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Experiments on frightening effects to fish by underwater sound emitters for diversion from dangerous areas of reservoirs

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ABSTRACT

Large reservoirs have areas dangerous for fish. For instance, water intake facilities, hydroelectric dams, etc. Therefore, it becomes necessary to protect or divert fish from such areas. One way to achieve this is to use loud underwater sound. Most fish are sensitive to noise. Acoustic underwater speakers, developed in recent years, transmit full-fledged sound information underwater. This made it possible to study the possibilities of scaring away fish by underwater sounds of various volumes and frequencies. The purpose of the experiments was the following: to set the dynamics of the sound volume attenuation, with increasing distance from the sound source; to study the fish reaction to different types of acoustic signal; to study the effectiveness of scaring fish with sounds of various volumes and frequencies; to set the duration of the effect of single and multiple acoustic scaring.

Keywords: Fish, Sonar, Sound, Frequency, Underwater speaker, Dam, Acoustic lens, Hydrophone, Fish scaring.

INTRODUCTION

Large reservoirs have areas dangerous for fish. For instance, water intake facilities, hydroelectric dams, etc. Therefore, it becomes necessary to protect or divert fish from such areas. One way to achieve this is to acoustically scare fish away from dangerous water bodies (Taft 1995). Most fish have developed hearing, and water is a good conductor of sound (Nikolsky 1963; Khajuie *et al*. 2022; Ambreen et al. 2023). Therefore, fish are very sensitive to noise. For fish living in low visibility conditions, the response to sound is a condition for survival and reproduction (Slabbekoorn *et al*. 2019). The detection and identification of sounds are used by many fish to avoid predators or find prey, and avoid obstacles (Popper & Platt 1993). The use of high-intensity sounds provides certain opportunities for controlling the behaviour of fish. All animals with developed hearing, including fish, have a loudness tolerance limit followed by a pain threshold. As the fish approaches the sound source, the volume increases. It scares them off or makes them leave before volume hits the pain threshold. Intense sound waves affect the soft tissues and swim bladder of the fish. Also, acoustic signals affect the sensitive lateral line (Schellart & Wubbels 1998). In response to this increased acoustic impact, the fish leave the area in uncomfortable conditions. The sensitivity of fish to sound allows it to be used to protect fish at water power facilities (Carlson 1994).

However, the difficulty lies in the fact that sound does not transfer well from air to underwater, and vice versa. Acoustic underwater speakers with molded acoustic lenses, developed in recent years, transmit sound information

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underwater that is comparable in quality to conventional terrestrial speakers. This made it possible to study the possibilities of scaring away fish with underwater sounds of various volumes.

MATERIALS AND METHODS

Experimental studies were carried out on a model reservoir - the Kirov reservoir in the West Kazakhstan region, Republic of Kazakhstan. To determine the background ichthyological data, scientific fishing was carried out by fixed nets with meshes from 22 to 80 mm. A total of 10 scientific catches were carried out. Sampling of juveniles was carried out using a juvenile circle designed by Russ and juvenile sled. A juvenile bottom trap was also used (Shalgimbayeva *et al*. 2017). In species identification of fish and juveniles, we were guided by well-known manuals (Koblitskaya, 1981; Maitland & Linsell 2006; Makeyeva *et al*. 2011). Ichthyological studies were carried out according to the generally accepted methodological guidelines (Pravdin 1966). A total of 320 fish specimens were taken to determine the species, age and size-weight composition of the ichthyofauna. The study of fish density was carried out using the echo sounding method (Kulikov & Kim 2018).

RESULTS AND DISCUSSION

Scientific fishing in the waters of the Kirov reservoir showed that pike, bream, silver carp, roach and perch live here. Pike in research catches was represented in the age range from 2 to 7 years. The average commercial length of fish varied from 31 cm at the age of 2 years to 63 cm at 7 years. The average weight of the fish increased from 297 g at 2 years to 1410 g at 7 years. The number of males was higher than the number of females by 11%.

Bream in research catches was represented in the age range from 3 to 7 years. The average commercial length of fish varied from 19 cm at the age of 3 years to 34 cm at 7 years. The average weight of the fish increased from 152 g at 3 years to 825 g at 7 years. The number of males was higher than the number of females by 17%.

Silver carp in research catches was presented in the age range from 3 to 8 years. The average commercial length of fish varied from 12 cm at 3 years to 35 cm at 8 years. The average weight of the fish increased from 138 g at 3 years to 760 g at 8 years. The number of males was higher than the number of females by 9%.

Roach in research catches was represented in the age range from 3 to 5 years. The average commercial length of fish varied from 14 cm at 3 years to 19 cm at 5 years. The average weight of the fish increased from 142 g at 3 years to 260 g at 5 years. The number of males was higher than the number of females by 14%.

Perch in research catches was represented in the age range from 2 to 6 years. The average commercial length of fish varied from 9 cm at 2 years to 23 cm at 6 years. The average weight of the fish increased from 129 g at 3 years to 271 g at 6 years. The number of males was higher than the number of females by 19%.

