon of ion absorption can be a source of error when conductivity is measured with conventional instruments. A ^{run on} ~~convection~~ measurement may indicate that conductivity is satisfactory for electrofishing; ^{but} ~~no~~ success results even when a 2 KW Mofix gear is utilized. No current flows through the water because of ion absorption on ^{chalk} ~~time~~ and humus particles. These ^{coating} ~~function~~ as condensers and respond only to alternating and pulsed current, ^{when also only a little} ~~In these water~~ you cannot anodically fish but pulsed gear must be used which does not produce the desired result in each case.

The chemical composition ^{siding} ~~composition~~ of the water (S80) can alter the intensity of metabolism of a fish and accordingly its behaviour in the electric field.

S93

Often it is observed for example, that a high concentration of potassium ion no anodic effect can be elicited even at the customary voltage and current density. In agreement with this phenomenon is the fact that potassium ion greatly increases the intensity of metabolism and the fish flees the electric field. Conversely the presence of such ions as magnesium or other ions which depress metabolism can enhance the efficiency of catching with the result that

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the fish ^{fall into} ~~succumbs to~~ narcosis at low current densities. Conductivity of waters, it may be seen, ^{fishing} effects electrofishing in a variety of ways.

S. 3

3. Are animals injured when an electric field flows through water?

Often the opinion is given that fish exposed to an electric current undergo injuries, growth inhibition and other harmful effects. Frequently, the view is held that fish eggs, larvae, and prey animals undergo permanent damage. Both view points are erroneous when the results of numerous experiments are considered. At any rate these findings apply to the type of currents used in electrofishing.

The physiological basis of the harmlessness of the electrical current is outlined on page 56. We may draw the following conclusion, the electric current evokes significant change in the metabolism of fish and other aquatic animals. Alternating current exerts the greatest effect, direct current a lesser effect and least in pulsed current, all these processes are reversible. After application of alternating current normal metabolism returns after 120 minutes (Fig.s 22 to 24).

Even Denzer investigated the question of the harmful effects of the electric current and he worked with current intensities far above those used in electrofishing operations in inland waters of normal conductivity. He found that no damage is inflicted on fish when direct current is used, but there is considerable risk when alternating current is utilized.

Denzer in his experiments used small aquaria (33.7 cm long, 21.5 cm breadth and a water depth of 6.5 cm) which at water temperatures of $8-10^{\circ}\text{C}$ he gave brown and rainbow trout, carp, perch, roaches and the very ^{sensitive} ~~sensitive~~ "collas gobio" one after the other. In these aquaria direct current was taken in with a current density of 438. TIL

Denzer tested consecutively at 8-10C, brown and rainbow trout, carp "Schlei" goldfish, minnows and the very sensitive sculpin (*Cottus gobio*)

Direct current was applied for several minutes to the container (60m A corresponding to a current density of 4.38). The current was five times the threshold required to elicit galvanotaxis. All the above fish survived. Only two fish required more than three minutes to revive from the narcosis and the others had recovered within one minute to the extent that no difference in their swimming movements could be detected.

For the current density of about 4g cited above, 4A of current pass through a cross-section of one square centimetre and this in practice corresponds to the field between two electrodes with a voltage of 651 volts across a separation of one metre. If you consider a typical electro-fishing device where ^{where} 2.6 kw. are available and the electrodes are 1 m. apart then it is evident that no harm can come to the fish. In the aquarium unlike the operational situation the fish have no means of fleeing the field and the current was fully applied for one minute. Fish at the electrofishing site are able to escape the influence of the electric field.

Experiments conducted in our institute on various fish species show that with the ordinary, commercially available electrofishing gear producing typical voltages and current densities also reveal no harmful effects. This, it must be emphasized, applies only to direct and pulsed current, not alternating current. In this latter type of current the anodic and escape reaction are obliterated by oscillotaxis - i.e. the fish loses its freedom of movement very quickly and becomes narcotized either in the vicinity of the electrodes or in contact with them. Here they are either killed or receive internal injuries. All this happens at currents half that of the direct current fields mentioned above.

Under consideration for various electrofishing installations in freshwater are the experience and experiments gained using 750 volts direct current and 1000 volts peak value for pulsed currents. With the exception of alternating currents no harmful effects are to be anticipated. In very few cases - for example when the water is very conductive and direct current is used - it can happen that fish which come into direct contact with an electrode suffer internal and external injuries.

Such fish as a rule display vertical dark stripes over their body caused by the breaking of bloodvessels beneath the epidermis. In mitten crabs the

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muscles of the unprotected leg joint are usually broken which results in the animal losing its leg. Other invisible damages may occur which can lead to its death. The muscle contraction can also cause dislocations and fractures of the vertebral column in fish as well as destroying vital organs. These kinds of damage occur only when direct current energized electrodes are kept for a long time in the middle of a school of fish. When pulsed current is used no damage is experienced even when the current is applied for a considerable time (i.e. up to 60 seconds).

Also in permanent installations - up to 10000 volts - no damage to fish will occur. In contrast to fish who respond to an anodic effect, fish which are repelled do not come into close contact with the electrodes since the nature of the electrode arrangement provides a repelling peripheral field.

That the current flow does not cause any stunting of growth or loss of weight is illustrated by an experiment of Kreutzer and Meyer Waarden in 1952. Carp, in their second summer were placed at the beginning of March in wooden "live boxes" (112cm x 53cm x 30^{cm}). The sides of the boxes, made of perforated lead served as electrodes which lay parallel to each other and provided a homogeneous electric field. This was important to ensure that the fish were subjected to a uniform electric field so that all experiments were comparable. The ensure that the same voltage was 'tapped off' by the bodies of the fish, animals of the same size were used (25-30cm). Experiments were conducted with 50 cycle A-C, sure D.C. and pulsed D.C. The exposure to these was varied as summarized below:

- | | | |
|----------------|-----------------------|----------------|
| 1. Experiment | 50 cycle A.C. - 140mA | for 10 seconds |
| 2. Experiment | 50 cycle A.C. - 140mA | for 20 seconds |
| 3. Experiment | 50 cycle A.C. - 80mA | for 30 seconds |
| 4. Pure D.C. | 300mA | for 10 seconds |
| 5. Pure D.C. | 300mA | for 20 seconds |
| 6. pulsed D.C. | 65mA | for 10 seconds |
| 7. pulsed D.C. | 65mA | for 20 seconds |
| 8. pulsed D.C. | 65mA | for 60 seconds |

In order to produce narcosis in the fish almost immediately the current density necessary to elicit this state in a carp of the same size was determined at the beginning of each experiment. Fish were tagged at the end of the test and reared into a pond containing carp which had not been handled.

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They were kept with these until the autumn harvest and the end of 1952 - i.e. until the end of the growing period.

The following table summarizes the results:

Experiment	N	mean length cm.	mean length g.
Exposed to the electric current			
1.....	8		
Not exposed to the electric current			

From these results I conclude that:

1. the carp with respect of their ability to survive were not affected. The loss of the electrically treated fish was the same as the control fish - 10%. This may have been caused by ~~lagging mortality~~ *marking*
2. Increase in growth in both groups was approximately the same. Even ^{when unfertilized} for carp ~~exposed~~ for one half hour there was no difference in growth or survival between the two groups.

Recently it has been assumed that aquatic animals exposed to a prolonged electric current can acclimate or adjust to it. As already mentioned the proportion of fish frightened at a fish ^{barrier} ~~harver~~ after one year in service is still 90% - evidence that fish do not adjust to the field if it is assumed that they avoid the field because of their experience in its fringe. Possibly the fish do have a considerable ability to remember.

Spawners, spawning product (milt and eggs) as well as larvae show no harm when exposed to the electric current provided that the field gradient is typical and contact with the anode is avoided. Fertilized and unfertilized eggs coming in contact with the anode produce a denaturation of globulin, as shown by a softening or cloudy appearance. (Scheminzky and Hauster 1924). Fe. and Fr. Scheminzky found that a minimum current density of 1.34δ ($\delta = 10^{-6}$ A per mm^2) at a water conductivity of 2×10^{-4} Ohm $\times$ cm^{-1} was the threshold at which the globulin denaturation occurs. The person who first attempted to solve this problem under experimental conditions which occur in practical electro-fishing was Riedel. He used for alternating current continuous and uninterrupted direct current. Leduc's current was generated by manually making and breaking the current - two seconds on and three seconds off. Alternating current was supplied from the mains and direct current from electrofishing gear.

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Experiments were conducted in an experimental vessel designed for this purpose. Current densities occurring under field conditions were produced in this vessel. ~~300 volts to ground were used.~~ The effect of direct, alternating and pulsed currents on fertilized and unfertilized eggs were studied as well these effects on the sperm^{or} and fry of pike, roach, bleak and rudd. In the investigations on eggs 20 eggs were placed in the experimental chamber. Riedel made the assumption that the number of eggs played no role since according to Hofer a body with a membrane is ^{not} ~~only~~ ^{influenced} involved. The current was turned on the average between 20 and 30 seconds - i.e. an interval similar to that prevailing in practical electrofishing. Below are the results.

1. Spawning fish of the above species were exposed to the electric current before spawning and fertilized thereafter. The fry which hatched were normal in number and every other respect.
2. Eggs exposed to the electric current before fertilization had the same hatching success as untreated eggs.
3. Fertilized eggs exposed five days after fertilization has the same hatching success as untreated.
4. Sperm, exposed for 30 seconds displayed no differences in quality compared to normal sperm.
5. During embryonic period exposed embryos ^{difference} showed no ~~departure~~ from normal development. The behaviour of the fry was also normal.

The problem of injury to the living organisms eaten by fish has been addressed by Riedel and Denzer. Both came to the conclusion that with the exception of a few insect larva (Agrion), there was no damage provided that voltages greater than those occurring in practice (stated above) were not used. Riedel developed a means of transforming values of voltage gradients around electrofishing devices into those produced in the laboratory. Cathode: 100 x 100 cm; anode: 40 x 40 cm; voltage between the electrodes 300V; Current at a specific resistance of 3053 ohm. centimeters at 12°C; 10A; separation of the electrodes 1000 cm.

These electrical data correspond to my own observations, obtained during four months' experience with 4 kilowatt, direct current equipment. Current density at the anode was calculated to be 10^{-6} A per mm^2 . Area of anode 400 x 400 mm. = 160000 mm^2 ; current strength in 10^{-6} A = 10 mill. 10^{-6} A, Σ = 10 mill. $160000 = 56 \frac{1}{2} (10^{-6} \text{ A per } \text{mm}^2)$ for electrodes facing each other and parallel. The maximum value of $56 \frac{1}{2}$ was measured only in the immediate

the 300 volts, used in practical electro-fishing, were reduced to the area of the experiment - 10 cm

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vicinity of the electrodes. The current density decreased quickly, for only 15 cm away from the electrode it fell to 10%. ^{Reidel} Reidel conducted his experiments in a glass trough of dimension , 40 x 60 x 15mm. Tin foil fixed to the ends served as electrodes. At a water level of 10mm corresponding to a volume of 24 cm³, the voltage was so regulated that 18.4 ^{mA} were recorded; water temperature 12C: ^{U_c} voltage between electrodes ^{U_c} 80V; ^{U_c} specific resistance 3040 ohm cm. The voltage value corresponded^s therefore to that prevailing in a field test for probes separated by 6 cm. Before each experiment the experimental vessel was filled with 23 cm³ of water to which ¹/_{cm³} of plankton-rich lakewater was added. The following animals were tested: mostly cladocera and some copepoda; also animals that fish feed on from the littoral region (mussels, snails, isopods and insect larvae). Exposure time: (only direct current was used) 20 seconds. The exposed animals were observed for about four days after the experiment.

At the international electrofishing congress of the FAO ⁱⁿ Poland (Sept./Oct. 1969) several types of gear from various countries were tested for their ability to harm fish. All were pulsed current devices. Harmful effects investigated were fatigue and mortality. Small cages were constructed in which the fish were placed. (Fig.43). They were 40 x 40cm ^{in order that fish} in size. A movable partition was placed in the middle of the cage. Fish in the front compartment were close to the electrode. The cage was fastened to a measuring stick.

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Fig. 43 For an explanation, see text. (Photo: Archiv.)

Test animals were rainbow trouts of the following sizes:

1. 5-10cm.
2. 10-15cm.
3. 15-20cm.
4. 20-25cm.
5. 25-30cm.

The test was conducted in the following way and may be adapted to any electrofishing gear.

The positive electrode of the electrofishing gear is placed directly in front of the cage and the corresponding cathode is fastened behind the cage. This arrangement ensures that the fish lies directly in the electric field. Fish of a given size range are placed in the cage and, using the movable partition are directed so that they are in front of the anode. If the gear being tested has a high and low voltage range, the highest possible range is

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70-

used. The experimental fish are exposed to the electric field for the following times:

1. 15 seconds 2. 30 seconds 3. 45 seconds 4. 60 seconds

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After this exposure the current is turned off and the time following narcosis for the fish to recover is measured with a stop watch. If the electrofishing gear is functioning well the "recovery time", even when exposed for 60 seconds is no longer than 20 seconds.

If direct current gear is tested it will be found that the time to recover is essentially increased i.e. fish treated in the manner described above for 60 seconds require often minutes before recovering. With direct current gear some fish may even be killed when exposed for more than 30 seconds.

When the results of all these experiments are summarized it is concluded that, under the normal conditions of electrofishing in inland water, no damage is inflicted on either fish, larvae or sex products; nor is the food upon which fish feed harmed. Even at peak voltages of 10000 volts in fixed installation no damage has been recorded.

4. Learning and ability to remember in fish exposed to electrical fields.

Stimuli are received by the sense organs of an animal and the nerve impulse generated pass along sensory nerves to the central nervous system. In response to the stimuli impulses pass along motor nerves to effector organs.

This sequence of events: stimulation of receptors - conduction of impulses to a nerve centre - conduction of the impulse to the effector - the reaction of the effector - is known as a reflex. Between these two, the processes ^{of} ~~back~~ the interior of the organism and the environment is the directed activity of nerves. This involves very ^{complicated} ~~developed, prolonged~~ metabolic processes in which excitation of the nerve bodies leave traces of substances (engram) ~~behind~~ which are again dissipated after a short or long time.

If at the same time or shortly before or after the original stimulus, an additional stimulus (signal stimulus) acts upon the animal, ^{which also excites} an engram ~~is also left behind.~~ ^{And if} these simultaneous (or nearly so) stimuli are repeatedly presented, it may happen that the engram of the original and the signal stimulus will be combined. It can now be observed that the response elicited by the original stimulus will occur when the signal stimulus

Original and signal stimulus can belong to the same ~~category~~ ^{or}

Handwritten marks and signature in the top right corner.

~~is presented.~~ The animal now behaves as if only the original stimulus was received. This process is called 'association' and the treatment of the animal is known as conditioning (dressage).

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The original and signal stimulus may be of the same modality or they also may be different. For example a fish might be subjected to an original optical stimulus (size shape) of a piece of food which causes it to swim around attempting to bite it. In this example the signal stimulus consists of colour or the brightness of the food. The trained fish behaves in such a case in response to the signal stimulus as if it were the original stimulus; i.e. it will react to an object of the same colour and intensity, and will swim around it, snapping, without the original stimulus of size and shape being present.

If the original stimulus is of chemical nature, however, i.e. taste of the food particle, and the signal stimulus is acoustical (a bell rung) the ^{dress}fish will swim towards the accustomed feeding place in the aquarium; ~~the~~ also when l food is not pres ~~food need not be present.~~ ("Pavlov's dog").

In training experiments 'wrong' behaviour in solving the problem is ^{punished} ~~published~~ and 'right' behaviour is rewarded until the animal learns to avoid the wrong and to seek the right behaviour. With fish receiving food is the reward. If the fish displays the desired behaviour it is given a piece of food. Punishment consists of mechanical or electrical shocks. Electric shocks are ~~not~~ a negative experience for the fish in every case which it seeks to avoid. If the pulses of direct current are applied at a certain frequency the fish will be drawn to the anode and will be unable to withdraw from the electrical source. (page 71).

How long the fish remembers an electric shock may be expressed in other words. How long the engram is dissipated from the nerve cells has not yet been thoroughly investigated. HERTER did not find any exact estimate of the duration of this memory. Some of the unpublished observations of KREUTZER may shed some light. With his permission, they are presented here: In a river near Falkenberg (Sweden) a canal 1m wide, 1m deep, an electric barrier extending some 30m in the direction of the flow was tested. Fifty ^{Whitebaites} "weibefische" were planted in this stretch and after a time to recover forced to swim into the electric screen. No fish swam upstream through the electrical barrier. All turned around in spite of the water turbulence and gathered downstream in the canal. The barrier was then turned off and the

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fish school again herded towards the barrier. At that place where the fish had turned around because of the electric barrier, they reversed their movement fleeing once more to the lower reaches of the canal. This occurred even though the electric barrier was not turned on and they were threatened with mechanical blows. An additional 50 'white fish' which had been captured with the original group but kept apart were reunited with the group, ~~They~~ ^{was} ~~were~~ distinguished by fin clipping. Both groups at once joined in a tight school and they were again driven against the turned off barrier. The 'experienced' fish characterized by a nicked caudal fin turned around immediately but the newcomers ^{swam} ~~swam~~ peacefully through the electrode array. The experiment was repeated with the same results. After 48 hours there was no difference in the behaviour of the two groups - the experimental group had forgotten about the presence of the barrier and the electrical shocks it delivered.

In the example cited above the electric impulse would be the original stimulus which elicited flight in the fish and which was associated with an optical stimulus - the signal stimulus consisting of the pattern of electrodes or other characteristics of the vicinity of the barrier. By training, the fish avoided the barrier even when no electric field was present.

When barriers are set up in experimental tanks or in the field, the author has observed that fish schools which have recovered from an electric shock assemble a certain distance away from the electrical field because they have learned to avoid the field. (The time required to learn and forget is not exactly known in fish.

All fish according to our Observations react to the electric field but it sometimes happens that fish swim right through it.

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SOME APPLICATIONS OF ELECTROFISHING

1. Application of the anode effect of the electric current in inland waters.

The anode effect can be used in the management of fish stocks and, on a limited scale, for commercial fishing. Such operations must be confined to small bodies of water, i.e. small canals, ditches or shallow streams which either can not be drained, or for other reasons, are unsuitable for conventional fishing methods.

Operation of electrofishing gear in these types of water bodies for the purposes outlined above offers many possibilities.

- (a) Removal of fish from small brooks prior to the planting of trout fingerlings

In practice the brook is fished out in order to eliminate predators and competing species before restocking. Predatory species comprise all large fish as, for example, trout and pike etc., which eat smaller fish and fish fry consequently threatening the stock of young planted fish. Competing species (which in this instance may be considered fish "weeds") consist of inferior fish such as chub minnows and roach. When these fish occur in great numbers, food is taken away from useful species and thus their growth rate of these latter is decreased.

- (b) The collection of sensitive brood fish which would be injured by other fishing methods or are unable to survive captivity.
- (c) The harvesting of food and commercial fish without harm, which are to be transferred to other bodies of water.
- (d) The capturing of migratory eels from waters in which fishing is difficult.

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- (e) The removal of sick fish, as well as carriers of infections in order to prevent the spread of disease.
- (f) The rapid removal of fish from bodies of water which are either drying up or have been made uninhabitable through construction.
- (g) Determination of the extent of pollution by examining the condition of health of fish populations.
- (h) The investigation of migrating and non-migrating fish species.
Stock taking may be taken for ecological investigations - for example, the species composition of a fish community could be determined for growth relationships.
- (i) The capture of fish for tagging. The number of marked fish recaptured provides information on the proportion of fish which remains in a body of water.
- (j) The removal of superannuated fish or "trash fish" which might be used as food in pond culture.

I would like to stress the implications of point (g) because of the necessity of monitoring the condition of fish in populations has become increasingly important within recent years. Conditions of the environment, the extent of which have not been known for years, compel us to regularly examine the health of fish in natural waters. Nuclear power plants, for example which have been constructed in increasing numbers on the shores of our rivers, remove great quantities of cooling water returning it as warm water to the river. ~~The~~ warming of natural water may influence the biota and consequently these must be regularly sampled. This applies also to other industries which pour waste water containing toxic chemicals into natural waters. Annual variations in

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the quality and quantity of this discharge water should also be recorded.

HOW TO CONDUCT A SAMPLE OF THE POPULATION

At least two years before an industrial plant is set into operation, populations of fish should be sampled yearly at various stations (at least two times during the year) not only downstream, but also upstream of the site of the plant. At these stations each fish which is captured is weighed, the length taken and recorded. The choice of sampling areas should be made by a biologist if he is familiar with the waters. In other situations it is advisable that he choose these stations with the aid of commercial fishermen or anglers. It is necessary to include back waters and harbor slips in this survey. The carrying out of such a population sampling is provided by a reference base - a base which may be used to compare the subsequent effects of the industrial plant on the fish in the sampling area. Naturally in the years following the beginning of the operation of the plant, sampling should be conducted during the same time of years as the preoperation period and the fish examined and recorded.

On the river Weser which has a high electrical conductance from 14.286 micro Siemens to 6,666 micro Siemens (70-150 Ohms-cms), population estimates at over 30 test sites were made several years before a nuclear power plant was put in service. After the plant was placed "on line" surveys were conducted two times a year at the same sites.

HOW TO ESTIMATE THE SIZE OF A POPULATION

The Weser River described above is overloaded with wastewater having

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a high concentration of potassium. Therefore Gammarus tigrinus, a salt tolerant crustacean is present there as nourishment for fish. Transects were fished with 12.5 k VA electrofishing gear as well as Thyristo impulse devices. The Weser is a navigable river and the transects are on the sides of the banks. The outer curves of meanders, backwaters, harbor basins and places which are favoured by fish are mainly fished. It is necessary to have a large enough boat, especially one which is sufficiently long for four to five persons must be stationed behind the electrofisherman. These people must have freedom of movement to collect the fish with dipnets. Also there must be enough room for the workers who weigh, measure and record the sex of the fish. The boat I used was 12 meters long. For exact maneuvering, the sampling vessel, must be towed upstream with a long rope a steersman is positioned to maintain a constant distance from the bank. This is especially necessary when the current is strong.

