FISH DIVERSION BY UNDERWATER SOUND AT DISCRETE FREQUENCIES

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1. Reasons for the studies.

Ontario Hydro has been experiencing some difficulties at Thermal Generating Stations due to fish entering the cooling water intakes and passing through the screens in sufficient numbers to clog cooling tubes. Since these fish tend to be of the same species and size, e.g. alewife schools, it appears possible that sound at a discrete frequency, possibly resonant, might prove a deterrent to their entrance and reduce their effect on plant performance. Therefore funds were made available for the research projects which are described briefly below.

2. General Background.

A long term problem associated with the generation of hydro-electricity has been that of providing for the safe passage of migratory fish around high dams and preventing losses due to turbine and spillway hazards. Various sound sources were investigated (1, 1953; 2, 1956) for the U.S. Fish and Wildlife Service and the results found to be discouraging.

Later papers by H. Kleerekoper and T. Malar (3, 1968), who worked as the fish behaviourist in 1972, and R.R. Fay (4, 1969) reported fish responses within the acoustic field and encouraged further investigation.

Meanwhile D.E. Weston (5, 1966) with P.A. Ching (6, 1969) had postulated that "Fish very often have a gas-filled swim-bladder which controls their low frequency acoustic properties and there is typically a resonance in the kilocycle region". The basic relationship is

$$L = \frac{8\sqrt{P_o}}{f_o}$$

where L = fish length in cms.

P_o = effective bladder pressure in atmospheres

and f_o = resonant frequency in kHz.

This swim-bladder resonant frequency appears to identify a sound which can be determined experimentally, to which fish will probably be sensitive, and which may cause discomfort leading to diversion.

In later conversations Dr. Weston expressed the belief that the power levels at which his projectors were working were such that fish would have been killed had they remained nearby. Since dead fish were not observed it may be inferred that live fish had moved out of the dangerously insonified volume of water. Unfortunately such movement was neither looked for nor observed accidentally so that no direct confirmation was available.

3. Field experiments in 1972.

A site was selected in which the water depth was about 6 ft. and which was sheltered from the normal prevailing winds and within reasonable distance from Glenora Fisheries Station and the Royal Military College.

The fish enclosure was 20 ft. long, 5 ft. wide and 6 ft. deep and was placed about 100 yds. from the shore. The sound projector and hydrophones were placed on the long axis of the enclosure with the projector 10 ft. from the near end at which hydrophone, H_1, was placed. Hydrophone, H_2, was at the centre of the enclosure and hydrophone, H_3, at the distant end. At all frequencies the output of H_1 was treated as standard and the outputs of H_2 and H_3 referred to it.

The T.V. camera was placed at the end of the enclosure nearest to the projector and observed a water column of smaller volume than was desired. Nevertheless the quantity of data video-taped was so great that its rapid analysis proved difficult.

When four species of the family Centrarchidae were introduced into the tank a well defined maximum attenuation at 1.15 kHz was shown. Attenuation effects below 0.5 kHz were only observed on one occasion (during the late evening) when they decreased with time and increasing frequency of applied sound. Due to poor and deteriorating light conditions fish behaviour could not be monitored during this time. Since resonant attenuation occurred at a much higher frequency it is considered probable that the fish were initially clustered at the end of the enclosure nearest to the projector, which faced the setting sun, possibly as a response to light orientation and intensity, and later dispersed as the light failed. It is also possible that the increasing frequency of the sound encouraged this dispersal.

Analysis of the video-taped data indicated that these fish were normally undisturbed by single frequency sounds between 0.2 and 20.0 kHz.

The most interesting results were obtained with alewife supplied by Glenora Fisheries Station. Sufficient data was available to use Weston's equation which gave f_o as 0.82 kHz. This was in good agreement with the experimental results.

Despite a shortage of data points, due to deteriorating weather conditions, considerable attenuation was shown at 2.0 kHz and school position and sound pattern appear to be related at this frequency, since H_3 produced its maximum output when the school could be observed by the T.V. camera. At this frequency the video-tape analysis indicated decreased school activity.

