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Catch selectivity by electrical fishing systems

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Electric fields affect large fish more strongly than small fish. Electrical fishing systems should preferentially capture the larger members of a fish stock, but in practice their selectivity is controlled by the uniformity of the electric field distribution and the particular fish reaction to electrical stimulation being exploited. From published data, the selectivity of a practical system is evaluated for various electric field distributions and types of fish reaction. It is found that the probability of capture by the system increases with fish size, but with a high electric field strength the system can be non-selective.

Introduction

Aquarium experiments on the reactions of fish to uniform electric fields have shown that large fish react at lower field strengths than small fish (Bary, 1956). Linear relationships between fish length and voltage along the fish have been observed. Consequently, a fishing system which incorporates an electric stimulus should preferentially capture the larger members of a fish stock. In a practical situation, however, selectivity will be complicated by two factors; the highly non-uniform nature of the electric field distribution developed by an electrode array in an unbounded medium (Dickson, 1954), and the range of reactions, induced by different levels of electric field strength, which could enhance the capture rate.

An electrical fishing system will contain an electrode array to generate electric fields of suitable strength in the zones thought to be tactically important; in the mouth of a fish pump (Le Mèn, 1971); before the groundrope of a trawl (Klima, 1968); or along the warps of a trawl (Kreutzer, 1950). Electric fields developed around finite-sized electrodes in unbounded media are non-uniform due to the spreading out of the current flow lines. An electrified fishing system therefore contains regions of high and low field strength, and it is possible for small fish to enter high field zones and be strongly stimulated, thus reducing the selectivity of the system.

Electrotaxis and electronarcosis can be used to aid fish capture, and systems have been designed to use these reactions (Nikonorov, 1971). Relatively high electric field strengths are required to induce narcosis, e.g. with 2 ms long DC pulses 40 V/m is required to stun a 25 cm long fish. Fish can detect the presence of weak electric fields, and the "fright" reactions produced can also be utilised as an aid to capture. The fringe zones of systems designed to induce narcosis have weak electric field levels, and if fish entering these zones are stimulated in such a way that they become more vulnerable to capture, the selectivity of the system will again be reduced.

The selectivity of any fishing system is of considerable importance. If the relationships between electric field strength and fish length for the reactions produced by a particular species are known, it should be possible to predict the selectivity of an electrified catching system when used on that species. The data obtained by Bary (1956) on the reactions of mullet to electric fields have been used to evaluate the selectivity of a practical electrode system, and the analysis, with its implications, is presented here.

Data

Figure 1 shows selected relationships between fish length (L) and voltage (V) along the fish for electrical stimulation by AC and pulsed DC. These data for mullet (*Mugil auratus*, Risso) are taken from Figures 3 and 4 of the paper by Bary and show threshold conditions for electronarcosis and detection of the presence of an electric current. Bary's measurements were made in an aquarium tank with a uniform electric field. In a non-uniform electric field, voltage is not a meaningful quantity unless related to dimensions within the field zone. To analyse fish reactions in a non-uniform field it is simpler to define the reaction thresholds in terms of the electric field strength, and not the voltage, experienced by the fish. Fish reactions in each part of the field can then be

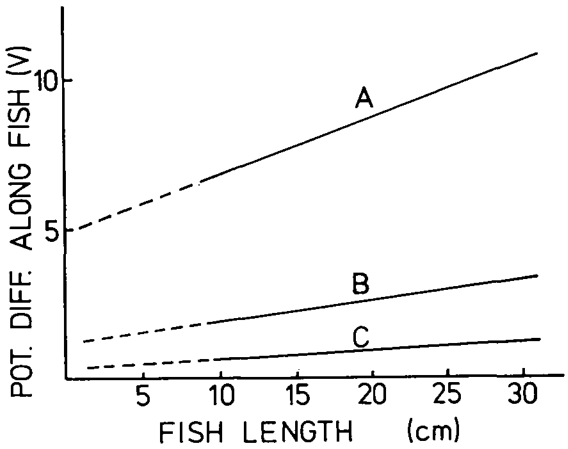

Figure 1. The effect of length of mullet on the minimum potential along the fish required to induce a minimal reaction (C) and narcosis (A and B). Stimulus: A – 2ms DC pulses at 20 Hz or more; B and C – 50 Hz (AC).

predicted by comparing the field strength with the known threshold values. In Figure 2b the data of Figure 1 are replotted as electric field strength ($E = dV/dL$) against fish length. The solid lines represent Bary's measurements and the dashed lines are extrapolations.