As already mentioned above, all fish captured in the test reach are weighed, measured and recorded. Any evident, extrenal signs of sickness must be noted and entered into a suitable protocol. This information can often be useful for investigations which are conducted in the future. Stomach contents as well as visible changes in the liver and kidney should also be recorded from time to time.

HOW THE SAMPLE OF FISH IS EVALUATED

The length of individual test transects is known although it may depend on local conditions. In subsequent samplings the identical transect must be used. Fish species are known as well as weights and lengths of the fish collected. The distance between boat and the bank is at most

approximately five meters and it is possible to calculate the area of the cross-section of the transect which can be related to the amount of fish captured. Investigation must be carried out not only in spring but also in autumn. Summer sampling may be a useful additon.

If a sampling program is conducted for at least two years (3 or 4 years would be even better) before the construction of a factory or power station, say, approximately 10 km upstream and 25 km downstream, the impact of the plant can be evaluated. Because of the standarized techniques comparable numbers can be used in the assessment. The numbers are, without a doubt, relative but practical work has shown that the biologist can work with these numbers to arrive at a valid decision. For the sake of completeness it is necessary to mention that separate investigation on the fauna of the areas must also be carried out.

In fast flowing waters or rivers on which there is heavy boat traffic, the techniques of sampling populations is often very difficult if not impossible. In these instances sampling may be done with electric check weirs (see the section entitled combination electrofishing installations with conventional fishing gear in inland waters - page 169).

2. Applications of the Anodic Effects in the Ocean

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While the most important thing in inland waters is the management and enhancement of fish populations, in the sea, the essential activity is to increase the commercial fish harvest. It is not just a matter of capturing more fish than with the conventional gear, but a better quality of fish in greater numbers. It is relatively easy to utilize the anode effect in fresh water, but in sea water is accompanied by considerable

technical problems. Because of the high electrical conductivity of sea water, only very large impulse generators can be used. In light of the present state of electrotechnical development, we consider the following applications of this effect to be possible:

1. Concentration of schooling fish and other sea animals which school near the surface with the purpose of capturing them in an easier and more efficient manner than is possible with traditional gears.
2. Concentration of schooling fish in deeper water or water in which it is very difficult to fish with traditional gear. Fish are attracted by the electrode, and with the aid of light shining down from the upper layers of the water column, so that they can be captured with the conventional gear on the surface of the water. Both methods can be combined with a fish pump.
3. Concentration of schooling fish in front of the opening of a trawl. This method eliminates the repulsive effect of the trawl on the fish in front of the net. An electric trawl can be used in place of a conventional trawl where the fishing ground is unsuitable or otherwise difficult to fish. In such instances, fish swimming on the bottom (example flat fish) are first attracted by the anode in front of the mouth of the net and then captured. It is necessary that the ground net is kept several meters over the bottom so that it does not touch the bottom.
4. Simplified removal of fish already in the net by a fish pump containing an anode on its intake pipe.
5. Removal of fish suitable for market from a school of fish. This idea is based on the principle of "snout-to-tail" voltage in which a minimum

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size of fish is only affected by an electrical field of a given intensity.

3. Application of the Repelling or Frightening Effect in Freshwater

In order to achieve a satisfactory repulsive effect, alternating and pulsed current must be utilized. Direct current is not suitable. Since the strong anodic effect has been shown to be unfavourable for this purpose, the fish should not swim towards the electrode but be repelled or guided towards a designated goal. Even 50 cycles are effective, there is a danger that the muscles of the fish will be paralyzed (tetanus) and that it will be unable to swim away. The most suitable current in this instance is pulsed current. Such a fish repelling installation can be applied in fresh water not only for fishing but also in front of intake canals.

1. The screening of turbine and pump intake may be used to prevent injuries or the death of fish through contact with the blades. The mesh size of the customary metal screens in front of these intakes cannot be arbitrarily decreased otherwise the hydrostatic head of pressure will be reduced from 20 to 5 cm. If the bars of the screen are separated by 2 cm about 20% of the eels swimming through the turbines are dismembered or injured. It is in this instance that electric screens may be of use.
2. Chains of electrodes can replace the leading fences of trap nets.
3. Mobile directing and repelling devices to capture fish from lakes which cannot be drained or are very difficult to fish; the fish can be directed into hoop ntes, pound nets, etc. They may also be

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herded into dug channels. There is considerable demand for this type of device in the Federal Republic of Germany, as well as, in other countries since there are many bodies of water which are unsuitable for fishing with traditional gear.

4. Weirs to guide fish to fish ladders or to attract them to other waters. The attracting current downstream from a fish ladder is usually weaker than that near the turbines; fish during their spawning migration seek the stronger current with the result that many would not use the fish ladder. These fish can be directed to fish ladders and passes by suitably placed chains of suspended electrodes. Young salmon, spawned out salmon and sea trout, moving down stream may be guided by such devices before they reach the lip of the dam into side channels from which they can continue their trip to the ocean. Silver eels during their migration may be guided into impoundments so that they will not be lost to the fishery. This kind of device is frequently found in Sweden where the courses of rivers are frequently altered. Each owner of such an alteration receives support to facilitate the passage of artificially hatched salmon and sea trout fry.

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5. The closing off of areas of water to reduce the up and down stream migration of fish. Such situations arise when:
- (a) Young fish are planted in a region and it is decided to prevent the penetration of predator or larger fish.
 - (b) To prevent the invasion of fish into a section of water which has been fished out.
 - (c) Fish which are kept in a "fish corral" for future planting or for commercial sale.

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(d) Fish, mitten crabs or other aquatic animals (example, muskrats, water rats, etc.) can be prevented from entering culverts or underground drainage canals.

(e) Crocodiles or other animals, dangerous, to man, can be kept away from bathing beaches.

(f) Fish may be herded out of areas of water where explosives are detonated.

In the first two cases (a & b) areas of water can be blocked off, upstream and downstream by electordes suspended by cables. Examples a & b may be used in fish cultured stations where valuable brood stock are to be held for long periods of time. In this manner breeding fish (for example, salmon and sturgeons) which are captured just before spawning are kept until spawning occurs. In this situation you can devise an impoundment with either two chains of hanging electrodes, depending on local conditions (lake, or a reach of a river) or with just one. In example (d) an electrically charged screen is simply placed over the pipe opening. In (e) a chain with suspended electrodes can also be sued. Example (f) has an application when blasting of rocks occur on the bansk of a river.

4. Application of the repelling effect in the ocean

The repelling effect of electric impulse current may be applied in marine fishing. At present, however, there are only a few types of devices in use. It is necessary to decide whether one wishes to employ this effect in coastal waters (fish screens protecting inlake canals or shark barriers) or on the high seas.

In the first case it is not difficult, - some installations are

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already in service and some are planned - since there is an abundant supply of electrical energy on land. On the high seas the required energy must be generated on a ship. Here the repelling system is subject to strong currents, tidal movements and even perhaps siltation. Such devices must be ruggedly built and reliable since unexpected conditions may arise. Like stationary fish - weirs and trap nets electrical repelling chains are only effective where there are concentrations of fish which are migrating and can be diverted into traditional catching gear or into shallow bays. The following applications are possible.

- (i) Tuna (red tuna, for example) which during their spawning migration come close to the coast in great numbers and are captured in large trap nets (called "tornare" in Italian and "almadrabas" in Spanish). By means of an anchored repelling chain of electrodes one can herd these fish into the effective capture area of these traps. The leads of these traps have lengths up to 6 km and depths up to 40 meters. The tuna however, when it encounters unfavourable temperatures swims past the traps and out to sea or else the traps capture only the outliers of a large school. In such situations a correspondingly large chain of electrodes could be effectively used.
- (ii) By means of this type of electrode chain the return route to the ocean of tuna sojourning in Dalmatian bays and inlets, can be cut off. Up to now large wall nets which when a look out from a watch tower spied the tuna school and gave a signal, were dropped into place. In Norway the idea to seal

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page III

off electrically inlets and bays also exists. These bodies can serve as natural holding pensils for fish to be used later.

- (iii) Sharks can also be kept away when they come too close to bathing beaches for example, in Sydney and Newcastle, Australia, up to the present this was attempted by the installation of "net fences" around the bathing area.
- (iv) According to a patent held by C. Kreutzer, fish can be herded together by an electrode chain in the form of a ring. Once the school is surrounded by the ring, they can be readily harvested with a fish pump.
- (v) Fish may be greightened away by electric impulses where underwater dentonation is taking place. For example, several firms were advised to carry this out when they were drilling for oil in Eckernfoerder Bay.

5. Application of the Electric Current in Stunning and Killing of Aquatic Animals

The stunning and killing of animals was first considered to be an undesireable side effect but today a different attitude exists. It has been shown that electrical stunning and killing of aquatic animals can be of use.

- (i) These processes can accelerate and facilitate the capture of commercial fishes, which, for example is the case in electrical angling of tunas. Usually about 50% of the fish which are captured tear themselves loose and are lost to the fisherman. This is not the case when the hooks are electrified. This is

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even so for the catching of red tuna (Thunnus thynnus) practised by German and Danish fishermen in the North Seas, as well as, for juvenile red tuna, and adult white tuna (Germon allonga) on the French Atlantic coast. This technique is also applied in the harpooning of whales. Closing of the

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circuit causes the death of the animal preventing its ripping of the harpoon line to regain its freedom.

ii) Undesireable fish such as predators and competitors of useful fish can be destroyed. Sick and diseased fish (also mitten crabs) can also be killed.

iii) Electricity can also be used to painlessly kill useful fish in keeping with the laws of humane treatment of animals. Recently, for example, eels are killed in industry by pulsed current. Trout farms which are short of work people also use electricity to kill table trout in great numbers for shipping or for fast freezing.¹ Electricity may also be used in small enterprises to kill eels before they are sold. It would be desirable to kill the Tunas which are caught at Almadrabas in the way described above, to prevent the disgusting method now used. Successful experiments were conducted years ago by the firm Dethloff-Electronics.

iv) By means of electrical killing the working procedures of catching and processing of fish can be simplified and speeded up, this results in the reduction of the number of workers needed (examples are found in point 3).

v) Electrical killing results in an improved storage life with respect to quality. Experiments of this type on trout, flounders, tunas, sardines, Baltic cod and other species have been successful.

¹ Earlier fish were killed only by the application of alternating current or direct or pulsed current when these were of the wrong magnitude. Today alternating current is rarely used to catch fish. The fishing industry uses alternating current exclusively to kill fish.

CHAPTER 5

ELECTROFISHING INSTALLATIONS

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In chapter 4 an overview of the various ~~possible~~ applications of the anodic, repelling, narcotizing and lethal effects of the electric current were given. In this chapter the electrotechnical gear and their operation in practical situations will be considered. We have endeavoured to describe the most typical applications of this gear. The commercial sources of the equipment are given for purely scientific and technical considerations.

1. Electrofishing Installation which make use of the Anodic Effect

1.1 Operation in ^{Inland} ~~Surface~~ Waters

1.1.1 Possibilities and Limitations of the Installations

The purchaser of an electrofishing gear is often not sure about the kind of device which is suitable for his purposes and for the kind of water body involved. Not seldom he experiences great considerable annoyance when he tries it out and expresses unjustifiable anger at the firm from which he bought it. In order to explain what can be expected in electrofishing gear it is necessary to discuss ^{their} the nature, economy and ~~their~~ limit, and to clearly indicate to the interested person what he must look for in choosing electrofishing gear.

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Those who have read the chapter on the physiological and physical bases of electrofishing (pp. 22-103) will know that the action of an electro-fishing gear, that is a device using the anodic effect has certain limits not only in fresh but also especially in seawater. In some instances even today with well constructed devices to produce a satisfactory effect. The reason for this is known by every electrofisherman; the water body because of its chemical and physical properties, its shape, and in unusual instances, the geological formation it lies on, displays a wide range of electrical conductivities. In a few cases the fish themselves have an effect. We know, for example, that the effect of the electrical current on fish depends on species, size (or better, surface area) and, not the least, its physiological condition. ^(p. 80) It has been observed in recent years

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that the sensory physiology as well as metabolism of fish has been affected by water pollution. The fish are still attracted to the anode but it is often observed that they react at .80m distance from the electrode or are indolent in their behaviour. The water of the Weser, for example, have a resistivity of 60 ohm cms (16.600 micro ^{Siemens} ~~Siemens~~) because of its high salt content. Toxic amounts of potassium ion are also present.

Further is the consideration that the effect of the electrical current diminishes as the square of the distance from the anode. As a result the effective distance is maximally 6-8m from the electrode even with the most modern gear. Fish beyond this distance will flee from the influence of the electrodes. It is known that a fish must tap off a certain voltage in order that it ^{will} ~~be~~ drawn to the anode; (p.53) at excess voltages it will ^{and fall} fall stunned to the bottom out of reach of the fisherman. Unfavourable conditions exist in very soft waters since the concentration of ions is too low and an insufficient electrical field is produced. The conductivity of bottom and banks may also influence the field.

Stronger — It is certainly possible that the above unfavourable conditions can be overcome by ^(?) ~~stronger~~ ^{sturdy} direct current gear. However, as a rule this is achieved with the presence of several more or less undesirable disadvantages. Oversized gear is heavy and unmanageable so that it ^{only} ~~may be~~ used where the topography is ideal. This gear is moreover expensive and the increased efficiency is offset by higher costs.

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In such instances it is better to use pulsed current. Because of the more physiologically effective action of pulsed current on the fish and ^{since} ~~because~~ each pulse lasts only a fraction of a second, the electrofisherman can ^{operate} ~~go along~~ with a much smaller device than that powered by direct current. To obtain the same effect with direct current you would have ^{to} use apparatus ^{producing} ~~giving out~~ six kilowatts. With pulsed current ^{only} ~~on~~ two kilowatts are necessary. In very conductive water (40-100 Ω ohm cm., i.e., 25000-10000 micro Siemens) a direct current gear of fifteen kilowatts is ^{needed} ~~necessary~~. In contrast, only 4.5 kilowatts of pulse current is sufficient. A spreading out of the effective area of the anode, beyond 8 m is not always attained with pulsing gear. The area of repulsion is essentially greater than in direct current gear. Modern pulsing gear, moreover, have the ^{advantage} ~~advantage~~ that they automatical adapt to water conditions. In earlier types of pulsing gear, pulse duration, pulse frequency and voltage had to be chosen by the proper choice of capacitor which matched water conductivity. These are no longer necessary since the development of ^{thyristors} ~~thyristors~~ (since 1965). Pulsing gear are easy to operate having an "on" and "off switch" and a potentiometer which is carefully adjuste when the electrodes are in the water. All pulsing gear with the exception of 150 watt battery apparatus are provided with volt- and ammeters. By ^V ~~hochfahr~~ the ^{required} ~~necessary~~ pulse duration is set to the prevailing water resistivity. For an average pulsing gear of 10 kg. a maximum current of 37 ~~A~~ ^{Aeff.} can be deliver

It should be mentioned at this point that pulsing gear should only be used in those situations in which water conductivity is too high or too ^{low} ~~small~~. When conductivity is too high (or resistivity too low) the direct current device required would be too powerful. When resistivity is high (conductivity low) the required voltage must exceed 1000 V.

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The highest ~~most reliable~~ voltage for direct current gear is, however, only 750 ~~v~~[✓]g. For portable pulsing gear it is 1000 V and for fixed installations as high as 10,000 V.

To summarize the employment of electrofishing gear with anodic effects, the following may be said: Electrofishing operations involving anodic effects should be used in inland waters on the basis of their economy. Since they are often used in difficult terrain, they should not be larger than a machine which is able to generate 6 kW (ca. 7.5 kVA). When direct current gear is used and conductivity values are in the range 333-1000 micro-Siemens (1000 to 3000 $\Omega \times \text{cm}$) the effective area extends 6-7 m from the anode. At lower conductivities - 200-333 micro-Siemens (3000-5000 $\Omega \times \text{cm}$) the effective area of direct current gear is smaller. This type of gear cannot be used in water of high conductivity 2000-30,000 micro-Siemens (30-500 $\Omega \times \text{cm}$) and pulsing gear must be employed. The required direct current gear would have to generate 25-30 kVA and weigh more than a ton. In both extremes - very low and

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(5115) ← Virtually no direct current gear is manufactured today containing a direct current generator, the power being provided by an alternating current dynamo and rectified. For a given weight this latter arrangement is lighter. The capacity of these devices is expressed by kVA (kilovolts - amperes.) This unit represents the apparent capacity to calculate the true output; you multiply the $\cos \phi$ stated on the nameplate by the apparent output to obtain the effective output. The 7.5 kVA gear of the working group for electro-fishing installations has an alternating current generator having the inscription $\cos \phi = 0.8$ on the nameplate. When you multiply 7 kVA by 0.8 you obtain an effective output of 6.00 kW.

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very high water conductivity pulsing gear has worked extremely well.

What to look for in buying electrofishing gear

1. The apparatus must match the water conditions. Before the purchase the manufacturer must determine the conductivity of the water (send them a sample). The co-operative for electrofishing operations will not sell any electrofishing device before a questionnaire has been filled out and a water sample has been received.
2. The machine must have some means of regulating voltage. The range of this device depends on the conductivity of the water in which it is to be used. In any case it must have a four way switch.
3. The gear must be so constructed that a pulsing device may be connected, if necessary, at no extra cost.
4. It must have the capability, (at no added expense) of energizing an electrified net conductive wire for the fishing of eels or for fishing in gravel pits.
5. It must have as wide of an effective field as possible.
(VDE = German Electrotechnic Commission)
6. It must be built following VDE specifications.
7. The manufacturer must provide a guarantee that the apparatus they suggest is effective in catching fish.

These guidelines are recommended to anyone who intends to buy an electrofishing gear. One final tip - never order any gear if the water conductivity is unknown. Send first a 50-100 ccm water sample to the firm.

1.1.2 Types of Electrofishing Gear

Since the beginning of electrofishing - some 50 years ago - the construction of anodic gear used in inland waters has changed considerably. Kramer's machine (1916) was a traditional generator. ^(alternating current 220V) Such machines were also used by Schönefelder and Schiemenz in their 1916-17 experiments. This device was abandoned for direct current generators when it was found that direct current provided a more effective anodic action.

Dynamos (or generators) convert mechanical work into electrical energy. A dynamo consists of a field magnet, a rotatable armature and electric brushes. Electrical currents are produced by induction; often this current is passed through the winding of the field magnet increasing the magnetism in this coil and the current induced in the armature. This process is repeated until the ^{dynamo attains} ~~dynamo reaches~~ its highest performance. ⁽¹⁹⁶⁷⁾

Using the principle of the dynamo, Werner von Siemens constructed serviceable generators based on the principle that half wave rectified direct current (wave current) produces a better catching effect. Smolian suggested that a generator be used in which flowing direct and alternating current could be obtained by switching over. Fish could be stunned with alternating current and could be drawn to the anode (by direct current) ~~when they awakened.~~ ^{after recovery. recovery}

Since the dynamos of the time were heavy and awkward to transport, battery powered gear was adopted after the war. The simplest, although ^{unwieldy} most ~~unwieldy~~ gear was that of the firm Schweer and Kuckuck, Steinhude, powered by batteries. It consisted of 36 2/3 motorcycle batteries (6V) in series, in two boxes protected by circuit breakers for safety. It could deliver 220V (fig. 50).

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The batteries contained lead plates immersed in dilute sulfuric acid and discharged if possible every two weeks; they were subsequently recharged. Disadvantages include the relatively heavy weight, the high cost of operation and the short life of the gear (replaced every two years). The batteries quickly lost their charge after a few hours which ~~limited~~ ^{confined} the operation to a charging station.

Then appeared the "Eisenwickelsammler" known as the Edison accumulator and filled with 21% potassium hydroxide. This Edison battery is superior to the batteries it replaced in many respects. It contains no acid, is unbreakable and is long-lasting. Also, it is lighter and is not damaged by interruption of the charging schedule. It is inexpensive and a capacity of 30-35 watt hours per kg cell weight.

In general it can be said about the use of batteries that, as a result of their few ampere hours, they can only be used when the water conductivity is favourable since high conductivity exhausts them within a few hours. To compensate for this disadvantage groups of batteries were used in conjunction with a single armature charger, which required a high energy input itself; as a result 12 or 24 v. batteries were quickly discharged. Only for historical reasons have these battery operated devices been mentioned. Those devices called battery-operated gear are exclusively pulsing devices having long operating times and an effective fish catching capability.

Motor driven devices were built by various firms after 1945 consisting of internal combustion motors which drive a generator. Small devices were carried, large ones transported in a two-wheeled wagon. The main advantage

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was the relatively high capacity (1.5 kVA to 20 kVA) which was assured by the availability of fuel. Unlike battery powered gear, they were not limited by the availability of electrical power.

Many of these are in use - numerous variations mostly constructed by private firms. In principle they are the same.

A great step forward in electrofishing was the developing of electro-fishing gear which produced pulses. The ~~physiologicus~~ ^{physiological} effect of pulses has ~~already~~ ^{already} been described (pages 48, 56). It can be said that the effects of pulsed current depends on pulse shape, pulse frequency and pulse duration.

In comparison with continuously flowing direct current, pulse current can ~~produce great~~ ^{elicit pronounced} effects with less expenditure of energy.

The early pulsing gear functioned with devices to interrupt direct current ^{by} a mechanical pulsing system; modern gear are entirely electronic.

1.1.3 Gear used Today

1.1.3.1 ^{Impulse} - Gears powered by batteries

Battery operated gear is used in those situations where it is awkward or impossible to employ a motor driven gear. These include mountain streams, waters with dense growth on the banks and finally for every body of water narrower than 5 m. These devices have the great advantage that they can be easily carried on the back and one can wade with them through the water. Naturally these waters can also be electrofished with motor driven gear, but they are heavy, requiring a long cable. This is specially awkward in bushes or rocky terrain. With battery powered devices you can fish in every brook.

