were not tightly packed but were scattered over a considerable area. The combination of clear water, scattered small schools and appearances at the surface late in the day presented too many difficulties for purse seining and no fish were taken by that method.

Several types of small fish are found in the Gulf and West Indies area in sufficient abundance to give promise of good sources of supply for live bait fishing. Weather conditions throughout a large part of the year are unfavorable, but how serious this is can only be learned by actual trial. Operations south of the hurricane belt are a practical possibility during hurricane season. There are some indications, too, that the tunas are more easily found in the extreme southern Caribbean in the months of December, January, and February. Any understanding of the potential of a live bait fishery for tuna in the area should come from exploratory fishing with live bait carried on over a period of more than a year.

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Some Practical Aspects of Electric Fishing in the Sea

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A great amount of interest has developed among commercial fishermen in recent years concerning the possibilities of using electrical methods of catching fish in the sea. In this paper the writer intends to present some of his current ideas and conclusions on this method of fishing arising out of a review he has made recently of literature dealing with this subject.

The application of electric fishing methods in the sea involves the establishment of an electric field of the required current density and distribution in a specified volume of sea water at periodic intervals of time.

For satisfactory results the apparatus for electric fishing must be capable of setting up at the boundary of a specified volume of water an electric field of such current density that a condition of electro-taxis is produced in a fish of a given size and species. This is a condition in which the fish orients itself in the electric field with its head pointing toward the anode or positive electrode and involuntarily swims in the direction of that electrode.

As the electric field in a continuous medium such as a large body of water spreads out in all directions from an electrode in an approximately radial manner, the current density in regions outside the boundary in which electro-taxis occurs will be too low for producing this effect. Any fish in these regions will be frightened by the uncomfortable electric field and will try to escape from it. In regions within the boundary for electro-taxis, however, the current density increases rapidly in the direction of the electrode and will everywhere be at least equal to or greater than that necessary for causing a condition of electro-taxis. Conceivably a fish swimming toward an electrode in a condition of electro-taxis would soon reach a region where the current density would be sufficient for producing a condition of paralysis. Should this happen the fish would become incapable of any further movement and probably would turn belly up and slowly sink toward the bottom. If the electric field were maintained for a long enough period of time while the fish were in this condition, it would die.

In water of a given resistivity the current density necessary for producing a condition of either electro-taxis or paralysis has to be determined experimentally for each species and size of fish. For a given species of fish, experimenters have found that there is an inverse relationship between the length of the fish and the current density required for paralysis. On the basis of data obtained while experimenting with salmon fingerlings and trout in fresh water having a resistivity of 10,000 ohms per inch cube. McMillan (1928) found that the relationship between the length of fish and the voltage gradient for paralysis could be expressed by the equation:

$$g = \frac{3.70}{L}$$

where g is the voltage gradient per inch to produce paralysis and L is the length of the fish in inches. Since the current density is equal to the voltage gradient per inch divided by the resistivity, this equation can be written in terms of current density as:

$$i = \frac{3.70}{\rho L}$$

where i is the current density in amperes per square inch taken in a section at right angles to the electric field and ρ (rho) is the resistivity of the medium in ohms per cubic inch.

McMillan also established that water resistivity has a very great affect on the voltage gradient necessary for paralysis. In a series of tests made in 1928 on salmon fingerlings in water, varying in resistivity from that of sea water having a resistivity of 11.6 ohms per inch cube to that of mountain-stream water having a resistivity of about 10,000 ohms per inch cube, he found that the minimum voltage gradient for paralysis changed from .27 volts to 1.23 volts per inch, or about 4.55 times. This led him to introduce a correction factor "W" for water resistivity in the voltage gradient equation above as follows:

$$g = \frac{3.70W}{L}$$

Using McMillan's value of W for sea water of .219, the above equation reduces to:

$$g = \frac{3.70 \times .219}{L} \text{ or } \frac{.81}{L}$$

This may be written in terms of current density as:

$$i = \frac{.81}{\rho L}$$

The ideal distribution of the current flow for electric fishing would be one in which the current density was uniform throughout the entire volume of the water between the electrodes. While it is possible to obain a fairly uniform distribution of current flow in a tank or trough of uniform cross-section, it is extremely difficult if not impossible to achieve such a distribution of current flow between electrodes immersed in a large body of water. Jeans (1908) has shown that the lines of current flow between two electrodes in a continous medium are identical with the electrostatic lines of force which exist when two electrodes are charged to different potentials in air. This means that the lines of current flow from an electrode immersed in a large body of water tend to spread out radially in all directions from the electrode. When the physical size of the electrodes is small in comparison to the volume of the medium in which they are immersed, this radial spreading of the current is practically independent of electrode shape. The fact that an electrode is a sphere or a flat plate has little or no effect on the radial spreading of the current. Therefore, it can be said as a rather rough approximation that the current density varies inversely as the square of the distance from an electrode.