Figure 2c shows an electrode array consisting of four parallel cylindrical electrodes (each 1 cm in diameter) being towed at right angles to their length. This type of array could be towed in front of the groundrope of a trawl, and used to force fish clear of the bottom (Stewart, 1974). Adjacent electrodes are energised at opposite polarities as shown, and the electric field distribution is non-uniform. In Figure 2a, the distribution in the plane of the electrodes is shown, with an applied voltage of 70 V, for two different electrode separations (d). The abscissa represents the percentage of the area, extending to $d/2$ on either side of the array, which has an electric field intensity $\geqslant E$.

Derivation of selectivity

The selectivity of the electrode array in Figure 2c can be deduced from Figures 2a and 2b. Selectivity is defined as the probability, expressed as a function of fish length, of reactions being induced in fish within the electric field. The fraction of the electrified region in which the field strength exceeds the threshold level for a given size of fish represents the probability of a reaction being induced in a fish of that size. Figure 2a must represent the field distribution experienced by the fish. For this to be the case it is assumed that the fish are randomly distributed, close to the plane of the electrodes, swimming in the direction of motion, and only receive one burst of electrical stimulation from the array, which is being intermittently energised. The frequency and duration of the periods of electrical stimulation are such as to allow the fish to gather whilst the electrodes are unenergised. Although the behaviour described is hypothetical, it is not unrealistic and serves to illustrate the selective properties of electrical stimulation.

The procedure used to derive the reaction probabilities in Figure 2 is illustrated for the case of a 16 cm fish. A fish of this size will experience narcosis in a pulsed DC field with 2 ms pulses at a field strength of 53V/m or more. This field strength can be encountered over 43% of the electrode array with $d = 1$ m, and over 16% with $d = 2$ m. The probability of the fish being narcotised is thus 43% in the first case and 16% in the second case. By this means the graphs in Figure 2d can be built up. The letter beside each curve in Figure 2d indicates the curve in Figure 2b from which it was derived.

The fish lengths considered in Figure 2 are not negligible when compared to the electrode separation, and the effective field strength over each fish is an average value. This will inhibit the stimulating effect of the high field zones near the electrodes, particularly for large fish. The field strength in these zones is, however, greatly in excess of the threshold values for large fish in the array of Figure 2c, and the averaging effect should introduce only slight errors in Figure 2d.

Discussion

Figure 2d displays a wide range of reaction probabilities, depending upon the field distribution and the reaction considered. Graphs B, C and C′ illustrate that it is possible to create conditions under which an electric fishing system is virtually non-selective. In these cases only the smallest fish have any chance of not being affected by the field, and in the most extreme example (C), there is 100% probability of a reaction being induced in all fish longer than 2 cm. This situation arises when the mean field strength