All pulsing gear available on the market (domestic and foreign) are exclusively battery powered which have technically improved in recent years. The following are available on the market:

1. TSY - 150 - battery operated developed by the electrofishing ^{co-operation} ~~co-operation~~ ^{Institute for Coastal and inland Fisheries} in conjunction with the Federal Fisheries Research Institute, ^{at} ~~of~~ ^{of the Feder. Republ. of German}
- Output exceeds 150 watts peak voltage of 530 V and a regulated frequency from 50-100 pulses per second. Pulse form: steep rise followed by a gradual decay (capacitor discharge). This device is the smallest electrofishing gear in the world. It has three settings which are adjusted according to the prevailing water conductivity. The same machine is used by high seas anglers with Tuna fishing hooks - proof that it is possible to fish in waters of high conductivity with satisfactory results. In this instance fish can be killed. This can be attained only with pulses. Fig. 44 shows the catching gear with anode, cathode and battery. The cathode here is floating, consisting

(130) ~~130~~ 1/2
are

of a bamboo stem on which at a distance of 5 cm, ~~the~~ copper cables ~~is~~ ^{fastened} fastened. This kind of cathode has proved itself. You can also use a metal ring ~~fastened~~ on both your rubber boots - "cathode shoes." Fig. 44 shows this arrangement in operation. The electrofisherman carries the battery in a sling on his back.

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Tow hooks are fastened on the front part of the carrying straps of the frame and the ~~pulsing~~ ^{pulsing} gear is ~~hung~~ ^{hung} on these: Total weight - 5 kg.

Fig. 44a - for an explanation see the text.

Fig. 44b - see the text for an explanation.

2. The "Martin-Pecheur" (Eisvogel in German) is a french pulsing gear, ~~developed~~ ^{developed} developed at the hydrobiological station at Biarritz and powered by a cadmium nickel battery (12V, 9Ah). Three ranges of voltage are available - 150V_S, 200V_S, 250V_S. These permit the adjustment of the gear to the prevailing water conductivity.

S 121

X (The following text you find on page 3,

Fig. 45 Battery pulsing gear. DEKKA

text
to
Fig. 45

The DEKKA is another german pulsing device powered by batteries and consists of the principal device, a battery container and various formed electrodes as fish catchers. 12V acidic batteries are used and connected to the principle device by a plug attached to a cable.

~~essential~~ ^{essential}
Below are the ~~important~~ data:

Voltage supplied: 12V=

(12) (13) 13

Text
to
Fig 45

Current supplied	2-7.6 amps.
Output voltage	300, 400, 500 and 600 V.
Power output	72 W/second
Pulses per second	30-80

The gear may use not only in small brooks but also in larger waters up to a depth of 2 m.

X

According to the manufacturer this device has been exclusively developed for trout streams. During an international congress in Poland the author was able to

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Fig. 46 French battery operated pulsing gear

Fig. 47 The gear with the back removed

S 123

demonstrate the effectiveness of this gear. The pulse form is rectangular and pulse frequency can attain a maximum of 400 pulses per second. Weight: 12 kg. Fig. 46 shows this device with the back off. Below may be seen the 10 cadmium - nickel batteries of 1.2V each. Above on the apparatus is the control panel by which current strength and voltage may be adjusted. In Fig. 47 the device is closed. Around catching net is recommended as anode. Cathode consists of a floating metal gauze supplemented by two metal plates fastened on the boots. This cathode is appropriately named the three point cathode.

Knapsack

Developed in Russia,

~~Knapsack~~ electrofishing gear ~~developed in~~ *in this country* Russia this gear is used in fish culture stations and also employed by ichthyologists in checking fish populations. Output consists of pulses 1.5-3.5 kW at a peak voltages of

(13²) (41)

200-800V. Frequencies include 5, 15, 25, 40 and 80 pulses per second.

Fig. 48 An Irish pulsing gear

- S 124
4. The "Brookmaster" - an Irish device powered by a 12V, 90 Amp. hour battery. Output voltage amounts to 350V_s - pulse rate: 30 to 60 pulses per second. Pulse duration varies with the water conductivity ~~is~~ and is about 15 ms. ~~and~~ the pulse form is that of a condensor discharge.
5. "Cybertronic MK XII" likewise an Irish pulsing gear connected to two 6 ~~va~~. batteries (Fig. 48). Output voltage 350V_s. Total weight 10.5 kg. The author has been convinced of the efficiency of this device.
6. An english ~~machine~~ ^{machine} battery pulsing gear have been constructed in England since 1950. (Shown opened up in fig. 49). ^{It is} Connected to a 12V battery having 10 Amp. hours. Batteries are housed in the closed lower half of the box. Peak output voltage: 350 volts, frequency: 20-66 pulses per second and regulated. The machine has also a pulse indicator.

All the battery powered pulsing gear are ~~ruck-rack~~ ^{"ruck sack"} devices. Operation of the gear is simple and the effect on the fish ^{is good.} ~~is good.~~ ~~are harmless~~

Fig. 49 English-battery powered pulsing gear

- S 125
- Fig. 50 shows a battery operated gear manufactured by the firm Schweer and Kuckuk. Because of its great weight and its unwieldyness it is only suited for electrofishing and ~~must be operated~~ ^{is} from a large boat.
-

Fig. 50: Battery gear of the firm Schweer and Kuckuk.

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1.1.3.2. Gasoline and Diesel powered combinations

Devices which use gasoline or diesel powered machines work with either direct or alternating current. If they are powered by alternating current they are used exclusively for the supply of pulsing gear (see the following chapter). The electrofishing co-operative^{on}, the largest organization in Europe in this field produces a number of different sizes of gear under the name "Mofix AS" which may be bought. The output of these devices are 1.5, 2.5, 4.5, 7.5, 12.5, 20.0 and 45.0 kVA.

(113) (134) (116)
a VW industrial motor

The 12.5 kVA device, ~~a VW industrial motor~~ is driven by the 20.0 kVA and the 45.0 kVA by a Hatz-Diesel. The remaining gear may be mass produced and provided with two stroke gasoline motor. Gear from 4.5 kA may be ^{also} supplied with a diesel motor. All gear basically has a range of voltage either 250/500 volts or 300/600 volts. Gear from 7.5 kVA have, in addition, a connection for electric nets. Connections for pulsing gear are available for sizes 4.5 ^{kVA} upwards so that without any additional cost, *the same way* *be used to fish waters with especially high conductivity* the larger members of this series have four ranges of voltage (65, 130, 260, 520 volts); this means that, out of a 20.0 kVA device, a maximum of 200 amperes may be obtained.

Fig. 51 shows a 7.5 kVA device. At the left in the picture is a transmitter with the receiver hanging on a rod so that the collecting current may be radio-controlled. Up to a range of 1 km the collecting current may be controlled without a cable. *may also be used* It ~~is also possible~~ in deep water.

S126 Gear powered from 7.5 kVA upwards have furthermore ^{the possibility} ~~the option of~~ *to be delivered with a 2-wheel -- fixed -- under -- carriage* connecting an electrified net. Connections for pulsing are available for all devices, 4.5 kVA and greater.

S127 Fig. 52: Control panel of the 12.5 kVa catching device.

Fig. 53: 20 kVA catching device.

S128

Fig. 54: English 300 watt direct current gear

Fig. 55: See the text for an explanation

Fig. 53: An ammeter is ^{inserted} ~~inserted~~ for each range of voltage. At the high current output which the device can produce it is not possible to use a voltage selector switch. The change over from one voltage range to another is accomplished only by rearranging the leads.

S129

Gasoline fueled devices are also built in other countries. The Marine Laboratory at Aberdeen constructed a 300 watt direct current device (Fig. 54) which was used in the Scottish Highlands. Another approach has been taken in Poland. A specially designed rectifier converts alternating current into direct current produced by a commercially available generator (Fig. 55).

1.1.3.3. Pulsing gear which can be connected ^{to} a motor system or nets.

The apparatus described in No. 1.1.3.1 although battery gear are also pulsing gear, in this section the large pulsing gear will be described. Pulsed current has made possible, the electrofishing of waters which have a very high conductivity. The Weser having a conductivity of 70 Ω cms can only be fished with this kind of gear. Otherwise a diesel generator of at least 12 kVA must be used and this because of its weight (600 kg) is difficult to transport. For this reason as well as physiological ones, pulsing gear have replaced generators.

Pulsing ^{gear} ~~gear~~ in the Federal Republic of Germany are produced by *the* Co-operative ^{on} for Electrofishing Devices. Various sizes are available. All gears are connected to 220V or 380 alternating three phase current.

(115) 118
(136)

When connection to a generator is necessary the size of the generator determines the output of the pulsing gear. All motor driven catching gear of the co-operative ^{on have} ~~are~~ from 7.5 VA ^{upwards} ~~upwards~~ ~~are~~ accordingly the capability of being drive ^{by} ~~by~~ a generator. In many instances it is even not necessary to have a generator if line current is available. The gear may be powered by this current through an appropriate transformer.

All pulsing gear ^{employs} ~~employs~~ thyristors and may be regulated continuously. Operating pulsing gear is quite simple since each gear contains only one off and on switch, the voltage being set by a potentiometer. Using the potentiometer, the voltage between the immersed electrodes can be increased until the needle of the ammeter shows the required level.

A pulsing gear used for pond culture on the Mosel is shown in Fig. 56. It is powered from the mains (380V). The largest pulsing gear constructed by the co-operative ^{on} ~~was~~ was sent to Australia. It was connected to a 45 kVA diesel generator, and used in sea and brackish water. There the gear was connected to 45 kVA generator and used in brackish or sea water.

S130

Fig. 56: Pulsing Gear

Pulsing gear built in England are also connected to alternating and three phase generators. The pulsing gear "Mark II" (Fig. 57) is connected to an alternating current generator. It delivers a peak voltage of 250V and has the possibility of varying pulse length. In addition to two connections to anodes and one for the cathode, the gear has an on-and-off switch as well as a ^{voltmeter} ~~voltmeter~~.

137 11/6 (12)

Fig. 57: The English Pulsing Gear "Mark II"

S131 In addition to the gear\$mentioned above, there are numerous other devices and also many "home made" ones. As far as we know the construction is similar, ~~and~~ they have not been discussed here. The gear\$ mentioned have been selected since we believe them to be typical. The worth of any type of gear is not indicated by being listed on the test, nor is an omission\$ imply inferior value.

1.1.4 Electrodes, Forms of Electrodes and their Arrangement

S131 Electrodes are important in the functioning of electrode devices and it is useful to consider their suitability, form, size and the materials of which they are made.

The anode (positive pole) can consist of metals such as zinc, copper iron, brass or aluminum. In most cases the anode is formed into a kind of catcher to permit the removal of fish when caught. The author works exclusively, except in waters of high conductivity, with anodes in the form of a catcher constructed from iron rods. The material is inexpensive and is not so susceptible to electrolysis. Soft metals should not be used in highly ~~conductive~~ waters since they are quickly ~~used up~~ *consumed*.

The collector (or catcher) should be constructed according to its mechanical application. The best is a catcher depicted in Fig. 58. In front are two straight, round iron bars parallel to each other, the inner rod is used for the fastening of the catching net. It is possible to remove fish from a stoney ^{*habitats*} or from reeds without damaging the front attachment of the net. The collector is tied to a ^{*polyester*} ~~polyester~~ tube (35-40 m thick) at least 2m in length. The cable is led through the tube and attached to the collector with electrical connectors. ~~When radius controlled the connection of a cable~~

When the catching current is switched by wireless receiver an additional connection of cable at the tube is ^{not} necessary for connecting the current on and off. ~~to central turning on and off the catching current is not necessary.~~

(See Ch. - Electric Fishing in Inland Waters). Any insulating material such as bamboo, wood, etc., may be used for the handle. The form of the catches can have another form for other electrofishing conditions.

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When water conductivity permits (page 87) and the gear is not working at its full capacity, two catching nets may be used. The cathode usually consists of a metal plate or screen. Relative size between anode and cathode should be at least 1:3. Since the size of the electrodes determines the amount of current it is necessary to adjust the area of these to the capacity of the current producer and the conductivity of the water. Avoid making the electrodes too large for the generator since the desired electrical effect will not be attained.

The construction of the cathode is determined by the type of fishing to be carried out. The shape of the cathode is not important, for example, in brooks or small ditches. In fishing in the seedy inshore waters of a pond or from a boat, it has been shown that the side of the boat away from the shore should be provided with a 6 mm thick, steel rope, hanging down at intervals of 5-10 cm. These 'rope electrodes' should be suspended and insulated along the entire side of the boat. Fish which attempt to swim out the field, encounter the repelling effects of this net cathode and turn again into the 'catching anode'. Bands of strap iron placed on the boat's bottom may also be used with the same effect.

It is not always possible to fish in waters of high conductivity with a catcher of normal dimensions. In this case the capacity of the generator must be matched with water conductivity; otherwise the pulsing gear is not suitable.

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(112) a

It must also be mentioned here that, at the beginning of the fishing operation, the level of electric current must be read from the ammeter when the electrodes are immersed. First the device is adjusted to the smallest voltage. If the capacity of the generator permits at the prevailing water conductivity, a higher voltage may then be applied. It is often more advantageous in some locations to employ two anodes at a low voltage rather than one at a higher voltage.

1.2 Use of Gear in the Sea

This chapter has been shortened during the revision of the first edition since it has been shown that financial and material expenses is considerably greater than the commercial advantages. Moreover most readers are interested in fishing in inland waters.

1.2.1 Possibilities and Limitations of the Gear

With the development of anodic functioning devices in the ocean, electric fishing in this medium is of importance under certain conditions. First of all it must be of such a nature that it can be mounted on a fishing boat and to increase significantly the catch of this vessel. There must be a favourable cost-benefit ratio. It must occupy little space since modern vessels require most of their space for the catch and other gear. The electrofishing gear

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[Handwritten signature/initials]

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must be sturdy and offer little wind resistance. Because of waves, especially in salt water, the gear must be easily operated and serviced. It must also fit into the routine work on board to economize on labor and nets.

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To effectively catch fish in sea water - a medium one hundred times as conductive as freshwater - pulsing gear must be used powered by 30 to 30 kW generator on board ship. The gear must conform to the conditions specified by HAIER.

To efficiently employ the electronic pulses it is necessary to affect a large an area of the water as possible to produce a current density sufficient to elicit the anode effect. Dissipation of too much energy in the close proximity of the electrodes must be avoided. According to HAIER this may be achieved in the following ways:

1. Electrodes of large area ^{to avoid} ~~void~~ the "bunching up" of lines of current at the electrodes - a condition arising from ~~occurring~~ small electrodes.
2. The potential at certain points or in certain areas of the electric field may be increased to guide the direction of the lines of current. Auxillary electrodes may thus cause the current to flow in a desired direction.
3. The lines of current flow must be concentrated.

How large the electrodes must be to minimize the uneven concentration of current lines and to, at the same time attain the best dispersion of the lines of force depends on the capacity of the pulsing gear, as well as the shape of the electrodes. The surface of a small rectangular plate is smaller than a perforated plate and larger than the surface of a hollow cylinder having the same outer covering. In the first case the lines of

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occur over the entire surface of the electrode; in the second case only over the surface of the outer surface of the cylinder. The calculated surfaces of various shapes of electrodes are shown on page 44. The types of electrodes used are summarized on page 139.

As already mentioned on page 45, about 60% of the voltage falls in a distance of 2 m from the electrodes. In other words the field is so weak 2m from the electrode that no anodic reaction can be produced in marine fish of average size. To minimize this drop in potential auxilliary electrodes must be inserted at a calculated distance to increase the potential. This makes possible the anodic effect to be elicited at a greater distance from the electrodes (about 4 m and beyond). One must therefore strive to impede the ~~boundless~~ *unbounded* radiation of current out from the electrode as well as the considerable drop voltage in order to minimize the loss of effectiveness in the vicinity of the catching electrode.

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Concerning the [“]bundling[”] of the current the following may be said. From the study of alternating currents it is well known that rapidly changing currents (alternating and pulsed currents) tend to produce counter currents in the medium around the cable carrying current. This effect causes the electrical field to have a preferred direction:

Fig. 59. Bundling of the current through a cable in the form of a loop

Key to symbols; A - when direct current is used.

B - when alternating current is used.

E - electrode K-cable S-ship

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(121)
(132)

1.2.2 Apparatus in use or under development

At present the following gear operating by the anode effect are used in marine fisheries or electrofishing devices.

1. Electrified fish pumps - in combination with traditional encircling nets for the capture of schooling fish.
2. Electrified fish pumps in combination with lights but without nets or any other traditional gear.
3. Electrified trawls for bottom fishes (fish or shrimp), pelagic schools or with bottom trawls on otherwise unfishable grounds.

Electrified fish pumps are used today in encircling nets for menhaden (Fig. 60). This method was developed by Kreutzer and has proved valuable in practice. In addition to the net a pulsing device is required and this is installed on the fishing boat. The pump mounted on the same vessel serves as the anode and is connected to the pulsing gear. The pump described in section 2 (electric pump fishing) has been developed by german companies, the Federal Research Institute for Fishery ^{of the Federal Republic of Germany} working in cooperation with the ~~French~~ ^{French} Fisheries Research Institute. This method differs from that of Kreutzer in that no encircling net is needed. Electrified pumps together with sources of light are only used. Menhaden, and sardines, for instance are first attracted by the light into the vicinity of the pump anode and this accumulation sucked up the pump to the ship.

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Concerning possibility 3. The electric trawl developed by Kreutzer in America, functions according to the following principles. The necessary current strength is produced by a diesel generator and converted into pulses. Output ^{of current} and frequency of pulses may be varied. After its amplitude has been increased by a transformer, the pulse is conducted through a

(123) (143)

- 9 -

coaxial cable with the towing cable of the net. The trawl is pulled a distance of 2000 m behind the ship. Underwater pulse transformers are attached to the trawl which convert the voltage to the level required. In that part of the trawl which forms the mouth four electrodes are evenly distributed (Fig. 61). By switching the primary coils of the transformers consecutively - step-down transformers ensure that the same current flows from each electrode. A homogenous field is thus produced at the mouth of the trawl. The peak current in the water amounts according to the size of the fish, to between 15 and 40 kA. The pulse duration varies from 1.2 to 1.5 ms. The relatively long pulses are necessary because the current at low pulse duration spread out into the surrounding water from the cable which connects them with the transformer.

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Device

Fig. 61: A-~~Device~~ for Fishing with an Electrified Trawl.

- | | |
|-------------------------------|----------------------|
| 1. Diesel motor | 5. Control device |
| 2. Generator | 6. Pulse transformer |
| 3. Electronic pulse generator | 7. Electrode |
| 4. Transformer | 8. Towing cable |
-

In this way the spreading out of the current from the electrodes is achieved. Figure 62 shows the catches from a series of experiments^{t/} with the trawl conducted 60 to 100 m deep off the North American east coast. Accordingly the catching rate of the electric trawl is, on the average 100-500% higher than that of an unmodified trawl. Further it was found that active bottom fish which could swim out of the way of the net were caught to a greater extent with the electric trawl than less active flat fish. In those cases

123 144 (14)

where large schools of fish were encountered, the difference in catch is especially great. This may be that when so many individuals of one species are together attempt to escape the net. Therefore it is not only the result of eliciting the escape reflex but also the coming together of fish of the same and other species when these are concentrated in front of the net.

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S 138

The anodic effect of the electric current excludes two areas of escape. Floating trawl fishing may also be improved by the techniques described above. With an electrified floating trawl not only fish between the surface and the bottom can be caught but also fish from stoney crevices. This last feature represents a substantial improvement of the catching technique than was possible before since fish may now be caught over otherwise unsuitable uneven sea bottoms.

Fig. 62

Comparative catch results of normal and electrified trawls*

*At present these are systematic comparisons of catches under various fishing conditions and trawl types in the German Federal Republic. These have been conducted from the research ship "Walther Herwig" operating out of the Institute for Catching Techniques. (Federal Fisheries Research Institute).

Shrimps are caught electrically in Florida. This is of interest because of the very difficult conditions for fishing presented by coral and sponge growth. Fishing over such a ^{substrate} ~~substrate~~ by traditional methods would damage the nets. Experiments have also shown that, using electrical methods it is even possible to draw shrimps out of their burrows in which they are hiding.

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S 139

Since alternating current has been shown to be more effective than direct current, 60 cycle a.c. is used being sent into the water through brass electrodes. The pulse duration of the alternating current must be shorter than 4 seconds since the duration exerts a greater effect than pulses of longer duration. Experiments show that shrimps which had burrowed into the bottom can be drawn from the bottom from burrows 30-40 cm deep into the effective area of the net. About 87% of the shrimps displayed a positive response when current density was 15 mA per 2.5 square centimeters, the pulse rate five per second and current interrupted in the ratio 1:3. The experiments further showed that this catching effect required relatively little voltage.

Recently shrimps have been electro-fished by Van den Broucke in Holland with considerable success. Experiments were conducted off the Belgian coast in the vicinity of Zeebrugge and Knoche. Van den Broucke used a pulsing generator of 2.5 kVA having a peak voltage of 100 volts at 2 cycles per second.

1.2.3. Electrodes, forms of electrodes and their arrangement

The form and size of electrodes are variable and must be chosen according to the conditions prevailing during fishing. The electric trawl developed by Kreutzer had four pairs equally distributed over the entire opening of the net. An underwater pulse transformer is fastened to the trawl itself which converts the power into the necessary low voltage and high current. By connecting the primary coils of the trans/~~f~~ormers one after the other to the electrodes a homogeneous electrical field over the mouth is achieved, since the same current flows between each pair of electrodes.

In electrified fish pumps the anode is placed on the head of the pump.