The rapid spreading of the current from an electrode deeply immersed in a large body of water requires a very large flow of current from the electrode to produce a current density sufficient for paralysis at a distance of only a few yards from the electrode. Assuming a uniform radial spreading of current, it can be shown that the total electrode current must approach a value of about 6530 amperes to produce a current density of 4 milli-amperes per square inch at a distance of 10 yards from an electrode. The current density used in this example is that necessary for paralyzing a salmon 20 inches in length as computed by McMillan's equation for the paralysis voltage gradient. To produce this current density, assuming that the resistance between the electrodes and the medium is about .25 ohms, the electrical apparatus must be capable of supplying at the electrodes about 10,700 kilowatts of power at 1630 volts. To extend the same current density out to a distance of 20 yards from the electrode, the total electrode current required is about 26,200 amperes and the apparatus must be capable of developing at the electrodes 171,200 kilowatts of power at 6520 volts. The total current in each instance here has been computed using the following equation which is valid for a uniform radial spreading of current from an electrode:

$$I = 4 \pi R^2 i$$

where I is the total electrode current, R is radial distance from the electrode in inches, and i is the current density in amperes per square inch.

The power required for electric fishing can be reduced by using short, periodic pulses of current instead of continuous current. As an example, suppose that square wave pulses of 2 milli-seconds duration are repeated at a rate of 50 per second. Then the current is on for only 100 milli-seconds or for only one-tenth of a second out of each second. This means that electrical apparatus in the examples above would need to provide only one-tenth of the amounts of power indicated there or about 1070 and 17,120 milowatts respectively.

Experimenters have observed also that some pulse shapes or waveforms and pulsing rates are more effective on fish than others. A recent report from Europe indicates that the German scientists, Kreutzer and Peglow, have determined that a square wave pulse of 2 milli-seconds duration repeated 50 times a second is very effective on cod and herring. At the California Academy of Sciences, Groody, Loukashkin, and Grant (1952) have found that the movements of sardines can be controlled effectively by means of sawtooth shaped pulses of 133 milli-seconds duration repeated 5 times a second. This indicates that the best waveform and pulsing rate have to be determined experimentally for each kind of fish.

It should be apparent now that the principal limitation to the application of electric fishing methods in the sea in a practical way at present is imposed by the radial spreading of the current from the electrodes. Because of this spreading of the current, the power capacity of the electrical apparatus aboard the ship must be very great to set up a current density of a few milli-amperes at a distance of only a few yards from an electrode. Future research in this field should be directed toward finding methods of concentrating or confining the electric field to a limited volume of water between the electrodes in so far as may be possible. Laboratory experiments should also be carried out to determine the correct current densities for producing the conditions of electro-taxis and paralysis in various kinds of commercially valuable fishes, as well as the best waveform, pulse length, and pulse rate to use with these fishes. Having ascertained these factors it will be possible to estimate the electrical power required and proceed with the assembly of the apparatus needed for applying electrical methods of fishing to a particular fishery in a practical way.

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Holding Fresh Shrimp in Refrigerated Sea Water[1]

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During the past several years shrimp boats in the Gulf of Mexico have been making longer and longer trips. The greater length of time spent away from port has increased the difficulty of landing high quality fresh shrimp. In addition, present icing methods result in a condition known as "black spot" on the shrimp. (Figure 1.).

The need for more efficient methods of refrigeration and control of the black spot problem led the Marine Laboratory of the University of Miami to conduct a series of experiments, for the Florida State Board of Conservation, in which shrimp were held in refrigerated seawater instead of in crushed ice.

Preliminary tests were conducted in which the quality of iced shrimp was compared with that of shrimp held in sea-water, fresh water, and solutions of calcium chloride and sodium chloride. Pink grooved shrimp (*Penaeus duorarum*), caught by a commercial trawler off Key West, were held in the various solutions at temperatures which ranged between 37.9° and 41.7°F. The quality of these shrimp was tested seven times over a period of 24 days. A testing panel of ten staff members of the Marine Laboratory rated the shrimp as to firmness, black spot, odor and taste. (Table 1).

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[1] Contribution No. 94 from The Marine Labortaory, University of Miami.