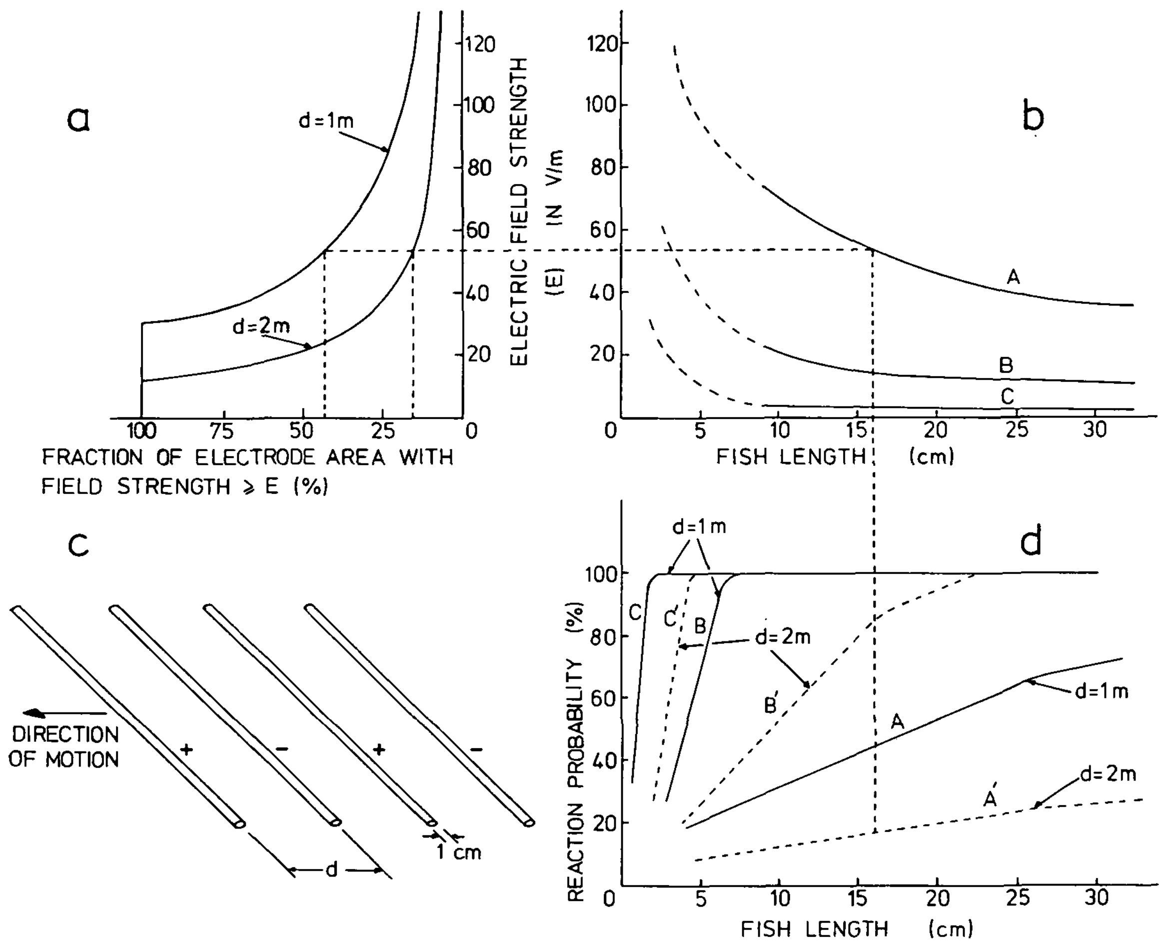

Figure 2. Evaluation of reaction probabilities for mullet in a nonuniform electric field. a) electric field distribution, b) reaction thresholds, c) electrode array, d) reaction probabilities.

is high compared to the threshold values. Graphs A, A′ and B however, show that electrical fishing systems can act selectively. The probability of a reaction being induced increases with fish length. The selectivity is imperfect, and is a compromise between efficiency in capturing large fish and relative inefficiency in capturing small fish. In a practical situation, the mesh size in the cod-end can be chosen to eliminate the small fish. The electrode voltage and the electrode separation can then be chosen to give a probability-length curve which reaches 100% at the maximum size of fish which can pass through the cod-end. This would ensure that the stimulus was used to maximum benefit.

If the weak field reaction to 50 Hz (AC) stimulation causes fright, resulting in capture, then the system selectivity will be very low (Graphs C and C′). Any system which utilises fright reactions, e.g. tickling flatfish up off the bottom, must use a less intense electrical stimulus. A suitable pulsed DC stimulus would have an electric field - fish length curve similar to A in Figure 2b.

The selectivity of any electrical fishing system can be evaluated if the information for Figure 1 and Figure 2a is available. The above analysis was based on the assumption that the fish in the electrode array were randomly distributed. This could be true if the gear had no herding devices preceding the electrode array, e.g. a beam trawl. If herding devices are used the fish will not be randomly distributed, but congregated in certain parts of the gear, and some size selection may have taken place. Further selectivity will then depend on the field distribution in these regions. If the field uniformity is improved, the curves of Figure 2a could be more linear and the selectivity would be improved. For any electrode array, if the path of the fish through the array is known, the appropriate curves for Figure 2a can be calculated. The literature contains little data similar to that presented in Figure 1, which is for mullet. In general, if selectivity is to be predicted, it will be necessary to conduct measurements on each species to define the threshold stimulus for the reactions of significance in any particular electrical fishing scheme.

Conclusions

a. The size selectivity of an electrical fishing system can be calculated;
   1. if the relationship between threshold electric field strength and fish length is known for the species and reaction of interest;
   2. if the path of the fish through the system is known, so that the appropriate electric field distribution can be obtained, and allowance made for the selectivity of other parts of the system.

b. The probability of capture by an electric fishing system increases with fish size, but with field strengths greatly in excess of reaction threshold values some systems can be non-selective.

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