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It may be in the form of a funnel to widen the sucking mouth of the device, it may also be in the form of two crossed, bent metal rods, one lying under the other and placed like a crown on the end of the pump - a form chosen by the firm Dethloff Electronics. During experiments off the French coast, Halsband shoved a narrow metal tube into the opening of the pump head. This form was advantageous since it did not ^{hinder} the drawing in of the fish which happen in the other forms. Moreover, the surface opposite the funnel is smaller which lessens the necessary electric output. In all cases the cathode is attached to the side of the ship in the form of a metal plate.

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2 Electrofishing situations using repelling and attracting effects

2.1. Operations in inland waters

2.1.1 Possibilities and limitations of the operation.

Anyone not familiar with the basic laws of electrophysiology might think that aquatic animals are not able to swim through an electric field across a river. As a rule this is the case. Pulses emanating from the electrodes often warn the fish 10-20 metres away and these swim away from the field. There are instances, however, in which aquatic animals (e.g. fish) do not react or cannot react, swimming through a field of increasing intensity or dart through it. The reasons for this

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S 140 fort

behaviour may be several:

1. Fish respond to electric pulses and the shape and frequency of these must be adapted to certain relationships. In most cases fishes of various sizes and shapes are repelled. These factors must be considered when shape and frequency of pulses are adjusted.
2. An important factor is pulse duration. Duration must not be shorter than the time, necessary to elicit escape movements of the fish. The pause between pulses must be long enough to allow the fish, after the pulse has registered by its nervous system, to respond to the electrical lines of force by a counter movement.
3. The speed with which the fish responds to a pulse of current, is not only dependent upon species and size but to other factors. A fish, at a temperature to which it is not acclimated, say undercooling, may have a different metabolic rate, and will react more sluggishly than in its customary temperature range.

An eel having a critical temperature of 9°C, reacts much less to electrical impulses at lower temperatures.

The eel fisherman considers the fish to be running at this temperature.

Indeed as the temperature falls, the eel returns to its winter quarters appearing again around May when temperatures rise above 9°C. We know also that ^{the} eels before sexual maturity and, during the migrations in the sea, ^{is} are effected more by the flow of rivers. It actively migrates and reacts slowly to the electric field in comparison to immature eels (yellow eels) in quest of food.

Because of the steadily increasing need for energy, more power generating plants are being constructed on our rivers. Warm effluents produced by these stations not only effect the living communities of the water, but also

disturb the behaviour of fish during the winter. A fish which displays a low level of responsiveness, especially in winter, will react to a greater degree under the influence of warm temperature. There are far too few results of the behaviour of eels in winter under the changed temperature regime which would provide information.

4. The deterioration of the general state of health of a fish through sickness epidemics and not the least polluted waters proportionally affects the action of electric pulses. We know from the metabolism of a fish (characterized by oxygen consumption, gut temperature, ventilation rate etc.) that it is changed by slight impurities domestic sewage, industrial effluents; artificial fertilizer etc. The well being of the fish may suffer but there are no visible external signs.
5. The velocity of the water in the vicinity of the electrodes should not be greater than 0.3 m. per sec. At greater velocities the fish does not have time to withdraw from the effects of the electric fields into which the current has brought it. Before the fish can move away from the field, it receives a further shock the strength of which increases as it approaches the field. It becomes increasingly difficult to escape the field. The water flow must, if at all possible not be turbulent at least not in the outer fringes of the electrical field. Such water require the fish to expend energy which would be otherwise be used to flee from the field.
6. Finally the effect of the electric field depends on water conductivity. At high conductivity levels (low resistivity) a smaller range of voltage must be employed. The choice of the array of electrodes is in any case dependent on the conductivity of the water course which is being blocked

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since the surface of the electrodes and the resistance of the water determines the strength of the electrical field. The higher the conductivity, the broader is the electrical field and the fish detects the field earlier. At low conductivities (high resistivity) the extent of the electric field can be extended only by increasing the voltage, electrode surface area and the installation of anti parallel switched pulsing gear.

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~~129~~ 21

S 142 fort

If you are planning to place a fish barrier in front of the intake of a power plant the following must be considered:

1. Detailed working plans of the intake canal.
2. Data on the conductivity of the water with maximum and minimum values.
3. Data on the topography of the waters around the power plant, the bottom and the banks.
4. Data on the chemical composition of the water, possible pollution or *drift wood*.
5. Data on water velocities in the forebay, just before the coarse screen, and three, five and eight meters away.
6. Information on the species and size of aquatic animals which the barrier is to repel.

If the cooling water is taken from the forebay by a canal, the situation at the beginning of this canal (where the forebay empties into the canal) must be shown in the drafted plans since the fish barrier must prevent the fish swimming into this water body.

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We can therefore see that a great number of situations biotic and abiotic exist which hinder the complete blocking of a sketch of water. Each fish reacts in different ways at various stages of its life history under conditions which depress its general well being. (for example, as the result of water pollution)

Up to the present, no perfect electrical barrier has been constructed. These devices are supposed to repel fish schools, *also* member of which are suffering from nervous and metabolic disturbances. Under the best conditions, one can count only 90% of the fish to

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display the desired response. Unfortunately this fact is not well known to the general public. We are taking the opportunity here to emphasize this point.

The construction of electric barriers, including pulsing gear should be undertaken under the direction of experts and from firms which have long experience in their construction.

While the control devices for the pulses differ mainly in the number and type of the thyristors, the nature of the barrier is determined by the arrangement of electrodes, their condition and the choice of materials.

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Often it is useful to look at the site. It is advisable to invite both the expert on fish barriers and the local representative of the department of fisheries to solve possible disagreements on the positioning of the electrodes at once, and on the spot.

Only when questions 1-6 have been investigated and explained on the installation of the pulsing device and the barrier electrodes, ~~construction of the barrier electrodes~~ ^{shall be} carried out. In most cases ~~by the issuer of the contract~~ to save money. A firm, may also be engaged to construct the barrier at the site from plans. These plans describing the arrangement of electrodes must be drawn by experts and contain all the necessary details. In any case everything must be done carefully by people who know what they are doing. If errors are made in the construction, these may cause partial or complete failure of the barrier. Thanks to modern electronics it is possible to construct good functioning barriers for all types of waters.

the construction of barrier electrodes will be made by the employer himself

Before discussing the variety of gear available, it is necessary to ask to what purpose the repelling effect of the electric field is to be used.

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Meyer-Waarden as early as 1958 enumerated the following possibilities.

1. The blocking of pump and turbine intakes to prevent fish from being killed or injured. To avoid this you use chains of electrodes placed in front of the intake canal and provided with pulsed current. These electric barriers can replace the legally required screens and therefore reduce the bars of waterflow caused by bars of 2 cm minimum breadth. This increase of flow can amount to 20% and increase the useful drop from 5-20 cm.

2. Fish may be directed to fish ladders or fish traps. The first applications is possible wherever there is an attracting stream having a flow less than that drawn in by the turbine. The fish swimming to the spawning grounds are used to swimming against the stronger current and collect in front of the turbine and, as a result miss fish ladders and fish ways.

In the second case, you use alternating or pulsed current in the cables to herd the fish into traps. This can be achieved (as described on page 170) in many ways.

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3. Portable electric screens may be installed in waters which are difficult to fish, for the herding of fish into stationary traps (hoop nets, etc) .
4. Stretches of rivers may be blocked off to impede the upstream and downstream migrations of fish. This may be done to protect young planted fish from predatory fish. To accomplish this barriers of electrodes must be installed on the up and downstream side of the section of the river. Very useful is the combination of an electrical barrier and a device working on the principle of anodic attraction. A bend or stretch of a river which has been fished out by this method and unwanted fish kept out to the following day when electrofishing is continued. Fish can also be kept in enclosures consisting of electric screens if they are to be sold or transferred to other waters. This is

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especially useful in trout culture when broad stock must be separated. Thus sturgeon, salmon etc. may be held until sexually mature. Electrically charged metal screens, placed in front of the openings of intakes of underground canals can impede the movements of mitten crabs and fish into these structures.

2.1.2

Equipment used today

The thought "to construct stationary or ^{movable} ~~movable~~ devices to contain or guide fish and other aquatic animals in fiords, sounds, rivers and similar bodies of water" appeared first before the first world war. The Dane N.D. LARSEN in 1912 patented this idea at the Imperial Patent Office.

(Page 10) The patent has the following description:

1. A system of containing or guiding fish or other aquatic animals in fiords, sounds, rivers and similar bodies of water, characterized by a direct or indirect connection with a source of electric current, or by an electric cable, or ~~conducting wires network~~ ^{conducting wires} from which the electric current is discharged into the water.
2. The type of installation in section 1 is characterized by either being stretched or floating over the water and connected directly or indirectly to the main cables provided with bare wire hanging down into the water.

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3. The type of installation according to the specifications of (1) characterized by resting on the bottom and connected directly or indirectly to the main cable from which bare wires branch off and are held up by buoys.

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by two motor-boats

LARSEN in 1912 had not only the idea of building a stationery installation but also thought of the possibility of dragging it through the water and supplying power from generators on board. He even mentioned that "the electricity can consist of alternating, direct, or pulses of current".

It is not known if Larsen's ideas were put into practice at the time. Apparently they were not. The thoughts found no echo since the repelling effect of electricity was used. It was then the practice to construct electrified willow weirs based on the same principle. When the minimum width for protective screens in Germany and America was introduced considerable loss of intake pressure resulted. *the repelling effect* of electric current was recalled.

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One
observed
that the
fishes
were dama-
ged by the
turbines

The American J.M. Cobb was the first to construct electric barrier after Larsen's ideas in 1923. There was considerable interest in this device. At first there was dissatisfaction with its efficiency since the design of electrodes and controlling devices were not based on physical, physiological and electrical principles. This situation changed as American industry and government research stations developed the basic principles

(footnotes)

1. The Prussian fishery laws of 1916 established that the minimum separation of screen bars was 2 cm.
2. There has been much research on the harm that turbines and pumps inflict on fish that pass through them. Approximately 25% of these are injured or killed. They can suffer damage by *by cutting through the fish bodies or infraction of the vertebral column. By bouncing against*
~~to not understand~~
the propeller of the turbines the fish can get effusion of blood or

The construction of electrical barriers increased in the following thirty years. The first concern was the guidance of fish (for example, salmon) to fish ladders when dams impeded their upstream migrations. Sea lampreys were also diverted into traps by electric screens during the spawning migrations of these pests. It should also be mentioned that electric screens were also installed to prevent the entrainment of fish into turbines and pumps.

More than 60 years separate Larsen's first idea from today. The first fish screen was constructed by J. M. Cobb 40 years ago. Today electric screens are installed all over the world to prevent the passage of fish into turbines and pumps.

Electric barrier installations consist of a step down transformer, a central device and screening structures (electrodes). While the Americans originally employed 60 cycle a.c. (house current), pulsed current is used today exclusively and is produced by a controlling device. Pulsing devices were developed for the most part by the cooperative ^{participation} ~~suspices~~ for electrofishing installations under the ~~suspices~~ of the German Federal Research Station. Over 100 projects have been completed by these two organizations both in Germany and in other parts of the world. For this reason the function of this gear will be described.

The controlling device for an electrical barrier consists of a transistor controlled thyristor which sends 2-3 pulses per second into the electrode array. Each pulse has the shape of a quarter sine wave (see fig. 27) of five ms duration for a water resistivity of $1000 \Omega \text{ cm}$, a positive potential. The ~~voltage potential~~ ^{voltage} lies between 300 and 800 volts according to water resistivity and the separation of the electrodes. When resistivity is less than $600 \Omega \text{ cm}$ ($16.7 \mu \text{ s/cm}$) it is advisable to use pulsing gear; it is necessary to use this for brackish and sea water.

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The material making up the electrodes is quickly lost by electrolysis when the current is direct.

When water conductivity is high (low resistivity) pulsing gear which have an "antiparallel switching" is used i.e. after each positive pulse, a negative pulse follows at the same interval of 5 ms. By this means corrosion of the electrodes is minimized.

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This "antiparallel . switching" which produces twice the current per unit time - instead of for example, three positive pulses per second, three negative pulses are sent to the electrodes. This system is also used when water conductivity is low. (high resistivity) By this means it is possible to increase the current density in waters of low conductivity in order to produce a repelling effect adequate for small fish.

Six types have been designed by the electrofishing cooperative^{on}, according to the extent of the waters being screened - "one sided", "two sided"; and "three sided" and if advantageous an antiparallel arrangement.

The schematic diagram of this gear is shown in figure 64.

Fig. 63 One sided, antiparallel pulsing central gear (opened)

As already mentioned above, all pulsing central devices function with a maximum of three pulses per second. Each pulse has a current duration of 5 ms so that 15 ms of current flows each second; the 'current free' interval is 985 ms. In antiparallel switched pulsing gear, the duration of current flow is naturally, doubled, and the ~~pulse~~^{interval} now consists of 970 ms per second. In most cases^{is} only a pulsing rate of ~~two~~^{two} times per second ~~obtainable~~, necessary.

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Fig. 64 Schematic diagram for a one sided antiparallel functioning controlling gear.

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The following serves as an example for those interested in electrotechnology and is a discription of an electric barrier functioning in brackish water.

A weir installed in front of the intake cannal of a nuclear plant on the lower Elbe. This installation consists of a "three phase-antiparallel" functioning pulsing gear (fig. 65)

Fig. 65 "Three phase-antiparallel" pulsing device (opened)

For alternating current of only ~~positive~~ ^{positive} half wave the following general formula applies.

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$$I_{\text{eff}} = \sqrt{\frac{1}{2\pi} \cdot \hat{i}^2 \int_{\alpha}^{2\pi} \sin^2 \alpha d\alpha}$$

If, as already mentioned, a thyristor is used which lets through positive and negative quarter sine waves (50 Hz) and the thyristor is controlled by alternating current (2Hz), the variation in current shown in figure 66 is obtained:

The effective value

$$I_{\text{eff}} = \sqrt{\frac{1}{2\pi} \cdot \frac{f_2}{f_{50}} \cdot \hat{i}^2 \int_{\alpha}^{\pi} \sin^2 \alpha d\alpha}$$

in which f_2 and f_{50} are the frequencies of the 2 and 50 Hz alternating current respectively, $\hat{i}$ the peak value of the current (determined by the electrodes) and $\alpha = \frac{\pi}{2}$..

(29)

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Fig. 66 A graphical explanation of the formula. The shaded surfaces represent the pulses. The thick line shows the changes in current.

As a result you obtain

$$I_{\text{eff}} = 7.07 \times 10^{-2} \hat{i}$$

The same calculation yields for a voltage

$$U = 7.07 \times 10^{-2} \hat{u}$$

The power is therefore

$$P = \sqrt{3} \times \hat{u} \times \hat{i} \times 0.5 \times 10^{-2} \times \cos \varphi$$

The peak voltage in Brunsbüttel amounted to 200 volts, the peak current 1000 amperes

$$P = \sqrt{3} \times 200 \times 1000 \times 0.5 \times 10^{-2} \times \cos \varphi$$

$$P = 1.73 \times 1000 \times 1$$

$$P = 1730 \text{ watts}$$

Even a fish shocking array in brackish water, as shown by the Brunsbüttel example has a capacity of 1.7 KW. This is obtained using a physiologically effective pulsed current of a quarter sine wave and a low frequency to repel fish.

The controlling device operates by a different system in Russia, Poland and Japan. The electric fish screen consists of a series of electrodes which are provided one after the other with a single phase (see Fig. 79). In this instance the arrangement of electrodes is important. According to ^{MUSJEMBAUM} ~~NUSSBAUM~~ of the Research Institute in Leningrad, a slow use of voltage is especially important. Experiments concluded by this author with

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a six phase fish barrier (type M.6) show that the electric field blocks the passage of 85% of young perch and 100% of the adult fish. (Authors comment: Since all organisms are affected by environmental pollutants (even fish), then metabolism is affected, 100% blockage is never possible.)

2.1.3. Electrodes and their shapes

Electrodes are very important components of electrical barriers, requiring special attention during construction. The shape and array of electrodes, as well as their composition must be adapted to the site. Site conditions comprise the position of the intake structure in relation to the intake cannal, water conductivity, bottom conditions, water velocity and the species of fish being repelled.

Only when all these have been considered can suggestions be made on the type of electrodes to be used. The physiological state of the fish must never be forgotten. We know, for example, that fish in front of an intake structure are oriented tangentially to the intake current.

Fig. 67 The main electrodes (10) are sunk in front of the coolwater intake cannal of the Stade nuclear power station with the use of a floating crane. The opposing electrodes consist of coarse screens and the side wall of the intake structure.

Plans may be obtained from The ^{German} Federal Fisheries Research Institute.

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They can only be successfully repelled when the electrodes are placed such that fish are maintained in the direction of their swimming.

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In any event the form and arrangement of the electrodes must be such that the fish are prevented from swimming too close to the intake lest they be drawn into the pump.

While electrodes and their arrangement are important, local spatial relations determine their construction.

Two sets of electrodes are always necessary - main electrodes, and "counter" electrodes. Counter electrodes are always connected to the basic terminal of the controlling device whereas the main electrodes are provided with positive pulses. In most instances the wave screens or metal ~~"Spundwand"~~ ^{"plugging walls (2) Sheet piling"} may be used as counter electrodes.

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If water resistivity does not exceed 1200 ^{Ω cm} and the depth where the electrodes are placed is not more than 4 meters, doubled T beams have served well as electrodes over the past years. The double T beams (also called T₂ beams) are mounted on concrete pyrimidal bases and provided with a joining cable. (Fig.67)

Fig. 68 Electrode array in front of the cooling water intake structure of the nuclear power plant. Obrigheim am Neckar.

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Fig. 69 Changing the intake heads. The old 'heads' are readily recognizable in the picture; the last head of the most recent construction is being submerged.

Another form of a main electrode is shown in figure 68 near the intake structure of the cooling system of the nuclear power plant at ^{Obrigheim} ~~Chugheim~~ on the Neckar. The electrodes are steel rods. Those visible in the picture serve to anchor electrodes which begin 10 cm below the water surface. Counter electrodes are about 6 m behind the main electrodes.

In many situations special constructions of barrier devices ~~is~~ ^{are} advisable. For example the drinking water supply of the city of Stuttgart is obtained from ~~V~~berlingen Lake by a pipe 60 m deep ⁱⁿ ~~by~~ two intake towers. One of the ~~pipe~~ is visible in Figure 69 before being submerged. The pumping station is separated by 420 m from the intake structures. In spite of the depth of these intakes a considerable number of young fish are sucked in; ~~for~~ ^{for} this reason repelling screens were necessary.

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Two screen baskets were used as counter electrodes. The author, for this reason recommended the ~~array~~ ^{not array array} of electrodes shown in Figure 70 ~~be~~ ^{assembled} constructed. They were first ~~constructed~~ on dry land and then installed at a depth of 60 m on the towers. Each pair of electrodes consisted of two insulated rings ^{radiating} from the electrodes, ~~radiate~~. The rods alternate between the R ^{-phase} and S-phases ^{is} which, in this case, ^{They are} equal 0, ~~and are~~ connected to the controlling device. Electrodes for the second tower are built in the same manner except the rods are connected to the T and S phases. The controlling device is a two part pulsing gear which works with phases R and T.,

(162) *NA* 2.

Fig. 70 Working drawing showing the array of electrodes for the drinking water intake of the city of Stuttgart. A and B are charged with positive pulses. C is 0.

The ball-like towers are protected from corrosion by spraying several layers of plastic coating. For small intake pipes, the intake is only screened and no special construction is necessary. A simple screening electrode (Fig. 71) may be placed in front of the opening and connected to the positive side of a pulsing device. The pipe itself serves as counter electrode when it is metallic. *the pipe is* If plastic metal plates may be fastened on the left and right side. The rods of this electrode which are bent *upward* ~~above~~ in an angle of 45° *and* end just below the water surface so that ice flows or driftwood cannot easily dislodge them.

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Fish repelling installations have been described up to now but the same control devices may be applied to *guide and* catch fish in stationary nets and weirs. Such a weir to catch and subsequently kill sea lampreys is shown in Fig. 72. It employs 8 pulses per second. Also guiding weirs have been set up in Canada to guide salmon migrating upstream (Fig. 73) *and protect them before water hydro-electric power station.*

Fig. 71 Covering electrodes for an electrical fish screen

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Fig. 72 Arrangement to catch sea lampreys in North America

It was shown at the beginning of this chapter that not only the form and arrangement of electrodes are important in generating a good repelling effect but also the selection of materials. A fish weir

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does not fulfill its purpose if its electrodes are quickly destroyed by electrolysis caused by the high conductivity of the water. The electrode surface being corroded loses its effectiveness. In sea and brackish waters substances which are resistance^{t/} to corrosion must be used. Galvanized iron or steel while suitable for fresh water, cannot be used in sea water because of electrolysis. Table 9 (Halsband) summarizes the durability of various materials making up electrodes energized by pulsed current^{consisting of} positive and negative quarter sine waves.

Experiments were conducted in glass containers in which each electrode was immersed 100 mm and had a diameter of 31 mm.

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(TABLE 9)

Composition of substances used as electrode surfaces

Electrode No.	Material	Thickness mm	Coating Treatment
1	Aluminum		
1.1		0.5	Without sealing
1.2		0.5	Incorporated graphite particles.
1.3		0.5	With carbon coating
1.4		0.5	Scaled with wax
1.5		0.5	Organic coating with imbedded carbon components up to 80% saturation.
2	Aluminum		
	Magnesium		
	Alloy		
2.1		0.5	Without sealing
2.2		0.5	With incorporated graphite.