It was not unreasonable to regard the school as moving slowly from one end of the enclosure to the other with the movement either due to or causing the variations in sound pressure level at the end away from the T.V. camera.

From these experiments it was concluded that:-

1. No broad band acoustic source is likely to be effective in modifying the behaviour of fishes since their acoustic environment is also one of broad band noise.
2. The resonant frequency of a sufficient sample of fishes can be determined.
3. Fish response to sound at an appropriate frequency may be indicated.
4. Work in lakes is difficult and may be useless because too many variables are beyond control or compensation.
5. Experimental work should be completed before the end of June to avoid fish problems due to July's high temperatures.

4. Laboratory experiments in 1974.

The tank size was limited by the space available in the Power Laboratory of the Electrical Engineering Department at the Royal Military College. It was 60 ft. long, 2 ft. wide and 2 ft. deep, constructed of wood and first lined with plastic sheeting to retain water and then with acoustic damping material.

Ideally, all experiments would have been carried out with healthy fish which had become accustomed to their surroundings. Unfortunately this condition was never achieved so that the results were obtained with dying and/or shocked fish.

a) Guppies

Despite the considerable precautions taken before the guppies were introduced into the tank, sudden and considerable deaths occurred after less than 48 hrs. so that it was necessary to proceed immediately with response experiments. Since the surviving guppies were clustered at the end of the enclosure nearest to the projector the standing wave pattern made any movement difficult to interpret.

The theoretical average resonant frequency was 5.4 kHz. No direct attenuation measurements were made but anomalous hydrophone outputs were obtained at 2.5, 5.0 and 6.0 kHz.

Below 10.0 kHz it appeared that guppies would respond to sound at any frequency by agitated swimming once a lower threshold of sound pressure level had been crossed. This threshold level was lower at 2.5, 5.0 and 6.0 kHz than at 0.70 kHz, the only other frequency at which the input drive to the projector was varied.

b) Shiners

Survival problems were not expected since lake water was being pumped into the tank at one end and out at the other. 120 fish were placed in the tank on Wednesday, 3rd July and the main series of experiments planned for Saturday to permit the fish to become accustomed to their surroundings and to ensure that there was no other activity in the laboratory. By that day the shiners had started to die at an increasing rate, possibly due to a combination of previous rough handling and high water temperatures. No responses were observed when systematic experiments were carried out.

A brief test on Wednesday evening in which the frequency was increased from 0.20 to 20 kHz indicated increased fish movement at 1.0, 1.5 and 2.0 kHz. This was the range over which discomfort due to swim-bladder resonance might be expected since the theoretical average resonant frequency was 1.4 kHz.

c) Alewife

Approximately 30 cu. ft. of ice cubes were needed to reduce the tank water temperature below the recommended upper temperature limit of 20°C. In view of this cooling problem and the known delicacy of alewife the main acoustic experiments were performed after the alewife had been given only 90 mins. to become accustomed to the tank.

The theoretical average resonant frequency was 0.92 kHz and increased activity was observed at 0.80 and 1.5 kHz.

When the water temperature was 19.5°C the healthy alewife appeared to avoid the sound source while the dying ones were stimulated into violent flapping. Whatever question there may be about the avoidance of the source by healthy fish, there is no doubt that sound at 0.80 and 1.5 kHz stimulated nearly dead fish into violent activity. When sound at 10 kHz was used the healthy fish appeared to swim more actively but there was no response from the nearly dead fish.

5. General Conclusions

1. Some species of fish react to sound at a discrete frequency once a lower threshold of sound pressure level has been crossed. These reactions appear to be most vigorous around the swim-bladder resonant frequency.
2. Experiments under fully controlled conditions are needed to determine the frequencies at which fish responses are clearly interpretable and the sound pressure levels and gradients at which they occur.
3. Such experiments would require the long term funding of an interdisciplinary research team containing at least a fish behaviourist and an underwater acoustician. An anechoic tank in which fish could be maintained in good condition for long periods of time would be necessary.

6. Acknowledgements

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7. Bibliography

This paper summarises three Royal Military College Electrical Engineering Technical Reports. These are:-

73/2; S. Buxcey and T. Malar, Fish response to underwater sound at discrete frequencies.

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