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A4_9 Electric Ray Fish

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Abstract
This paper examines how a higher resistivity of freshwater, in comparison to saltwater, results in an increased emf output produced by strongly electric ray fish in this habitat. It is discussed how the arrangement of biological electric cells relates to the emf output for both fish.

Introduction

Strongly electric ray fish have evolved organs which allow them to emit strong electric pulses in order to deter predators or capture prey [1]. These bioelectric organs, situated on either side of the fish's head, consist of several cells, referred to as electroplaques [2]. These electroplaques operate similarly to batteries by providing a high voltage pulse, which is then transmitted to the target animal. In order to understand how freshwater and saltwater electric ray fish differ, it will first be discussed how the electroplaques operate.

Electroplaques

The electroplaques consist of a negatively charged cell with a membrane of variable permeability, controlled by nerve impulses. The electric ray fish can cause current to flow by allowing the negative charges inside the electroplaque to flow out, resulting in a potential of approximately 0.1 V per electroplaque [3]. Studies have shown that for electric ray fish in saltwater, where the electroplaques are arranged in parallel, the measured total emf is approximately 50V. For freshwater fish, where the electroplaques are arranged mainly in series, the emf is approximately 500V [4]. This difference will now be examined in further detail.

Freshwater Fish

By treating each individual electroplaque as a source of emf, similar to a battery, the total emf provided by the electric ray fish can be estimated. The total emf, ε_{TOTAL}, is found by considering *N* number of electroplaques, each with an emf ε, connected in series. As emf sources act similarly to emf sinks (i.e. resistors), the equations describing the equivalent resistance of a combination of resistors can be used to find the total emf by replacing resistance with emf. For freshwater fish, it will be assumed that all the electroplaques are in series. Therefore, the total emf provided by an electric ray fish in freshwater is approximately [5]:

$$\varepsilon_{TOTAL} = \varepsilon + \varepsilon \ldots = N\varepsilon. \quad (1)$$

Therefore the total emf, ε_{TOTAL}, for an electric ray fish adapted to freshwater is the sum of the emf provided by each electroplaque, ε.

The total voltage delivered to the target can now be approximated. This is done by expressing the situation as a simplified circuit diagram, as illustrated in figure 1. Figure 1 shows the electric ray fish, which acts as an emf source, and the effect of the water and the target shown as resistors, as they are emf sinks. By using Kirchhoff's rules [5], the voltage delivered to the target, V_{TARGET}, is shown by equation (2), where *I* is the current and R_{FW} is the resistance of freshwater. It can be noted that the IR_{FW} term represents the voltage lost by the resistance of freshwater.

$$V_{TARGET} = \varepsilon_{TOTAL} - IR_{FW} = N\varepsilon - IR_{FW}. \quad (2)$$

This demonstrates that the voltage delivered to the target depends on the total voltage provided by the electric ray fish and the resistance of the water.

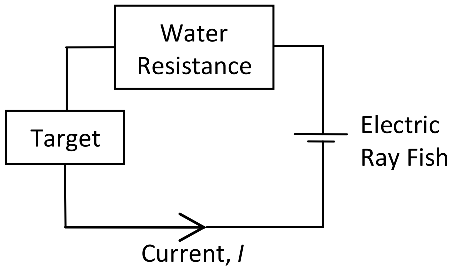

Figure 1. A circuit diagram representing the flow of electricity from the electric ray fish through the water and the target.

Saltwater Fish

For saltwater electric ray fish, all the electroplaques are assumed to be arranged in parallel. Therefore, the total emf provided, ε_{TOTAL}, is equal to the emf of one electroplaque [6]:

$$\varepsilon_{TOTAL} = \varepsilon. \quad (3)$$

This shows that the total emf provided by a saltwater electric ray fish is equal to the emf from one. By comparison to the result for freshwater fish, shown in equation (1), it can be seen that the total emf is smaller for saltwater fish.

As for freshwater fish, the same method can be used to find the voltage delivered to the target. The result is shown in equation (4), where R_{SW} is the resistance of saltwater. The IR_{SW} term corresponds to the voltage lost through the saltwater's resistance.

$$V_{TARGET} = \varepsilon_{TOTAL} - IR_{SW} = \varepsilon - IR_{SW}. \quad (4)$$

As with freshwater fish, the voltage delivered to the target depends on the total emf provided and the resistance of the water.

Discussion

The analysis shows that freshwater fish produce a greater emf output than saltwater fish. This result is in agreement with measurements of the emf output, as previously discussed. The difference is due to a difference in the resistance of saltwater and freshwater. Typical values for resistivity, found by taking the reciprocal of the conductivity [5], are approximately 20Ωm for freshwater, and approximately 0.2Ωm for saltwater [7]. This is as expected because saltwater has an increased number of ions in the fluid, which results in a decreased resistance compared to freshwater [8]. This implies that the voltage lost through the resistance of the saltwater is less than that of the freshwater. Therefore, the emf required from the electric ray fish to shock the target is reduced in saltwater.

This concept can be illustrated by a comparison of equations (2) and (4), assuming V_{TARGET} is constant for both situations. For freshwater fish, the term representing voltage lost through the water is increased, so ε_{TOTAL} must also be increased. On the other hand, the voltage lost through saltwater is decreased, so ε_{TOTAL} is not increased.

Conclusion

This paper has discussed how the electric ray fish has adapted to its environment in terms of the arrangement of electroplaques. The results demonstrated that the electroplaques are arranged in series for freshwater fish, as a higher emf is required to provide enough voltage to the target, and arranged in parallel for saltwater fish, as a lower emf would be sufficient.

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