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TABLE 9 - continued

2,3		0.5	With carbon coating
2,4		0.5	Sealed with wax
2,5		0.5	With organic coating and imbedded carbon components up to 80% saturation,
3	Chrome nickel quality steel		
3,2	V4A	0.5	With incorporated graphite
3,3		0.5	Carbon coating
3,4		0.5	Sealed with wax
3,5		0.5	Organic coating and imbedded carbon components up to 80% saturation.
4	Lead		
4,2		0.5	With graphite incorporated
4,3		0.5	Carbon coated
4,4		0.5	Sealed with wax
4,5		0.5	With organic coating and imbedded carbon particles up to 80% saturation.
4,6		0.5	(Steel padding fence posts?) Without Stahlhaftpolster organically coated by LWK-B-006.2
4,7		1,0	with steel padding, organic coating with graphite and carbon components

S158 Fig. 73 Electrical fence to guide downstream migrating young salmon into catching installations

S158 At least three pairs of electrodes were tested under the experimental conditions outlined below. A container (35 cm x 22 cm x 24 cm) was filled with seawater and electrodes of the type listed in Table 9

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inserted and connected to the type of control gear. The control gear was set at two pulses per second. The dividing point of the voltage amounted to 260v. In all, twelve experimental tanks were constructed. The total peak amperage in these tanks lay between 600 and 800 A. It was not possible with such a large number of experimental tanks to work with a greater number of tanks since at these high current pulses sensitive instruments and controls were disturbed.

Conductivity of sea water lay between 50,000 $\mu\text{S}/\text{cm}$ (~~resistivity~~ $\rho = 20 \text{ Ohm} \cdot \text{cm}$) and 10,000 $\mu\text{S}/\text{cm}$ ($\rho = 100 \text{ Ohm} \cdot \text{cm}$) depending on the weather conditions of the day of water intake. A cooling coil was inserted in each tank because of the temperature increase caused by the flow of current and to minimize correlations between temperature and current.

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Peak current and temperature of the sea water ^{were} ~~was~~ measured at regular intervals and, in each case, conductivity and temperature were recorded. The effective performance was calculated from the recorded peak current values.

Of all the electrode coatings tested lead showed ^{smallest} ~~no~~ corrosion and ~~had no corrosion~~ when applied to electrode No. 4.5. Electrodes No. 1.1 to 3.5 which displayed the longest life ^{of} 474 hours, were not suited for sea water since they were corroded by the high amperage pulses required in this medium.

Since the experiments demonstrated that the electrodes coated with lead could withstand the heavy electrical current, electrodes 4.2 to 4.7 were subjected to additional investigation. Currents leaving the electrode surface were 60 to 100 times higher than those occurring in practice.

It was consequently revealed that electrodes containing incorporated

a greater number of tanks

the material (see table 9, No. 4,5)

graphite (electrode 4.2) showed a dramatic increase in current after 40 hours which ^{a change at} was indicated by the surface of the electrode. The power requirements of electrodes coated with carbon and sealed in wax changed little. The exterior of these electrodes indeed showed that, after 180 hours in use under severe conditions, little change was evident. These electrodes were not investigated further since additional experiments did not reveal any significant change in power used.

Electrodes with organic coatings and imbedded pieces of carbon up to a saturation of 80% which showed no changes were subjected to 1500 hours of operation.

In summary it was established that lead electrodes which were organically coated and contained carbon particles are best suited for sea water and high current density. These electrodes, moreover, have the advantage that, by imbedding more or less carbon particles the necessary current can be exactly adjusted.

2.1.4. Some tips for the construction for chains of electrodes

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Below is some practical advice on producing a good blocking effect with electrodes.

1. ~~Note that~~ ^Frequently it is not a single factor from the living or non-living world which influences a fish barrier; ~~but~~ many factors ^{closed} which can offset each other. Consider the conductivity of a ~~cloud~~ body of water when part of the water has evaporated (i.e. in ^{when} summer). Intensity of the current remains the same ~~if~~ ^{also} even the surface of the electrodes have been decreased.
2. Make sure that the potential gradient in the electrical field between plus and negative pole (O and R and S phase) is properly used. An

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WAG

adequately strong field strength (volts/cm) should be maintained. There must be in front of the forward electrode chain a dispersion of the field sufficient for the fish ^{at} to detect ~~some~~ 2 to 5 metres.

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3. In order to attain the necessary field strength between the electrodes and to prevent a loss in potential, the cable connecting the controlling device and the electrodes must be insulated with plastic. For cables coated with lead or steel, ~~there can be a loss of 50% potential can be~~ lost through magnetization and demagnetization. ^{when impulses are used.} The shape of the pulse may also be distorted. Cross-section of the cable should not fall below 50 $\square$ and the connecting cables over 80 m length even as much as 96 $\square$. Controlling device and electrode should be ^{not} ~~be~~ longer than 120 m.

4. Chains of electrodes must not be mounted vertically over the other in rivers as is practised in the USA where electrodes are laid on the bottom in the form of a ring or a rod with the counter electrode represented by a chain hanging from the surface. These arrangements produce a more-or-less vertical field lacking any substantial breadth and consequently no favourable shocking effect. If the rows of electrodes are placed parallel to each other as it is in Germany this will not occur. The electrical field in this instance is wider and the lines of current ^{around} ~~between~~ the electrodes more favourably arranged such that the fish have difficulty in penetrating the electrical field. The blocking effect can be improved by arranging the chain of electrodes at an angle of 45° to the current.

5. Current for the electrode chain is usually supplied at both ends of the supporting cable. If fish, however, are ^{to} ~~too~~ be led into a fish

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ladder, the chain must be supplied with current such that the electrical field gradually attenuates in the direction of the fish ladder; the waters in its immediate vicinity are free of electrical current.

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2.1.5. Examples of electrical barriers.

We have often demonstrated that repelling gear may be adapted for various purposes and it is of extreme importance for the effect on the fish that it is carefully planned and built in accordance ^{with} local conditions. Below are examples of some actual barriers as illustrations of adaptations to the site to produce the best possible effect.

The examples have been chosen from the rich program of the cooperative of electrofishing installations since we have little experience with the products of foreign firms.

Six barriers in all are described:

1. Electrical barrier in front of the intake structure of the Wurgassen nuclear plant.
2. Electrical barrier in front of the intake structure of the Obrigheim nuclear plant.
3. Electrical barrier in front of the intake structure of the Stade nuclear plant.
4. Electrical barrier in front of the intake structure of the Brunsbüttel nuclear plant.
5. Electrical barrier in front of the intake structure of the Dow chemical nuclear plant.
6. Electrical barrier in front of the intake structure of the Butzfließ nuclear plant.
7. Electrical barrier in front of the intake structure of ~~the~~ a power plant in Japan.

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1. The Wurgassen nuclear plant (Fig. 74) has a capacity of 670 MW. For cooling 28 cubic meters per second are drawn from the river Weser through 15 grids (Fig. 75). Fish populations, especially young fish are protected by a repelling electrical barrier. This prevents them from being drawn in and from being destroyed on the screens. Three I-beams, 4 meters from the grids are inserted in the river bottom as main electrodes. The counter electrodes consist of 28 electrode tubes arranged behind the grids. The controlling device is a "three sided, antiparallel" switched thyristor. The three beams are connected to phases, R. S. and T. and the ⁽²⁸⁾counter electrodes to MP. An anti-parallel switched thyristor ^{gear} is necessary since the resistivity of the Weser is between 130 and 350 Ω cm. because of the salinity of the river. Even in years having low rainfall the resistivity is 70 Ω cm over a long period of time.

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Fig. 74 Nuclear Plant Wurgassen/ Weser

Fig. 75 Intake Structure of the Nuclear Plant Wurgassen on the Weser

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Tests in front of many fish barriers are made either by the officials of the industry or government representatives. How this is carried out is described in the chapter: Checking the Repelling Effects of Inland Electrical Barriers.

2. The nuclear plant Obrigheim (Fig. 68) has a capacity of 380 MW. For cooling 11-18 m³ of water from the Neckar river is removed. To protect the fish population a repelling barrier was constructed. In

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the dry years 1971 and 1973 it was not possible to test the barrier because of poor conditions of the "white fish". They would not display a normal reaction to the electrical current. Positive electrodes consisted of steel rods and counter electrodes were placed 6 m behind these main electrodes.

The controlling device is "two sided" with the isolated transformer having a secondary output voltage 450/500/550 volts. Its performance was tested.

Fig. 76 Intake Canal of the Nuclear Plant At Stade

3. The nuclear plant at Stade has a capacity of 660 MW. The intake canal is over 100 m long and 21 m wide (Fig. 76). Cooling water from the Elbe amounts to 34 m³/sec. ~~Several~~ *Seven* beams are installed 8 meters in front of the intake canal (~~IPB~~ 220) each ~~being~~ *being* 4 m long and mounted on cement footings (Fig. 67). These are arranged such that sensitive fish of the Elbe must swim around the intake canal. The main electrodes are connected to phases R, S, and T, counter electrodes consist of the coarse screen and the *pile planing* "Spundwand". Connecting boxes for the cable are placed on the intake head. The cables leading to the electrodes are protected by a special *hose*. The cable leading to the river bottom are protected by steel tubes. In addition chains are wrapped around the cable by a diver so that they will not be displaced by the tides which are strong ~~here~~ *at this site*

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4. The nuclear plant Brunsbüttel has a capacity of 770 MW. The intake canal (Fig. 77) is in the Elbe about 130 m from the bank. Water is

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pumped through ^{8/}intakes lying 7.5 m under the normal water level to the pump house 220 m away. About 35 m³ of cooling water are drawn through per second. At a distance of 3 m from the intake are three round iron electrodes, 200 mm in diameter mounted on cement ~~pyramids~~ ^{pyramids}. At an angle of 45° to these electrodes are two additional electrodes ~~to~~ ^{to} impede the lateral swimming of fish. These electrodes are connected to the positive leads (R. S. T.) of the pulsing device.

Fig. 77. Intake Structure of the Nuclear Plant at Brunsbüttel
(Lower Elbe).

Counter electrodes are placed five meters behind these electrodes in the direction of the bank. In all there are 16 consisting of steel tubes 191 mm in diameter and are fastened to wood with wooden screws.

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Main and counter electrodes are connected to a "three sided" pulsing gear. Because of the high conductivity the apparatus is operated "antiparallel" to minimize corrosion. The required transformer is rated at 200 ~~kVA~~ ^{kVH}.

The main electrodes (positive) are supplied with a 70 mm² NYY cable. The connections are held far above the water to avoid corrosion. For each four counter electrodes 25 mm² NYY cable are connected by a distribution box. The four distribution boxes are connected by 70 mm² NYY cable on the controlling device.

An excellent repelling effect was found during the test. The intake structure of Dow Chemical in Butzfleth is in the Elbe far from shore (Fig. 78). Three pumps draw in the necessary water. The coarse screens

3-6

- 12 -

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are hung insulated so that they can be connected to the positive side of the controlling device. Heavy installation cannot be used since the installation is flooded. The three pumps serve as counter electrodes.

The electrical supply consists of a "one sided" antiparallel functioning control device and a 75 kVA isolated transformer. Here also the results of the tests were good.

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6. On the river Oito in Kyushu, Japan a "three phase fish barrier" has been constructed in front of the intake of a small power plant. The barrier does not produce pulsed current but rather emits individual phases directly into the water from the electrodes. Individual phases are arranged in a triangular pattern to each other (Fig. 79, a. b. c.) Voltage is 65 v. This arrangement may be effective for small plants. Two of the upper electrodes may be seen in Fig. 80, indicated as a. and c. (Fig. 79) below the control house. In the two left cement 'noses' Electrodes b. and a. are installed.

Above are only some examples of the over a hundred fish screens built by the Federal Fisheries Research Station and the Cooperative for Electrofishing Installations. The arrangement of electrodes, choice of electrodes depends on the water and the nature of the site.

2.2. Installations in the Sea

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Since the appearance of the first edition in 1965 many more power stations have been constructed on sea coasts because of the need for energy. Because of the corrosive nature of sea water much more precautions must be taken. The input of heat into our rivers from existing and planned nuclear stations is already so great that the establishment of industries on the coast is becoming more necessary.

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In warm countries where supplies of cold water from rivers is not available (In Spain and Italy) cooling water has been drawn from the sea. Electric barriers have been installed in front of the intake structures not to protect fish populations but to prevent plant shutdowns.

An example is Térmicas del Besós - the only open air power plant in Europe. Turbines and generators are unprotected. Total capacity is 450 MW.

On three raised ~~conduits~~ ^{conduits} of 2.20 m diameter 60000 m³/h of Mediterranean water are drawn into the plant. At the entrance of each conduit, water velocity amounts to 1.5 m/sec. Salt concentrations over the year are around ^{34.6 ‰} ~~34.6 ‰~~. About 8 tons of fish are sucked in ^{especially} ~~especially~~ in spring and blockage of the screens can occur. The common fish species ^{are} ~~in~~ the "Meeraschen" ^(?) between 25 and 50 cm in length.

sea - graylings

Fig. 81 Cooling Water Holding Basin at Térmicas del Besós in Barcelona

The cooling water is pumped into a long ~~holding~~ ^{holding} water holding pool (Fig. 81); screens are installed in this basin.

Since the power plant is constructed directly in front of the Besós estuary, fish migrating upstream occur often in great numbers. Up to 8 tonnes a day have been sucked up by the pump and have reached ~~the~~ cool water reserve basin. Since the cooling water is continually chlorinated, to prevent the colonization of the pipes by mussels, large amounts of fish are killed and clog up the intake screens to the extent that the power plant is shut down.

For this reason the Spanish authorities commissioned the Federal

Research Institute to construct a suitable fish screen. The gear was manufactured by the Cooperative for Electrofishing Installations.

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2.2.1. Construction of the Electrodes

Two meters in front of each intake pipe an I beam was diagonally installed. These three electrodes constituted the main electrodes.

Counter electrodes also consisted of I beams which, with one exception, were secured to an imbedded I beam. These counter electrodes were placed five meters from the intake structure because of the high conductivity of Mediterranean water, all electrodes consist of one material and that is ordinary construction steel. To minimize corrosion and flaking off of material, electrodes are operated antiparallel. The elements of the electrodes are ^{chosen in a matter} ~~so chosen~~ to permit inexpensive and ready assembly and disassembly.

2.2.2. Construction of the controlling device

The pulsing gear is three-sided device which supplies the three main electrodes with phases R, S and T respectively. The counter electrodes are all placed at the MP. The device operates by an antiparallel switching arrangement with six thyristors of the type Bst-N-25100. To protect the thyristors they are placed in a wind channel equipped with a wind protection switch. The control is transistorized. By using phase shifting elements, it is possible to adapt the device to the local situation by adjusting the width of the pulses.

The controlling device is hooked up to a separating transformer of 250 kVA. This transformer has the following specifications:

primary: 3 x 380 V

secondary: 3 x 60 V/3 x 120 V/ 3 x 180 V/

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The cross-section of the cable contains:

2 x 95 mm² NYY for each main electrode

2 x 120 mm² NYY for each counter electrode

Peak value of the pulsed current is approximately 3000 A.

3. Combination of electrofishing systems with ~~traditional~~ ^{traditional} fishing gear.

Many bodies of water (ponds, grave pits, deep holes) for many reasons cannot be fished with conventional gear (weirs, hoopnets, etc.) or anodic functioning electrofishing gear. In this instance various types of gear may be combined.

S170 3.1. Stationary electric repealing devices combined with electrified nets or weirs

On the estuary of the river Indaldäven in Sweden a type of weir was experimentally constructed (Kreutzer and Lindroth). This consisted of an installed leading weir, flanked by two movable wings 3 x 3 x 1 m leading into metal traps of 10 cm metal screening (Fig. 82).

Fig. 82 Electrical arrangement for catching young salmon in Sweden
(Kreutzer and Lindroth)

The purpose of this year is to catch young salmon, swimming upstream. To increase the catching effectiveness the gear was submerged under the river and both alternating and pulsed current was used. The middle leading weir serves as a positive electrode and the two wings as negative electrodes. The middle weir has a net section which is not supplied with power so that the area in front of the trap is not electrified. A metal rod may be inserted in the trap and supplied with direct current. The wings and

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the electrified alternating or pulsed current middle weir have the function of forcing the fish in the immediate vicinity of the trap. After swimming into the trap they are killed with current supplied by the metal electrodes within the trap.

The electrical field is produced by a direct current generator (250 V and 20A). The rectifying components consist of 6.5 kVA, primary 380 V, 50 periods per sec, secondary 250 volts at 20 A load. In addition a ~~condensor~~ ^{condensor} of 6 kVA serves as a current smoothing device. The construction of this electrified system resulted in catches essentially better than that of unmodified weirs.

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There are similar systems on the rivers flowing into the Great Lakes in America to prevent migrating fish from swimming into lethal electrical fields. These fish ^(sea lampreys) are dangerous ectoparasites of other fish (Fig. 72). The fine mesh screen of these weirs serves as an anode. The cathode consists of a metal net strung across the surface of the water. Both electrodes are energized with square wave direct current pulsed three times per second. Thus the fish swim in the direction of the anode and are attracted to the cage.

3.2. Movable repelling devices and anodic catching gear combined with electric nets

In heavily travelled stretches of water (eg. the Rhine) it is not always possible to construct stationary electrofishing devices. Movable devices are advantageous in these ~~situations~~ ^{situations}. Shipping traffic is greatly reduced during the night and shocking, *and in our example which is only allowed during downstream passages, the shocking net is electrified.*

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A "shocker" is a boat which is usually anchored at the outer curve of the river where the water is deep. It is usually stationed about 20-50 m from the shore. On one side of this boat a net having an opening 6X12 m. is fastened. (area 72 m²). The net produces a standing wave in the flowing water which warns the fish so that many swim away from the net opening. For this reason the net is electrified to block the movement of the fish away from the net opening.

~~Guiding~~
Construction of the guiding weir to lead fish

The following ^{weir} was constructed at Gernsheim on the Rhine. Electrode chains ~~are~~ stretched from the upper and lower beams as well as to the middle of the river such that the inner angle ^{is now} ~~is~~ 30°. The inner chain extending to the middle of the river is 100m long; the outer chain is 45 m long including the anchorage. The counter electrode consists of a steel cable installed about 5m in front of the net opening. In this ^{way} ~~was~~ the catching area is increased from 72m² to about 250 m². Moreover the barrier chains, as described above, act to guide the fish to the opening of the net. Current is supplied by 12.5 kVA three phase current generator with a VW industrial motor a transformer

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Fig. 83 Power supply for the electrified guiding weir.

Fig. 84 Paying out the steel cable of the electric guiding weir.

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and a thyristor 3 phased pulsing gear (Fig.83). Figure 84 shows the guiding weir being ^{installed,} ~~payed out~~. Since the depth of water in the experimental reach of the river was more than 6m. *the weir was secured to the bottom by 3 steel cables (14mm diameter) separated by a distance of 3 m and tied vertically to each other.*

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In this way the steel ^{cable} ~~cable~~ was almost stretched over the bottom, the second and third at the same time 2m over this. In order to maintain the separation between the cables and to stabilize the arrangement, the individual cables were ^{to m} connected each 10mm to small cables imbedded in the bottom. In the upper end of each of the 6mm cables, buoys were attached to float the ^{cables} ~~cables~~. Fig.85 shows this type of shocker; ^{cables} ~~the cables~~ leading to the bank are visible ^{near} ~~where~~ the pulsing gear and ~~the~~ generator ~~are~~ visible.

Using this system it was possible to increase the catch, especially of eels, more than 100%.

In the chapter "Application of the anode effect of the electrical current in freshwater" the procedure for estimating the population is described.

The method described here may be applied to busy waterways to sample the fish population which would not be otherwise possible.

Fig. 85 The shocker employed in the experiment. The cables leading to the stationary gear on the bank are clearly recognizable.

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~~successfully~~

The 'pull net' has also been ^{successfully} ~~with success~~ electrified in the federal fisheries research station, by the Institute of Gear Technology.

G. Freytag, W. ^H ~~H~~orn and R. Steinberg write:

"Inland fisheries and other branches for years have operated with the need to catch as much fish as possible with a minimum of labour. As a contribution to this goal the Institute of Gear Technology has developed a series of trawls.

Basically ~~there have consisted of~~ a so-called two-ship trawl i.e. a net pulled by two boats with the horizontal spread determined by the distance separating the two craft moving parallel to each other. The resistance of

2 wings
~~other boards~~
~~encoder~~

3

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of the ~~other boards~~ is greatly reduced so that the power of both boats acts on the net. For this reason a relatively large net can be dragged by craft with small motors.

Because of the importance of
~~Since~~ the eel fishery ~~is so important~~ a special kind of net was constructed and tested. From the beginning this net proved effective. Moreover the net can be handled by a total of two men. It consists of a double flapped seine encompassing 800 mesh ^{width}..... with mesh 40mm wide in the front part of the net. The wings were 200-300 mesh long. Mesh width in the back net and ~~steer~~ ^{is} 24 mm.

Experiments were begun in 1970 with the purpose of combining ~~a~~ eel seines and electrofishing to extend the season and to improve the catch.

The gear used at the institute consisted of a motor generator, pulsing gear and a cable drum for 200m of ~~cable~~. ^{cable.} ~~The~~ transfer of energy from boat to net was achieved by an independent tow cable held in front of the net and supported by 5 floats, 5m apart from each other and kept off the bottom. This prevented a repelling effect. The ~~cable~~ ^{cable} is attached to the corner of the net through an eyelet. The electrodes are fastened to the top (anode) and bottom (cathode) hawsers.

Fish catches

Catch using an electrified eel seine ~~seine~~ ^{trawl} ~~show~~

The former experiments ~~to demonstrate~~ ^{to} by comparison the more effective ^{is with} method ^{trawl} of catching eels ^{and} by an electrified eel ~~seine~~ ^{were} was conducted with the special purpose of extending the normal season. To make comparisons valid local conditions and different times were taken into consideration.

1. Lake Ratzeburger (Lake Kuchen) 3/5.5 1970

At the time of the tests water temperatures were so low that no eels could be caught with ~~conventional~~ ^{conventional} gear. In spite of the short experimental period.

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and the small number of hauls there was a pronounced tendency for an increase of catch with respect to eels perch, and pike with the electrified net.

Table 10. Average catch per hour in Lake Ratzeburger (5 hauls) with

	Eels (number)	Pike (number)	Perch (number)	"Weissfisch" (in pounds)
- With electricity.	31	4	51	292
- Without.	3	-	22	150

2. Lake Steinhude 25/26.5 and 27-29.10.1970

The two consecutive investigations on Lake Steinhude yielded, especially in late autumn, a definite increase in catch with the electrified eel seine.

Table 11. Average catch per hour in Lake Steinhude on 25/26 May 1970 (10 hauls)

with electricity	----eels, pike, perch, white fish (lbs)
without "	68 13 250 } pounds
	41 4 100 }

Using the electrified eel trawl beyond the limits of the season, showed,

in comparison to the results in ~~spring~~ ^{spring} the superiority of this type of gear.

Water temperature in this relatively shallow lake had decreased to 7-8°C.

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Table 12

Average hourly catch of comparable hauls in Lake Steinhude

	eels (number)	pike perch number	white fish pounds
With electricity	61	35	820
Without	3	14	520

The size composition of the whitefish catch shows a selective influence in favour of electricity.

3 Lake Witten (Eckernförde district) 30.11-2.12.1970

~~Trials~~ ^{Trials} with an electric ~~haul~~ ^{trawl} in Lake Witten were extremely successful with hourly catches of 50 kg of eels — much more than expected for that season.

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Table 13

comparable
Average hourly catches of comparable hauls in Lake Mitten in December
1970 (2 hauls)

The size composition of the "whitefish" catch illustrates the selectivity of the gear with respect to size.

	eels (numbers)	whitefish (pounds)
with electricity:	141	1180
without "	7	1900

3. Lake Witten (Eckemförde district) 30.11 - 2.12. 1970

The experiment had to be discontinued when large numbers of young morone appeared simply there are "bread and butter" fish for the fishermen to protect them for the important.

Summary of the experiments to date

1. The catch may be increased, Especially increased. Can be used economically in fresh water. Tuck 2000
2. Fish catches may be increased by electrifying eel dragnets. increased beyond
3. Eels may be profitably harvested out of the normal season.
4. The catch of fast-swimming fish (ex. pike-perch) may be increased with an electric trawl.

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These trials demonstrate that the effectiveness of the eel dragnet is increased by combining it with an electric field. This provides the inland fishery an effective tool to harvest eels. Trawl

Dragnets are also electrified in Poland, the German Democratic Republic and Russia where Shentjakov of Leningrad has conducted many experiments.

3.3 Hager's Cathode Net

Master fisherman Hager of Braunau, Austria has developed a method which combines shocking and catching effects with traditional fishing gear. Kathode nets rather than barrier chains are used. It consists of a simple stationary net in which a copper wire is woven into the lead line and connected to the negative pole.

The electro-brant catch in this lake was exceptionally successful (50kg/hr) - exceeding the anticipated catch for this season.

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of electrofishing gear. A customary metallic catcher forms the anode.(fig.58).
In large bodies of water two catchers may be used.

Fig. 86. Catching fish with Hager's cathode net.

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In his experiments Hager originally ~~used~~ ^{employed} a 2kW direct current apparatus but later switched to pulsing gear. The following technique ~~is~~ ^{was} used. The cathode net is stretched between two boats and dragged upstream toward a stationary net which blocks the stream 100 m below the cathode net. At the same time the catcher is immersed in the vicinity ^{to} ~~and~~ ^{fish} ~~stun~~ the assemblage of fish which is then removed. Those on the periphery of the electric field which do not respond to the anodic effect are repelled by the same field and congregate near the stationary net.

Those animals which attempt to swim upstream in the direction of the cathode net encounter the field of the catcher, become stunned and are removed. The process ~~is~~ repeated until the cathode net being pulled upstream is in the immediate vicinity of the stationary net when the remaining fish are netted from this narrow confined area.

 Stationary

Fig. 87 An electrified net in water. (from Hager)

Instead of a stationary net at the end of reach of the river where fish are being removed an electrified "Wadennetz" has been installed.

Key to symbols

- | | |
|------------------------------------|---------------------------|
| 1. Pouch of seine with two funnels | 6. Fishermen's Boat |
| 2. Copper braid of the net. | 7. Generator (220v, 2 kw) |
| 3. Cork line | 8. River bank |
| 4. Positive poles of the catcher | |

By carefully closing off the reach of the river with the cathode net and skillfully ~~maneuvering~~ ^{maneu} ~~maneuvering~~ the electrodes Hager was able to catch fish attempting to escape between the lower edge of the net and the bottom. This almost 100% efficiency would not be attained with a chain of electrodes.

S 179 The cathode net can also be installed in large lakes but these bodies of water must be fished in sections. Nets are placed parallel to the shore and one is closed off to prevent the lateral escape of shocked fish.

The stationary net at the end of the stretch of water may be replaced by a net with a pocket. This works well when there are large numbers of fish - especially eels - and there is a risk of the fish either escaping over the top or the bottom lip of the net. This trap net is electrified in the same manner as the cathode net. A copper cable is woven into the lead line and the current is supplied by a second generator in which the positive pole is connected to the copper cable. (Fig. 87). You are now fishing with two electrified nets: the movable cathode net described above and the trap net fixed in place. Fishing procedures are the same as described before. Only when the movable cathode net has reached the wings of the fixed trap net do the two nets enclose a space. At this point the pulsing gear energizing the trap net is switched off. The generator supplying the cathode net is now switched to supply the trap net and fish are removed as shown in Fig. 86.

4. How to test the field of freshwater electrical barriers.

There are often many complaints that it is difficult to measure the effectiveness of electric fields in shocking fish. These objections are unjustified.

Fish barriers are not products of mass production and must be designed with great care. They must be adapted to the conditions of the site (electrical conductivity of the water etc.). When barriers are installed by following the plans of the Federal Research Institute, healthy fish populations will respond in the desired manner to this electrical field. However, there are narrow departures from the field strengths predicted.

There are methods of testing the response of the fish to the electric field. Halsband, for example, tagged fish with strings attached to ping-pong balls and placed them in front of the barrier. Their movements could be easily followed.

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Fig. 88. Net boxes placed in front of the fish barrier at Aura (Frankish Saale) to determine the effective electrical field. Length: 8 m; height: .80; breadth: 1.00 m. *(Photograph: Halsband)*

The effective field of an electric fish barrier may be explored by slowly moving a net box containing fish towards the barrier. (Fig. 88) In channelized reaches of a river or in fish ladder this may be achieved using an electrical counter. The fish used must be, as in the care of the first two methods, kept for the preceding 24 hours in a live box to habituate to the water conditions. Needless to say ~~the must~~ ^{they must} not be used repeatedly without sufficient intervals between trials.

4.1 Fish lagged with ping-pong balls.

Thread is pushed through the dorsal muscles with the help of a surgical needle with the loose end corresponding to the water depth at which the fish swims. A ping-pong ball is tied to the free end. This technique has been successful with eels, carp, *tench*, *beaw*.

Tagged fish are placed 10-15 m in front of the barrier. If placed directly

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in the field the test fish will become disoriented, swimming either away or towards the barrier. The method may only be used when the bottom is free of snags.

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4.2 Testing with net boxes

The net box (Fig. 88.), constructed following C. Kreutzer's design, containing fish is drawn slowly towards the field of the barrier. Since, fish, as a rule, swim at right angles to the barrier, the box must be drawn such that it is at right angles to the lines of electrical force. The behaviour of the fish may now be observed - i.e. how they react to the field, at what distance they sense the field and when they attempt to escape.

4.3 Electrical fish counters

A good example of this device is the system used in north Scotland to count fish using a fishway on the power generating station Pitlochry and Clunie on the river Tummel. The counter works on the basis of the differences in conductivity between fish and water. It consists of a detection tunnel which forms the arm of a Wheatstone bridge. Power is supplied by a battery. The fish swims through two metal annular electrodes in the polyethylene tunnel, which is resistant to corrosion and other disturbing influences. The presence of the fish disturbs, the equilibrium of the bridge causing a voltage change which is registered. Amplification of these signals drives a counter. Voltage across the annular electrodes is kept below 0.8 v to avoid effecting the fish. The potential difference produced by the fish depends on its resistivity, size and water conductivity. Experiments have shown that twigs leaves and ^{detritus} ~~Geyoll~~ have the same resistivity as the water and are, therefore not registered. The device can be adjusted to respond to a minimum size of fish. Simultaneously size and number of migrating fish can be determined. It can be adapted not only to

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small spaces but adjusted to waters of changing chemical composition.

Automatic fish counters are used in the U.S.A. with various modifications. The detector for example can be used as an alarm or to trigger the shutter of a camera permitting recognition of the fish being counted. Further modifications make possible the counting of several fish at one time.

The author used ~~such~~ a device to investigate the functioning of the fish barrier at Würgassen. The electrical field in front of the screens was mapped both vertically and horizontally. The structure of the intake structure and its orientation to the river Weser necessitated ~~to maintain an~~ ^{the maintenance of} electrical field up to 8 m from the screens so that small fish could be diverted.

Electrical field strengths were determined 2m. 4m. 8m. and 10m. from the intake screen using an oscilloscope. Probing electrodes were adjusted to the size of the fish.

The example below is for a 10 cm long fish swimming into the intake cannal at a depth of one metre

2m	in front of the screen:	4.0 Volt
4m	" " " "	1.2
8m	" " " "	1.2
10m	" " " "	0.3

Because of a water resistivity of 150 Ω cm on the day of the tests a voltage of 0.3 to 0.4 V. across the electrodes were necessary to shock the fish (2.56 Ω) .i.e. at least 8m in front of the screens the field was still strong enough to divert the fish from the intake structure.

In Spring ^{of} 1971 tests were conducted in the presence of a representatives of the industrial ministry, employment and social ministry of the province of North-Rhine Westphalia as well as land administration office of Lower Saxony, Also present was president ^{of Annaberg} ~~of Annaberg~~ of the fishing ^{association} ~~association~~. Eels tagged with ping-pong balls were placed at the beginning of the electric field under conditions of full pumping operation to test the effectiveness of the barrier.

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The water works' office of Hameln kindly supplied a boat for our use which lay about 40 m above the intake structure and anchored 15 m from the bank. The author released the tagged fish and observed their reactions as they ~~swim~~ ^{swam} around the intake structure. They were cut free from the celluloid balls after the ~~observation~~ ^{observation} period was concluded. All eels without exception were repelled 10 m in front of the intake. A small eel, (app. 150 g) for example, swam in the direction of the intake structure and, as it sensed the first impulse, swam 50 m further upstream. This was a considerable effort for an eel especially when it had to pull a ping pong ball fastened by a 4 m nylon cord against a current of 3 m/sec.

It was important to measure the "stride" voltages in the field to protect human swimmers and boaters. *The "stride" voltage is the potential across the body of a human in the water.*

Fields were tested with electrodes separated by 2 m. At a distance 50 m from the screens a voltage of 0.4v was found. At 12 m the 'stride' voltage was 10 v, at 3 m - 60v and at 2 m, 80 v. The measurements determined whether the boatsman was in any danger from the barrier if he fell in ^{to} the water.

5. Electric stunning and killing systems

These systems have the purpose of improving the efficiency of traditional gear, the destruction of harmful organisms, the painless killing of aquatic animals and prolonging the shelf life and quality of edible fish.

The application of these systems are varied and each system must be constructed in a different way. All must cause the stunning or subsequent death of the fish. Alternating current of 220v or rapid pulses must be applied to electrodes close to the animal. Otherwise much of the current is lost to the surrounding water and the effect is reduced.

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The physiological processes occurring during stunning and killing are described on page 202.

5.1 Examples of stunning and killing devices in freshwater fisheries

Examples of these are installations to kill mitten crabs and sea lampreys. Devices are also used to painlessly kill fish in the trade.

5.1.1. Mitten crabs

The firm Sommer and Meister (Leipzig) have been developing electric gear to stun and kill this species. Before the second world war they used a stepdown transformer which converted 220v to 4-8v. applied across two chains. These consisted of ca. 1mm brass wire coiled around a round rubber core about 7 mm in diameter. Separated by 8 cm, by transverse metal pieces ~~they~~ ^{and} had a separation of about 10 cm and provided the ladder with some rigidity. This arrangement also prevented short circuits. The length of the barrier chain which was laid from the bank along the bottom at Lauenburg on the Elbe was 15 to 25 m long. (Fig. 89)

Fig. 89. The electrode chain of a mitten crab barrier at Elbe/Lauenburg.

From Sommer & Meister. (Photo Tiews)

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Since this installation only partially fulfilled the objectives a new device was ~~devised~~ ^{developed} by Kreutzer after the war. Alternating current interrupted by a switch on a cam shaft. (Figs. 90 and 91) Another gear developed by Wentorff worked by the following principle: Alternating current from the mains is transformed into direct current and interrupted by a system of relays and condensers.

Fig. 90: Control box for the electric mitten crab barrier at ^{Lauenburg} ~~Lauenburg~~ on the Elbe. (Photo Meyer-Waarden.)

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Fig. 91: Chain of electrodes of the mitten crab barrier according to Kreutzer.

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This produced pulses lasting 2 ms having relatively steep and trailing edges. Kreutzer's device lost considerable current to the waters of the Elbe and Wentorff tried to minimize this lost by dividing the chain in 40 m segments by insulators. Each segment (outer and inner electrodes) was provided with water-proof pulsing devices. Since the pulsing gear was directly connected to the electrode pairs at the time it must be enclosed by a water-proof housing.

Halsband developed a third method which provided an electronically produced pulsed current of variable frequency and of reliable performance. The control device was ~~similar~~ similar to those of other barriers in which alternating current from the mains is passed through a thyristor controlled by transistors. Frequencies could be adjusted. Voltages are in the range 300 to 500 v. The ~~switching~~ ^{switching} scheme of this apparatus is shown in Fig. 64.

Fig. 92: Arrangement of electrodes in the mitten crab barrier according to Halsband. (Explanation in text).

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Kreutzer and Wentorff utilized barrier chains consisting of two lengths of wire fastened to oaken planks and separated 40 cm from each other. Halsband employed four wire ~~cables~~ ^{cables}. It has been shown that the mitten crab, a well-known bottom crawler can move over the chain without causing a short circuit with their extremities. For this reason Halsband introduced a second pair of electrodes between the two already present such that each inner electrode

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was separated about 16 cm from the outer. (Fig.92). Two electrodes were thus created two external which were weak and a middle field 4 cm in width. The middle field was made especially strong since the mitten crab would migrate to the middle during the pause in the electric current and pass over the outer part of the ^ffield without injury. With Halsband's modification the crab would be exposed to the strong interior field and would either be killed or have its extremities extended which would lead to its death.

Fig. 93: Combination electric fish and mitten crab barrier in the Elbe at Hamburg. (Photograph by Halsband)

The same principle has been applied to a barrier constructed by the provincial fisheries association of Schleswig-Holstein in the vicinity of Nordfeld on the Eider river (130 m wide); ~~since~~ the Eider at this point becomes brackish and therefore a 100 kV¹¹ - transformer was used

Footnote: Dimension of the planks 400x80x30mm. To prevent them from being moved by the strong current they were anchored at intervals of 10 m with heavy stones.

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A similar functioning mitten crab barrier has been installed in front of the intake canal of the BP oil refinery in Hamburg harbour. This device works in the same manner described above ut also includes a fish barrier in its design (Fig. 93). The controlling device includes two electrical circuits which are independent of each other one for fish and the other for the crab. The pulsing frequency is different for each. Arrangement of electrodes for these two groups is also different. The fish barrier consists of pairs of electrodes hanging in front of the intake and the crab barrier rests on the bottom as lengths of electrified cable between the rows of electrodes. Thus two electrical fields are created- vertical (fish barrier) and horizontal (crab barrier) as well as a combination of these two fields (Fig. 94). Because of this combined field no crabs, smelts, glass eels, and other small fish penetrate the 30 km long cooling system of the refinery. Before the installation of the electrical barriers the pumps had to be throttled to remove aquatic animals that swim into the intake canal are held back by this combination barrier. This is probably the highest attainable value for an electrical barrier (page 142). A 100% blocking is impossible for biological reasons since other factors can influence the electrical field in a negative manner. In stopping mitten crabs various water currents in the river can interfere with the action of the barrier. Not only must the horizontal rails be placed on level bottom in such a case the voltage does not collapse which would happen when alternating current was used; only the charging time is shortened. This, however, has no affect on the physiological action of the pulsed current and consequently no effect on either the narcotizing or lethal effects.

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5.1 Installation of electrical killing devices to increase the quality of fish flesh.

The idea to improve the quality of fish flesh as well as the storage life was conceived by KUROKI in Japan and MEYER-WAARDEN in Germany about the same time. The later noted that workers in a tuna processing plant could easily distinguish between fish killed by conventional means and those killed electrically. The workers were guided not by the initial colour of the flesh but by the better consistency of the flesh as well as the prolonged storage life of those killed electrically. After similar observations made on sardines treated in the same way and in the Japanese investigations mentioned above the author with FR.BRAMSTEDT with the support of K. TRAUTNER and H. THIEDE investigated the electrophysiological and chemical physiological processes going on in the body of a fish when killed electrically. Facilities for this investigation were provided by research groups of the food industry.

Investigations were conducted not only on freshwater fish (trout) but also on marine fish (sardines, sardellen, plaice, Baltic sea cod). A group of fish were killed by a blow on the head and a comparable group killed electrically. In each group some fish were killed when relaxed while others were pursued in the tank before slaughtering. With the marine fish the experiments could not be carried out so systematically since the test fish had first to be captured in an encircling net which certainly caused considerable commotion. In the first trial (sardines) it required at least half an hour before the purse of the net could be hauled on board the ship but they must be raised to the surface and inspected from time to time since the possibility of siltation is great. It was necessary in the River Elbe to lift the barrier once a month since even thin layers

of slime or sand can greatly reduce its killing effectiveness.

5.1.2. Devices to stun and kill for pond culture, eelsmoking operations and the commercial fish trade.

Recently developed devices to kill fish in pond culture are used to kill fish (carp, trout, eels etc.) for retail sales with a minimum of effort and time. Catching the fish with nets requires much time which is especially inconvenient in winter. The customary method of knocking the fish over the head often requires several blows to kill the fish. Eels being slippery, often wriggle out of the grasp of the fish culturist. A further simplification is the application of electrical killing devices when great numbers of "portion fish" (eels etc.) must be slaughtered for smoking, freezing of for hotels. Ready for the kitchen. In this instance the fish are placed in an electrified vat for killing. The Federal Fisheries Research Institute has constructed a very simple device for this purpose of interest to the industry.

The killing device described below was built by the co-operative for electrofishing gear following advice from Halsband. Each killing device consists of a switching container and a killing container. Size depends on the number of fish to be processed. The killing container is a plastic box with the electrodes built into the sides. The container shown in Fig. 95 is 0.85 m high, 1.0 m long and 0.80 m wide. The only visible electrode is that attached to under the cover. The other electrodes are fastened to the bottom.

Fig. 95. An electrical killing box. See the text for details. (Werkphoto)

5.2.1 Electrical Stunning and Killing of Tuna Fish

It has already been mentioned that tunas are caught by hook and line,

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in the North Sea, off the French, Spanish and Portuguese coasts - and as far out as Cape Verde. This method is based on the principle that the fish are caught by a baited hook suspended with a float from a fishing rod. The disadvantage of this method is the loss of 50% of the fish which work themselves loose from the hook. The fish which remain on the hooks often struggle for half an hour before death and this impairs the quality of the flesh. Electrified hooks shorten the time to die and reduce the number of fish which escape. The system works in the following way: The long line has a core consisting of a thin flexible wire energized by an electric pulsing device on board the ship and in turn connected to the hooks. When the tuna takes the hook it senses pain and attempts to escape. The tug on the line completes the circuit and the current flows through the copper wire of the fishing line into the hook and from there into the body of the fish. From here it returns to the cathode which may take the form of a metal plate fastened to the side of the ship or the propeller. The problem is technically solved in this way: On board a diesel motor (at least 100 h.p.) drives, by a belt, a 35 kVA three phase alternating current generator as a power source for a pulsing device. This device provides pulses at a rate of 40 - 120 per second adjustable continuously and capable of a peak voltage up to 400 v.. The pulsing device is provided with a distribution box which offers the capability of energizing 35 hooks at one time. (fig. 96) In this box a relay is available for each hook which can be attached by a seawaterproof bayonet connection. In order to prevent the angling lines lying on the deck from being electrified an arrangement has been developed which provides current only when the hook is immersed in seawater. The optical controls near the safety elements are

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also present. An isolation transformer of 4 kVA having a primary coil of 220 V, 60 Hz and a secondary of 200/300/400 Volts. is also installed. Moreover in the control box an additional transformer 200 v / 24 v provides protection and is activated by a microswitch built into the lid of the box. This microswitch is necessary to prevent an undetectable disturbance of the electrodes caused by opening the lid. The voltage in the killing chamber can be regulated by the control box separated from the former by at least two meters, when the top is closed. If this top is unintentionally opened before the current in the killing box is turned off the current is automatically switched off.

The killing box may be made of plastic at a series of sizes up to 1.50 m x 1.0 m x 0.85 m. For these dimensions it is advisable to install a three-phase connection for the control box since three electrodes are attached to the ends of the killing box and must be provided with single phases. The electrodes under the cover are connected to the MP of the isolation transformer.

Another device was constructed for the co-operative in Brade (Denmark). In this installation a tiled trench about 4 m long 1.80 m deep and 1.50 m deep was connected by a tube of 40 cm diameter which connected the trench to the tank holding 10 zentners of rainbow trout. The fish were induced to swim through the tunnel to the trench. If the cover, to which the underside has the R electrode fastened, is closed the lethal voltage can be switch on---.

S191

The sieve plate serves as a zero conductor. The killing system protected by a housing is galvanically separated by the driving net. Up to 5 t of trout may be killed per day using this arrangement.

This system of stunning and killing fish can also be used in the fish

196 175

retail and wholesale business, to kill fish humanely and legally. As far back as 1939 the "Narcostat" was developed by Siemens-Schuckert. The device consisted of a container filled with water the narrow sides of which were covered with electrodes. Alternating current was supplied to the container by activating a contact knob and quickly stunned or killed the fish. The stunned condition lasted from a few seconds to several minutes and the time in which the fish were slaughtered was sufficient for this purpose. MEYER-WAARDEN used the Narcostat to tag eels. Fish are narcotized in a similar manner in England and America before tagging. In these countries 110 volt alternating current essentially serves this purpose and is supplied through electrodes separated by a distance of 60 cm. Two minutes in the stunned condition occurs after an exposure of 5-7 seconds.

According to a report of G. Oesten written in 1898 this technique was used already in 1890, by his encouragement of the scientific division of Siemes and Halske AG, Berlin. Fish were easily stunned at voltages of 100-200 v. Oesten also recommended this method for the killing of eels.

5.2 Units for stunning and killing in sea fisheries.

There does not seem to be much application for stunning and killing devices in freshwater fisheries although there is some in sea fisheries. But also in sea fisheries very few plans have so far been realized and, in most cases, these are viewed doubtful. Overlooked is the methods which have been used for several years to kill tuna in the large killing compartment of the trap nets (Tornare, Almadrabas) on the Mediterranean coast (especially in Sicily) and on the Atlantic coast of Spain, Portugal and Morocco. Perhaps the interest of the fishing industry would be greater if it was known that this method is not only humane but is time and personnel saving. The electrically killed fish have a better quality and a longer storage life than fish

(197)

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killed by ordinary means. This is also true for electrically killed sardines and tunas (electrified tuna hooks).

S 193

negative pole of the battery is connected to the relay through a safety buoyancy switch.

Fig. 96 Electrical device to catch tunafish of the Electrofishing Co-operative. The device has connections for 35 hooks.

Explanation of symbols

- 1 - diesel motor.
 - 2 - ?
 - 3 - generator
 - 4 -
 - 5 - 24 volt battery
 - 6 - above deck
 - 7 - below deck
 - 8 - fixed electrode
 - 9 - hand switch
 - 10 - safety floating switch with a waterproof pressure switch and supporting spring. length: ca. 20 cm, diameter: ca. 5 cm.
 - 11 - control wire
 - 12 - catching wire
 - 13 - plug and outlet
 - 14 - fuse for control circuit
 - 15 - 24 v relay
 - 16 -
 - 17 - main switch
-

This safety buoyancy switch (Fig. 96, No. 10) fastened to the rod connected to the hook interrupts the current flowing to the relays. The connection can be restored through the highly conductive seawater thus allowing the relay to function to send the killing current into the fish. The positive pole of the battery is directly connected to the relay. Since numerous hooks must be set out from the ship at the same time and since often several

S 194

hooks have fish, an automatic current switch has been developed which turns the current on as soon as a tuna is caught or one awakes from the electro-narcosis. Since the tuna has a bony pallet and cautiously takes the hook

198 177

into its mouth it is first stunned when the point of the hook works itself deeper into the mouth, is swallowed or hooks the lip.

The automatic current switch operates in the following way. A rubber rope is inserted in the angle line near the distributor box and when a fish tugs on the line this force is transmitted to the spring of a relay contact which turns on the current. When the tuna is killed or narcotized tension is reduced on the rubber causing the contacts to open. This process is repeated each time the fish regains consciousness. Thus only the attention that one usually gives a string of baited hooks is required. Formerly without the electrical modification this was especially diffecult when many fish were biting at the same time.

The fishing line consists of a copper wire insulated with a plastic coating. The "Vorfach" is manufactured in Swedish steel and insulated by nylon. (Fig. 97)

A smaller version of the above has been developed by the electrofishing co-operative for sports fishermen. This device electrifies two hooks. (Fig.98) by a battery-operated pulsing gear delivering 100 pulses per second at a peak voltage of 300 v.

Fog. 97. Fishing line Vorfach with hook and float for electrical Tuna fishing. (Photo; Electrofishing Co-operative.)

S 195 Fig. 98. Battery-operated pulsing gear for catching Tuna. (Photo: Electro-fishing Co-operative)

5.2.2 Killing sardines with electricity

There has long been a need in the French sardine fishery for gear to

kill the fish encircled by a net within the space of a few seconds. Without this technique the vigorous movements of the fish in the net or on board ship causes them to lose scales. Sardines displaying much loss of scales are considered defective by the consumer and command low prices. Attempts to develop such gear began in 1956. Engaged in these efforts were L'Institut Scientifique et Techniques des Peches Maritimes, the authors, and the Federation Nationale des Syndicats Français de Conservateurs des Produits de la Mer, Paris, and later certain german firms.

The ²dvice which was constructed resembles that used to kill ~~tuna~~ and is powered by a three phase alternating current generator and pulsing gear. The maximum peak current is 300 amperes per phase. The generator sends the current by means of a switching mechanism to three electrodes in the water. One electrode, in the form of a cylinder is fastened in the middle of a plastic ring and held floating in the bag of the net. The other two electrodes consist of a right-angled metal screen of about 16 cm² area fastened to long bamboo poles. These poles are immersed on both sides of the bag of the net.

Fig. 99: A device to kill sardines electrically.

Key to symbols:

- | | |
|--|---|
| 1 - battery | 10 - instrument case |
| 2 - diesel motor | 11 - below deck |
| 3 - generator, three phase 100 / 200 v. | 12 - above deck |
| 4 - shield, three pole activated with d.c. | 13 - battery, neg. pole in water |
| 5 - plug and outlet | 14 - plug and outlet |
| 6 - field controller | 15 - opposing electrode to No. 13
consisting of a cable, electrode
and a protective screen. |
| 7 - current converter | 16 - contactor - feeler. |
| 8 - protective device | |
| 17 - purse sein | |
-

¹ Since the sardines are mostly packed in oil the french consumer wants to find a flaw less mirror of skin when the can is opened. Because of these desired optical properties the industry is compelled to pack fish which have not lost scales.

After the purse sein is drawn the current is switched on for about 10 seconds. The sardines are killed withing this time. (Figs. 99 to 101)

Sardines killed in this manner lose almost no scales, have firm flesh and are free from hemorrhages. They are of high quality and a processed product of great value. With the gear it is possible to kill 150 kg of sardines confined in the purse sein within 3 seconds. It should be mentioned that the gear was mounted on a cutter about the size of the sardine catching ships in the french trade, and corresponded closely in specifications of these vessels. This gear differs from that used in large vessels in that it does not require high power generators.

S 197 Fig. 100: Generator used to produce the pulsed current for killing sardines electrically. (Photo. - Halsband)

5.2.3 Killing Whales Electrically

The idea to kill whales electrically was already conceived 100 years ago. In 1852 A. Sonnenberg and P.H. Rechter of Bremen obtained a paten for this technique. It was proposed to install in a whaler a hand operated induction machine which would electrify a harpoon. The hand thrown harpoon was connected by a cable to the machine. The harpoon thus took the form of an electrode. The opposing electrode was a copper plate fastened to the

201 V 180

outside of the boat. This scheme which was never practically tested illustrated long ago the essentials of this technique for killing whales electrically.

S 198

Fig. 101: Negative electrodes fastened to the side of a boat used to kill sardines.

Another application for a patent(although the claim is not known) appeared in England in 1868. The first practical trials were carried out by the Norwegians in 1881. Details on these trials are not available. Birkeland's idea of killing whales electrically was revived in 1904, carrying out of the plans at the time foundered on insufficient technology. First of all the german engineer A. Weber as part of contract with "A/S Elektrik Hvalskytning" renewed the attempt and after many years of experimentation obtained a solution in 1934. Weber utilized 220 V a.c. at 50 Hz obtained from a generator on board the ship. The harpoon he used also had undergone development by Svend Foyn. A grenade harpoon had evolved from the hand thrown weapon Weber converted the explosive head of the harpoon into an electrode having a sharp arrowhead point and two claw like protruberances. This "electroharpoon" was the same size and weight as that of the grenade harpoon. The rope attached to the harpoon contained an additional electric cable. The harpoon was again shot as usual from the gun propelling the grenade weapon.

S 199

German, English and Norwegian whaling enterprises used this method to catch whales up to the outbreak of the second world war. More than 2000 whales were collected.

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Electric whaling developed further after the war, but now the more effective pulsed current was employed, under the initiative of C. Kreutzer. While he did not construct any gear he gave many hints to those that did. He however, was actively involved in developing pulsing gear for catching small whales.

Fig. 102: Harpoons used to kill whales electrically.

(explanation in the text) after Weber, Left: harpoon closed, Right: harpoon open.

S 200 Fig. 103: Catching whales electrically according to Weber. Explanation in the text.

Harpoons were also greatly improved after the second world war, R.Marsden, in England, made use of a 3.4 kg harpoon in many trials in which the shaft was detachable and separated at the moment the harpoon entered the whale. The separation is achieved by a split and twisted tip fastened to the shaft by a special catch and a spring. (Fig. 102). The electric cable on a drum is, as usual, attached to the harpoon line.

The principle of electric whaling is similar to that employed in angling for tuna. A harpoon is shot from the ship from a cannon into the body of the whale and the electric circuit is completed (Fig. 103). In the traditional method an explosive charge is placed in the head of the harpoon which is detonated when it penetrates the whale's body. This is certainly not a humane way of killing. The time required to kill the animal usually is about two hours. Sometimes the whale is gravely wounded and the increase of adrenalin during the struggle decreases the quality of the

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flesh.

The electrical harpoon method has quite opposite effects. After the penetration of the harpoon the whale is narcotized within a few minutes because of the great surface of its body. In many instances the animal is killed. Usually only 35 - 60 A are necessary to achieve this effect, when the shot is in the dorsal musculature. For shots below the vertebral column, (visceral shots) the current strength required lies between 78 abd 92 A. If the harpoon is shunted, which occurs when the hook protrudes from the body, currents up to 100 A and more are necessary. Even when the whale is only narcotized from the most successful shot death occurs no longer than 10 minutes.

Electrical killing is completely painless for the whale. It is important to raise this point here since whales are highly developed creatures having the sensitivity of other mammals to pain. The animal is not torn apart by an explosion and the meat is less tough, being in fact tastier than the flesh of a whale killed in the usual manner. Since the animal does not bleed no adrenalin is formed in the tissues.

The method developed by Weber in conjunction with the Siemens-Schuckert plant used 50 Hz alternating current at 220 volts. The base electrode consists Ofthe ship's hull and the electrode producing the potential difference is the tip of the harpoon head. The current required is produced by the generator. When killing by pulsed current a pulsing device is employed powered by a generator.

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Fig. 104: The shunt arising from a discharged harpoon.

If you compare the two different methods of killing whales then pulsed current is preferable. Narcosis using the latter method is assured and followed certainly by death, which is not the case when all explosive charges are used. Alternating current does not produce the desired effect and the animals would dive away. Another advantage for pulsed current is the small amount of current required compared to that required when alternating current is used. Since more reserve current is available in the pulsed technique narcosis is caused even when the shot is in the bone and the shaft of the harpoon has not quite penetrated the body of the whale. Even an extension line formed by the harpoon with the water is incidental. before they were available for experiments. In the second instance (Baltic sea cod) we had to transport the fish several hours in the hold after they had been caught in a trawl until they could be transferred to a holding tank in the harbour before experiments could be carried out.

A further modification of the experimental sequence consisted of not killing the fish electrically when hauled on board but keeping them on ice and without ice. After the killing they were stored in liquid air. Later in the laboratory ATP (adenosine triphosphate) and glycogen were determined in these fish. The less violent the slaughter the higher these constituents were in the fish flesh. Previous experience suggested that the electrical killing method was the most gentle method. Of all techniques this method resulted in the least decrease in ATP. Electrically killed fish displayed, as a result a prolonged rigor mortis meaning that bacterial decomposition and autolysis occurred later. The details are as follows. After death ATP is dephosphorylated to ADP (adenosine diphosphate)

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Part of this ADP is converted back to ATP using the energy of glycolysis and part is transformed through dephosphorylation and deamination to IMP (Inosin monophosphoric acid). The possibility exists that ATP is deaminated in the first step and the pyrophosphate residue is converted to IMP. As a result the ATP content becomes less and less until no more ADP is available for resynthesis into ATP. The amount of glycogen present is converted into lactic acid and the pH decreased such that the glycolysis enzyme system is deactivated. After death the amount of ATP and glycogen decreases whereas the amounts of lactic acid and IMP increases. It must also be recognized that in death the muscle goes through the process of rigor mortis. In living muscle a large portion of ATP is bound to the protein fraction of myosin. This combination is responsible for the elasticity and suppleness of the muscle., In proportion to the breakdown of ATP .

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flesh of a whale killed in the usual manner. Since the animal does not bleed, no adrenalin is formed in the tissues.

What electric solution has been found to kill whales? The method developed by Weber in conjunction with the Siemens-Schuckert plant used 50 Hz alternating current at 220 volts. The base electrode is formed by the ship's hull and the electrode producing the potential difference is the tip of the harpoon head. The current required is produced by the generator. When killing by pulsed current a pulsing device is employed powered by a generator.

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5.3 Installation of electrical killing devices to increase the quality of fish flesh.

The idea to improve the quality of fish flesh as well as the storage life was conceived by Kuroki in Japan and Meyer-Waarden in Germany about the same time. The latter noted ^{in 1989 at Morocco} ~~that~~ workers in a tuna processing ^{company} ~~plant~~ could easily distinguish between fish killed by conventional means and those killed electrically. The workers were guided not by the initial colour of the flesh but by the better consistency of the flesh as well as the prolonged storage life of those killed electrically. After similar observations made on sardines treated in the same way and in the Japanese investigations mentioned above the author with FR. BRAMSTEDT with the support of K. TRAUTNER and H. THIEDE investigated the electrophysiological ^{cal} ~~and~~ and chemical-physiological processes going on in the body of a fish when killed electrically. Facilities for this investigation were provided by research groups of the food industry.

Investigations were conducted not only on freshwater fish (trout) but also on marine fish (sardines, sardellen, plaice, Baltic sea cod). A group of fish were killed by a blow on the head and a comparable group killed electrically. In each group some fish were killed when relaxed while others were pursued in the tank before slaughtering. With the marine fish the experiments could not be carried out so systematically since the test fish has first to be captured in an encircling net which certainly caused considerable commotion. In the first trial (sardines) it required at least half an hour before the purse of the net could be hauled on board the ship before they were ^{available} ~~available~~ for experiments. In the second instance

(Baltic sea cod) we had to transport the fish several hours in the hold after they had been caught in a trawl until they could be transferred to a holding tank in the harbour before experiments could be carried out.

A further modification of the experimental sequence consisted of not killing the fish electrically when hauled on board but keeping them on ice, and without ice. After the killing they were stored in liquid air.

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the myosin combines with a second protein fraction -actin- to form actomyosin. This combination is stiff and unelastic. The relationship among the ATP content glycogen and the maintenance of quality is summarized in the following account:

S 204 The greater the final concentration of ATP the longer the time necessary to break down the ATP- myosin combination and the formation of the actomyosin complex. The stage of rigor mortis is therefore drawn out. On the other hand the greater the terminal concentration of glycogen the more ADP can be converted into ATP with the resulting formation of lactic acid and the lowering of pH. The lowered pH inhibits bacterial composition but also promotes the action of proteolytic enzymes. Bacterial decomposition, however, plays a more important role than breakdown by the enzymes and thus an excess of lactic acid is favourable for the preservation of fish flesh. The quantities of glycogen and ATP ^{which} are responsible for the formation of lactic acid ^{are influenced very strongly by} ~~and this is affected in turn by~~ the activity of the fish just before capture. Since movements of the fish before capture by electrofishing are very much reduced it follows that fish obtained by this technique have flesh of higher quality than those caught by other methods. This applies only to fish which have been killed while in a quiet condition rather than thrashing about for some time in a net.

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Fish flesh of high quality is obtained only when the fish are first caught using the anodic or repelling effect and subsequently killed immediately electrically. Once killed they must be placed in ice as soon as possible. KUROKI provides the following demonstration:

One hundred and fifty chopped crucian carp weighing each 10 g were killed by various techniques, (normal and electric). Increase of ammonia resulting from the breakdown of protein was determined, ^{pH - Value} Protein and ~~non-protein nitrogen~~ was also determined. It was found that fish killed electrically had a lesser tendency to putrefy than those killed by normal methods. The release of nitrogen in electrically killed fish was less.

In addition 24 carp, 100 g in weight were also investigated. The fish were divided into six groups of which four were killed electrically and the remaining two by conventional means. Properties of the proteins were determined by the methods described above. The concentration of thyrosine was also measured as well as pH. Significant differences were found between the normally and electrically killed fish. In summary it may be said that no great difference exists between the flesh of fish killed electrically and by normal means. This difference became evident later during the storage life of the fish. Additional experiments shed light on this difference. Freshly caught fish are immediately killed on board the fishing vessel by interrupted direct current with a discharge voltage of 85V at 400 mA. Frequency of pulses was 20 Hz.

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The fish regained consciousness after ¹⁰~~10~~ seconds exposure to this current ^{after 3 sec.} but were killed at exposures of 40 seconds.

Experimental fish were mackerel, pike and kihadas.

Values of pH were determined by a device manufactured by the Toyo Filter Company. Tests for the consistency of the flesh were conducted using the Tauchi fish grading method. The following constituents were determined: glycogen, lactic acid, volatile and basic nitrogen, volatile and basic organic acids.

Flesh of the electrically killed fish was found to be in better condition, supporting the use of this technique. Moreover the electrically processed fish showed no discolouration in comparison to normally killed fish after several days.

Kuroki also came to the conclusion that glycolysis proceeded at a much slower rate.

6. Other Applications of Electrofishing Currents

Living sardines when used as bait for Tuna are normally kept in containers and injure themselves by swimming into the walls and are subjected to decreasing levels of dissolved oxygen in the water. The Japanese minimize these losses by applying electric impulses. They achieve the same results as the French and others who paint the container white and illuminate it electrically. These techniques cause the fish to swim around in the container in a tight school.

In Japan it has been discovered that the spawning in Mytilus edulis can be elicited by faradic stimuli (50 pulses per second).

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A stimulus of 20 V is sufficient when applied for 5 seconds. Sexual products are dropped after an hour and the time bears no relationship to the strength and duration of the stimulus. The spawning act is natural and the eggs are fertile responding to the sperm.

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Quality of fish flesh is also maintained in the Soviet Union by electrical methods. Fish are stunned by an electric shock and then placed in crushed ice. Even after a trip of several days they can be sold as fresh fish ~~conserved~~.

It seems possible to use pulsed current to inhibit the growth of bacteria. E. HALSBAND and H. SCHEER were able to kill lactic acid bacteria and other forms which settle on fish flesh. This observation suggests that the process can be used to prolong the shelf life of preserved fish.

Special gear has been developed to catch crocodiles - something necessary in Ethiopia and Angola. The apparatus is a special adaptation of the 3-kW-Mofix gear and consists of a catching anode, the cathode and a distribution box possessing four terminals for harpoons. Pulses of current are regulated by a hand switch. All parts of the gear may be transported in a boat which has places for at least seven men. Operations are conducted at night. Crocodiles are spotted with flashlights. It is necessary to approach the animals as close as possible and endeavour to place them in the range of the anode. When this is achieved the crocodile which is vulnerable is selected. A harpoon is then shot into the reptile using the silent gear and a

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pulse of current applied through the handswitch. If the animals are stunned the plug of the harpoon is pulled out of the distribution box so that the harpoon is without current and the wire thrown into the water. An attached buoy marks the location of the crocodile. The animals are ^{at first} ~~therefore~~ drawn to the anode, stunned and, after applying the electrical current killed with the electrified harpoon, (Fig. 105).

Another application of the effects of the electric current not directly related to electrofishing is the scaring or frightening of gull} and other water birds from fish ponds and reservoirs. Since fish ponds are peaceful and free from traffic, gulls find them a favourite resting place. To discourage them from settling on the banks of the pond an electrical device has been developed. A kind of "fence" is constructed around the pond consisting of metal rods 8 cm apart and 10 cm high. These electrodes are provided with 30 pulses per second with a peak voltage of 35 - 50 kV.

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A technique has also been developed by which the changes in the sensitivity of fish to electrical current in the presence of polluted waters can be investigated.

Fig. 105: Electrical gear used to catch crocodiles
- the Co-operative for Electrofishing Devices

Correlations exist between the sensitivity of fish to electrical stimuli and their metabolism. When metabolism is elevated fish are easily stimulated: when depressed the fish are more difficult to arouse. Metabolic rate depends upon the composition of the surrounding water and pollutants. This provides a method of assessing the degree of pollution in water by determining the response of fish to standard electrical stimuli.

Testing apparatus has been developed which makes this possible. Values of pollutant stressed fish are compared with those of fish living under normal conditions. Threshold values for the onset of electrotaxis and electronarcosis are recorded. Percentage deviations between normal and stressed fish provide some measure of the degree of pollution. The method is quick and easy to carry out and is applicable for use in the field. In any event this method yields an estimate of the amount of clean water which must be mixed with the polluted water to restore the normal behaviour of the fish.

Electrical current can be used to inhibit fouling organisms on the hulls of ships. This is an old method. Edison received a German Imperial patent in 1890 to produce a blocking electrical field by means of surrounding the ship with a ring of floating electrodes.

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S 208 Fort The suggestion to place an electrical charge on the hull making it a cathode to protect it against corrosion and fouling at the same time was already made 50 years ago. Earlier experiments conducted by H. KUHL showed that application of alternating current as an anti-fouling procedure was difficult to achieve in practice. Since in recent times the application of the cathodic protection against corrosion is used very frequently it is necessary to look at the problem of anti-fouling from a different perspective. Experiments were carried out on the Elbe river ^{at the} ~~using the ship~~ "Alte Liebe" of Cuxhaven. Rectangular pulses were applied and were produced through contact free switching transistors. It was found that there was no effect up to a field strength of 0.5 volt/cm in sea water. Since ^{as Balanus} the animals growing on the surface of the hull ~~were~~ "see pocken" [?] were difficult to see in the water ~~experiments~~ were carried out in the laboratory where the cypris and other planktonic larvae could be observed under the microscope. Their movements were recorded kinematographically. Observations on the larvae ready to settle on the hull were especially important since the adults were protected by a thick shell. The passage of current was achieved either by two fine platinum points ^{of} (2 mm separation) or two platinum plates producing an almost homogenous field parallel to the surface of the hull. Homogenous electrical fields vertical to the colonization surface were produced by a platinum wire and an iron plate. In the attenuated electric field the organisms reacted to minimize the potential across their body, ^{so that} their viability was not affected. This means that only strong electrical currents

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can be used to protect ships against the settling of larvae on their hulls.

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Electrofishing in Inland Waters - some Practical Considerations

1. Preliminary Examination of the Waters

Each fishing operation must be planned in advance since each body of water has its own peculiarities and these must be taken into account to carry out a worthwhile fishing operation. Attention must be paid to the following:

- (ii) The topography of the body must be known i.e. extent, depth, and the shape of the basin. Also important are the nature of the banks, bottom as well as the plant growth on these.
- (iii) Water conductivity must be measured.

1.1 Topographical Survey

Most favourable for electrofishing operations is calm water of limited boundaries, i.e. trout streams up to 3 to 6 m wide. The banks must be firm but passable for the electrofisherman if he does not wish to wade in the water.

✓ The depth of the water may be less than 1.5 - 2 m.

Muddy ~~dog~~ water is often unfavourable since it conducts away much of the electricity and allows the fish to burrow in the mud. Thick plant growth has similar effects. On the other hand such dense growth can hinder the escape of the fish and make it easier to catch. Such a situation is found on the reed fringes of Steinhude Lake.

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Reaches of a brooks up to a width of 6 m and elongated lakes of the same width are easier to fish than broader bodies of water. In these waters fish excited at the fringe of the field can easily escape and are difficult to recapture.

Large bodies of water should be divided into small sections by stationary nets. (see page 170) or electrified nets combining the attracting and repelling properties of the electrical current.

Water velocity determines the type of electrodes and boats to be used. At high water velocities floating electrodes are unsuitable and sinkable metal plates must be employed. Since the fish can be quickly swept away at high velocities weirs and nets must supplement electrofishing operations. (see page 177 for Hager's method).

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1.2 Physical and Chemical Examination

Water conductivity is undoubtedly the most important factor in eliciting good anodic effects. Conductivity depends upon the chemical and physical properties of the water as well as the geological formation. The degree of industrial or domestic pollution also has an effect. (pollution load)

A good example of the influence of geological formation on water conductivity is provided by the water chemistry of lakes in the Franconian Jura in the Bavarian forest and of lakes in the ancient (precambrian) formations of Sweden. Examples are also provided from districts of Switzerland and the central alps. Waters of these regions have water resistivities in the range 5000 to 60,000 $\Omega \times \text{cm}$.

As mentioned on page 29 the essential formula is:

$$I = \frac{U}{R} \quad \text{i.e. Current} = \frac{\text{Potential difference}}{\text{Resistance}}$$

(Ampere)

The smaller the current strength at a constant potential the greater is the resistivity of the water. If the resistance between anode and cathode is 500 Ω then, at a potential difference of 250 volts I (current) will be $\frac{U}{R} = \frac{250}{500} = 0.5\text{A}$. To increase

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the number of ampères you have to double or triple the voltage for the same value of R, to achieve a current of 1.5A.

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Example: At 750 V I is $\frac{U}{R} = 1.5$ A.

In water of high resistivity of lower conductivity it is sometimes impossible to attain sufficient current intensity to elicit the anodic responses at the usual input voltage. In these kinds of waters gear must be used which generates a much higher potential difference. All gear of the Electrofishing Co-operative have two ranges of voltage built in to the system and the higher range must be used in these instances. You really must know the characteristics of each body of water to attain the most efficient electrofishing effect. In water conductivity greater than 15000Ω maximum voltages of 750 V are not sufficient and it is necessary to work with pulsed current. The allowable peak voltage for moveable gear is about 1000V and, for stationary installations as much as 10000V. (See the chapter on V_{DE} determinations).

In very conductive waters (those of low resistivity) a relatively high current is produced when R (resistivity) is small. Since $I \times U$ is very great equipment capable of delivering high current must be used. Example: If the resistance between anode and cathode is 10Ω and the potential difference is 300V then the current required is $\frac{U}{R} = \frac{300}{10} = 10$ A. The wattage of the gear is then $U \times I = 300 \times 10 = 9$ kW. When the resistance is smaller an even larger generator must be used. If the gear used was only 7 kW and 9kW were required the voltage would be reduced otherwise

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the circuit breaker would be tripped to avoid overloading. In the example cited here the voltage would have to be decreased to at least 260V since $\frac{260}{10} = 26A$ and this corresponds to a capacity of $260 \times 26 = 6.7$ kW. The voltage can be only reduced to that providing the minimum field required to produce the anodic effect on fish.

Reducing the current strength is another possibility. This can be done by decreasing the surface area of the electrodes and therefore the extent of field of current lines. This is of course, only a makeshift arrangement. In waters of high conductivities and low resistivities pulsing gear must always be used.

2. Electrofishing in Inland Waters.

Electrofishing in freshwater requires a team consisting of an electrofisherman, an equipment attendant, an assistant and a helper. The electrofisherman operates the catching device and directs the operations. The equipment ^{attendant} ~~addendant~~ looks after the gear and the cathode; the assistant catches the fish which are flushed out of their hiding places. The helper receives them for identification. If the electric current energizing the gear is controlled by radio and requires only one person who does the fishing, and has the fishing permit, then one other person is instructed by the fisherman, (the catcher) in the control of the switch. This is necessary for the safety of the ^{operator} ~~operators~~ in the event that the current must be quickly turned off.

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Three basic methods are used in electrofishing waters:

1. Fishing from the banks
2. Fishing in the water (wading)
3. Fishing from a boat.

Fishing from the bank is recommended when the water is shallow (about 1.5 m deep) and not wider than 5 to 6 m. Sparse vegetation on the banks is necessary since there must be good access to the water. The gear remains on land and must be either carried or wheeled in a cart. The two electrodes are immersed in the water at a distance of at least 10m. Then the current is turned on. The separation of the electrodes can be as much as 500 m by the use of a length of cable. In shallower water (less than 1.5 m) it is better to wade especially when the banks are overgrown with vegetation. The gear can either be placed on the bank or carried on the back of the assistant or fisherman when small enough. In the first instance the electrofisherman must make sure that the cable does not get tangled in the vegetation. In the second the fisherman carries his own gear on his back and the assistant carries the battery nearest the cathode. He should also take care that the cathode is separated from the anode by the proper distance so that the connecting cable is not caught on snags and stones in the water. The TSY 150 gear (page 119) is light because of its transistor circuitry and is carried by the assistant while the fisherman operates the catching electrode. When the catching electrode is a plus pole then the fisherman can remove the attracted fish.

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With other anodes the customary catcher is used to retrieve the fish.

It is advisable to fish against the current in rapidly flowing brooks with the anode immersed above the cathode. Narcotized fish carried down stream remain in the electrical field longer and may be attracted to cathode.

The "three catcher method" can be used in larger water courses. In this instance the one catcher remains in the water and the fish are removed by the other two. It often happens that the current is shut off when the catcher is lifted out of the water and ^{then} ~~some~~ stunned fish escape.

If it is desired to keep the captured fish alive a wagon supplied with containers and bottles of compressed oxygen must be available. Oxygen must be supplied as soon as the fish have recovered from the electronarcosis.

If the shallow water is to be totally fished out it is necessary to install a fine guage net which extends from bank to bank of the body of water. A second net is placed about 25 m away from the first and a third about 100 m from the second. The first space is fished and the wall of the second net hinders the flight of the escaping fish. After the first space is fished out the third net is brought closer (25 m) and the second net dragged toward it. The first net now takes the place of the third and is 100 away. In this way most of the fish can be removed from long reaches of a river.

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You cannot fish from the bank in waters wider than 5 or 6 m; in this case a boat must always be used. In general a river boat with a flat bottom is sufficient. The boat is maneuvered upstream alternately from side to side.

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Electrical gear cable and other equipment remain in the boat. The electrodes are inserted in the water from the boat and the cathode is dragged about 5 m behind (Fig. 106). In this example it would be advantageous to use a cable cathode as described on page 133.

It is advisable in large stretches of water where electrified nets cannot be used, to divide up the area with stationary nets and to fish out the various sections independently of each other. It is still desirable, if possible, to set electrified nets in the water.

Fig. 106: Electrofishing in a canal on Speicher Lake near Munich. Small bream are being removed which have been attracted by the heated water in the canal.

In the chapter "Movable electroshocking devices and anodic catching gear combined with electrical nets" the construction of this kind of a net ^{is} described. When a seine of any kind is available it can be electrified in a very simple way. The catch is always improved when the body of water is blocked off with a stationary net. In any event the time spent to catch the fish is considerably shortened.

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The author in the course of his many investigations in foreign countries has often been compelled to electrify the available nets, even hoop nets. The success of fishing way always improved. In Fig. 107 the installation of an electrified net in eel waters in France is shown.

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A steel cable is drawn over the entire upper and lower ropes of the net and connected to a pulsing gear. Since small eels up to 100 g can slip through the mesh a finer unelectrified seine must be drawn behind. Within two hours (including the time to electrify the net) more than 0.5 tons of fish were caught. Not one eel was caught when the same net, unelectrified, was drawn through the same stretch of water. Sometimes when the net was electrified it was necessary to switch the current off since the fishermen were unable to remove the catch fast enough.

Fig. 107: Fishing out a brackish water channel on the Atlantic coast using an electrified net.

In ponds with uneven bottoms the fish can first be attracted by feeding food and then fishing them electrically. This feeding must be carried out regularly at least two to three weeks prior to the fishing operations. Since fish tend to stay in sheltered areas a wooden plate about $2m^2$ is placed in the water and the food thrown in the water over this area.

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The anode may be placed in the water and the cathode consisting of an iron chain pulled over the bottom. The field formed between the electrodes leads the fish in the direction of the anode.

Fishing with the aid of a boat and fishing by wading is preferable to fishing from the bank since the catcher can be operated better to catch fleeing fish. Fishing from the banks, moreover, is difficult in most cases because of the electric cable is often caught by the vegetation.

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Nowadays electrofishing in inland waters is limited to the fishing of small sections of water bodies. Fishing the entire water body is rarely done: as a rule this kind of operation is carried out when trout ponds are to be completely fished out before fingerlings are reintroduced. If a large body of water is to be electrofished it must be done when the fish are concentrated in a small area which is accessible to the fisherman. An example of this is the fishing of eels in the cold months of the year when they overwinter in thick clusters in the mude. The fish can be electroshocked to move into the fringing reeds and caught by the anode effect.

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To operate in this manner a good knowledge of the physical setting of the water and the habits of the species of fish is necessary. To obtain an optimal effect the best time to conduct fishing must be chosen. Fish, for example which spend much of their time at the bottom or are buried in the ooze over

the winter are best caught during the warm season when their responses to the electric current are good. This is especially true for carp and tench as well as similar fish species. For the remaining species, as has been shown for the eel, winter is the best time since at cold temperatures the electrical conductivity of water is high. If blank eels are to be caught swimming at this time downstream they must be shocked during their resting period on the bottom. Yellow eels are caught, in contrast, during the warm season when they find shelter in stone rubble and bundles of faggots.

The Care and Maintenance of Electrofishing Devices

All electrofishing devices require regular maintenance (see VDE No 0136, parts one and two and 0686, parts one and two) Before installation of all devices they must be cleaned and checked. Poorly insulated spots on the gear and the cable must be eliminated. Attention must also be paid to the corroded parts of the metal structures; these must be removed for insertion of the gear in the water.

Chapter 7

VDE Specifications for the Regulation of Electrofishing

Electrofishing requires special regulations. Unskilled workers can harm fish stocks using improper methods or even endanger human life. The German Association of Electrotechnologists (VDE) has been concerned for years with developing specifications for the construction and operation of electrofishing devices. A commission was formed in 1956 originally under the chairmanship of Dipl. Ing. HEIDER and subsequently in 1960 by Dr. Lauer who undertook the leadership.

The author assumed chairmanship in 1973 and has held this position since. The following were published:

1. Regulations for the installation and operation of stationary electro-fishing devices in freshwater (VDE regulation 0136/section 1 March 1959 Revised August 1969.
2. Regulations for the construction of electrofishing gear for freshwater (VDE regulation 0686/section 1. September 196 . Revised August 1969.
3. Regulations for electrofishing operations in coastal waters and on the high seas. (VDE regulation 0136/section 2. May 1969.
4. VDE regulations for the construction of electrofishing installations in coastal water and the high seas. (VDE regulation 0686/section 2. May 1969
5. Special regulations for operating electrofishing installations in freshwater coastal waters and the high seas (VDE regulation 105/section 5. August 7, 1969

The above regulations have been recently revised and extended.

VDE regulation 0136/Part 3: directions for the installation of electroshocking devices in inland and coastal waters.

VDE regulation 0136/Part 4: directions for the installation of electrofishing killing gear

VDE regulation 0686/Part 3 directions for the construction of electrofishing shocking gear in fresh and coastal waters.

VDE regulation 0686/Part 4: directions for the construction of electrofishing killing devices.

VDE regulation 0105/Part 6: special directions for the operation of electrofishing shocking installations in fresh and coastal waters.

VDE regulation 0105/Part 7: special directions for the operation of electrofishing killing installations.

These regulations and directions will come into force at the end of 1973 or, at the latest, at the beginning of 1976.

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These regulations may be of interest to the reader of this book and are discussed briefly here. Electrofishing on the high seas and in coastal waters will be treated here only for the sake of completeness. The author as a member of the VDE committee is totally familiar with the work of this body and will touch on the problems of concern to the commission. *of their current.* In no way is their ~~currently~~ final decision anticipated.

1. Construction and Operation of Electrofishing Devices in Inland Waters

VDE regulations distinguish between fixed and movable installations.

Movable installations comprise portable or mobile devices which, according to the type and customary usage, are moved when the current is switched on. In this category are devices which employ the anodic effect

and movable shocking gear.

Fixed installations are mounted in one place either because of their nature or because of a mechanical attachment to one spot. Examples are: installations on ships, fish barriers and fish guiding devices to either weirs or fish ladders.

Mobile installations are permitted the following voltages across the electrodes:

750 volts for direct current

1000 volts peak value for pulsed current.

In fixed installations the maximum voltage allowed is 10,000 v. (effective)

Electrofishing operations are divided into three categories:

Electrofishing gear in the first category must be provided with a three-pronged plug (or connection) so that it can be grounded. This is especially important for fixed installations.

In the second category no grounding is necessary but wires must be well insulated ex. anodic catching gear connected to more than 24 V.

Gear in the third category may, because of the low operating voltage, require no protective insulation up to 24 v. (an example is battery operated gear of voltages less than 24 V.)

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For electrofishing devices operating at voltages greater than 24 V the whole device must be completely insulated or protected against accidental contact.

All catching gear must have an arrangement which prevents the electrodes being left unintentionally plugged in. There should be either a hand-operated switch, an other intermediate switch (ex. foot switch) or a remote control (radio-operated) switch. In any case each device must be provided

with an accesible protective trip switch (safety circuit breaker).

Safety fuses should not be used. Some arrangement must be present in pulsed gear to discharge the condensor. i.e. a switch to produce a short circuit. The cable, insulating materials, housing of the equipment and protective clothing must be protected from the harmful effects of weather and humidity.

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All the parts that make up an electrofishing device such as generators, storage batteries, converters, transformers, condensers, resistances, switches, regulators, measuring equipment, and conductors must conform to VDE regulations.

Regulations for these individual components may be obtained at any time from the Association of Electro-technicians. (VDE regulations). This information is found in the appendix to regulation VDE 0686 which is concerned with the construction of electrofishing gear.

Movable devices must be operated by at least two persons, the electrofisherman and his assistant. The electrofisherman assumes responsibility for the operations as well as the maintenance of the equipment. Both personal should master the details of VDE regulations 0134 concerned with first aid if accidents occur.

2. Construction and Operation of Electrofishing devices in Coastal Waters and the High Seas.

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In part I the areas are defined which states that, in addition to installation and operation regulations, there are the DIN (German Industrial Standards) of the German Lloyd-DIN 89001-VDE regulations 0100, 0101, 0105, 0111, 0141 as they apply to the construction of ships.

The second part explains the concept contained in this section One has to distinguish, as in regulation VDE 0136/1, between movable and stationary electrofishing devices.

In part III the general conditions are given and safety measures to be taken to prevent accidental touching of components under electrical tension (voltage) and for too high contact voltage. Regulations for operation, servicing and maintenance of the equipment are also specified.

The general regulations stipulate that electrofishing may be conducted in coastal waters and on the high seas when the proper voltage and nature of the current are used. When the electrofishing device is powered from the electrical mains or the current network on board ship the functioning current must be supplied through an isolated transformer - a converter with its own winding to separate them electrically. The seaman's union has responsibility when the gear is on board ship.

The safety measures ensure that all parts of an electrofishing devices which operate at voltages greater than 24 V must be insulated in all parts of the apparatus. In some instances a special type of construction could prevent accidental contact with the electrically charged parts. Each device which is electrically activated must have a means by which the current is turned off when protective doors are opened. Moreover, all those conductive parts which are not part of the circuits used in electrofishing but which are accessible, must be connected to a common circuit breaker. Emergency switches to turn off the current at all important stages must also be provided.

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3. Special Regulations for the Operation of Electrofishing Devices in Inland, Coastal Waters and on the High Seas.

The areas where these regulations apply have been defined in part I.

The concepts in these regulations have been outlined in part II and are referred to in items 0136 and 0686.

Part III states that at least two people must be present during the operation of movable electrofishing gear. The electrofisherman has the responsibility for the fishing operations and receives his mandate from the regulating organization.

The details may be read in the current edition of the VDE regulations obtainable at : VDE Verlag, 1 Berlin 12, Bismarckstr. 33.

Chapter 8

Overview

The application of electricity in fishing has been solidly established as a catching method in many countries. It has certainly found its place in inland fisheries. With the development of new methods and gear, especially pulsed current - the way to improved commercial fishing has been opened. In this chapter in the first edition the wish was expressed that the repelling effect of the electric current

It is not easy to make predictions on the future of electro-fishing in the ocean. Not because there are no applications - on the contrary - there are many important examples. There has not been time to define the financial conditions that make the operation profitable.

Electrofishing was conducted in the ocean first after the war and had to overcome technical, scientific and, not least, financial difficulties before the first pulsed gear was developed and proved to be practical in the ocean. Even today the number of properly functioning devices which are used is limited. Beyond that there are electrofishing devices which are combined with lights, a practice used by the French. Electrical barriers installed in saltwater in front of the water intakes of factories and power station have proved their worth; likewise have narcotising and killing gear. One has to merely recall the application of the electric harpoon and Tuna hook. It would be desirable in the future for these two methods to be used more than they have been up to now. Not only would the fish harvest be greater but the product would be of higher quality. Especially in the catching and killing of sensitive valuable fish as sardines etc. electricity should be used. Fatty fish are extraordinarily sensitive and can be processed in electrical killing devices to improve the quality of the flesh. The quality is better than that resulting from traditional methods. It would be a profitable exercise for technology to undertake the development of suitable gear. We are aware of some firms which are engaged in such activities but practical results are yet to come.

This gear must, above all, be inexpensive since it would be used by the financially weak cutter ship industry.

Electrofishing in the ocean has indisputedly gained during the

be applied in the construction of intake structures (pumps turbines, etc.) In the time following publication, I am pleased to report that all industrial operations in which water is drawn from an intake canal are now provided with electrical fish screens. The public already knew that about 20% of all fish passing through turbines were either injured or killed. - most of these being valuable fish such as eels. Nowadays the fish screen has been fully developed to achieve its purpose. It is admitted, however, that in only very rare cases is a complete blocking effect achieved. It is necessary to adapt the electrical barrier to the prevailing hydrological conditions and to recognize that factors as temperature, water currents, water chemistry, water pollution life stage as well as the health of the fish are important. In spite of these variables a 80 to 90% blocking effects can be attained in a properly functioning barrier.

The electrical means of killing fish has also proved to be of great value. By means of this technique less labour is required in the processing of trout and eels. Money is saved in the preparation of smoked and portion-sized trout. It may be applied someday to the fish retail business to kill fish since approved methods of killing do not come in question.

The question whether the method of killing electrically leads to an improvement of the quality of its fish flesh and prolonged shelf life may be considered solved.

It may be shown that, in catching fish, prolonged shocks, harassment etc. should be minimized. While plausible, this practice is often not followed. At last we can settle the matter using the results of biochemical and electrophysiological investigations.

last years and will certainly make more progress in the future.

Unfortunately the number of scientists, technologists and companies which are concerned with electrofishing is extremely small. As a result the rate of progress cannot be predicted. Again the amount of investment for marine fisheries is usually prohibitive. High costs of development limit the marketability.

Today we are convinced that electrical collecting, repelling and stunning methods neither cause pain to animals nor injure them internally or externally, (apart from unavoidable exceptions). Harmful genetic effects - or harmful effects to the progeny - are also not produced. Ignorance of electrophysiological and electrophysical laws, often in fisheries experts have retarded the development of electrofishing.

You cannot complete the reading of this book without realizing that more must be done to explain this field. This book serves this purpose.

We hope that anyone who is seriously involved with this problem has now the necessary intellectual armament.


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