An analysis of these data shows that there are no deviations from the average values of size and weight in adult fish. The indicator of commercial fish productivity was 32 kg ha^{-1}

The study of the species composition and density of juvenile fish in the fry stage of development showed the following. The density of pike juveniles was 345 ind. ha^{-1}, with an average fry length of 51 mm and an average weight of 2.4 g. The density of carp juveniles was 82 ind. ha^{-1}, with an average fry length of 47 mm and an average weight of 1.8 g. The density of silver carp juveniles was 8947 ind. ha^{-1}, with an average length of fry of 30 mm and an average weight of 0.9 g. The density of bream juveniles was 2528 ind. ha^{-1}, with an average length of fry of 25 mm and an average weight of 0.64 g. The density of roach juveniles was 1738 ind. ha^{-1}, with an average length of fry of 29 mm and an average weight of 0.59 g. The density of perch juveniles was 1214 ind ha^{-1}, with an average length of fry of 31 mm and an average weight of 0.8 g.

An analysis of these data shows that there are no deviations from the average size and weight for juveniles in the fry stage. The density of bream juveniles was most noticeable which may be due to the high population size. An interesting fact is that carp juveniles were observed in the reservoir, but adult fish were not. The reservoir is annually stocked with carp under-yearlings, so they are found in samples of juveniles. However, obviously, most of the juveniles leave their reservoirs, during the discharge of water through the hydroelectric complex. This explains the absence of adult carp in the reservoir.

The purpose of the first experiment was to establish the dynamics of the attenuation of the sound volume, with a step-by-step removal from the sound source. For this, an OCEANEARS DRS-8-003/SA430 Mod 2 underwater speaker installed in the water was used. From it, a cord with meter markings was stretched over the surface of the water. Moving along the cord on the boat, from the turned-on speaker, we measured the sound volume underwater at a distance of 1 to 20 m. To measure the sound volume, an MS6701 digital hydrophone was used. It is known that there is a certain sound background underwater, which is associated with the movement of water and the behaviour of fish during feeding, movement, and communication (Rountree *et al.* 2006). Our measurements showed that the underwater sound background on the model pond is 23-25 dB. For the experiment, a set of acoustic signals was used: HORN, WAIL, YELP, and PHASER. These types of warning acoustic signals are widely used in various alarm systems. The results of the experiment are shown in Table 1.

Table 1. Dynamics of sound volume attenuation, with gradual removal from the sound source.

Type of acoustic signal	**Sound volume level, at different distances from the sound source (dB)**																			
	1 m	**2 m**	**3 m**	**4 m**	**5 m**	**6 m**	**7 m**	**8 m**	**9 m**	**10 m**	**11 m**	**12 m**	**13 m**	**14 m**	**15 m**	**16 m**	**17 m**	**18 m**	**19 m**	**20 m**
HORN	95	92	90	86	75	72	70	65	63	60	58	57	56	55	54	53	50	49	48	45
WAIL	92	89	80	77	73	71	68	63	60	57	55	54	53	51	50	48	46	45	43	42
YELP	92	88	79	76	73	70	67	63	59	57	54	53	52	50	48	47	45	43	42	40
PHASER	94	92	89	85	74	72	70	64	63	59	57	56	55	54	53	52	50	48	47	43

Analysis of Table 1 shows a dynamic decrease in sound volume as it moves away from the included underwater speaker, which may be probably due to the higher density of water compared to the density of air.

It is known that intense sound radiation induces an avoidance response in fish (Maes *et al*. 2004). An interesting question in this area is as follow: which sounds scare away fish, and which ones attract them? Within the acoustic modes available to us HORN, WAIL, YELP, and PHASER, we tried to partially clarify this issue. To begin with, we present the characteristics of these acoustic modes:

- HORN, horn, (rattle) giving a sharp sound with a frequency of 3984 to 4078 Hz, very quickly intermittent every 0.1 seconds;
- WAIL, a lingering signal of the "wolf howl" type, with a smooth change in frequency from 760 to 4071 Hz, every 5 seconds;
- YELP signal (dog barking) with fast frequency change from 760 to 4070 Hz, every 1.2 seconds;
- PHASER also often referred to as phase vibrato, is a series of highs and lows in a spectrum. Fast frequency change from 580 to 3985 Hz, every 0.2 seconds.

The study of the reaction of fish to different types of acoustic signals was carried out both under normal background conditions and under conditions of attraction. This is because in conditions of attraction, fish behave more persistently. Probably, the attractive effects weaken their innate caution somewhat. Fishing bait was used as an attraction (Fig. 1).

During the experiment, the underwater speaker was installed at the bottom of the reservoir. The fish were observed using the video camera of the Giadius mini S underwater drone. When fish accumulated next to the speaker, a certain sound signal was turned on for 10 seconds, at a maximum volume of 92-95 dB. Sound travels much faster in water than in air (Hawkins & Popper 2017). Therefore, the results were not long in coming.

Under favourable conditions, the following data were obtained:

- when the HORN sound is turned on, the fish freezes in surprise for about 0.7 seconds, then quickly swims away from the bait;
- when the WAIL sound is turned on, the fish reacts more slowly, after 2-3 seconds it leaves the bait;
- when the YELP sound is turned on, the reaction of the fish is approximately the same as with the WAIL sound, but somewhat faster, leaving the bait after 1-2 seconds;
- when the PHASER sound is turned on, the reaction of the fish is about the same as with the HORN sound, the fish freezes for about 0.7 seconds, then quickly swims away from the bait.

Under background conditions, the results were somewhat different:

- when the HORN sound is turned on, the fish immediately quickly jerks away from the sound source;
- when the WAIL sound is turned on, the fish swims away immediately, but not as fast as in the first case;
- when the YELP sound is turned on, the fish swims away immediately and somewhat faster than when the WAIL sound is turned on;
- when the PHASER sound is turned on, the fish immediately quickly swims away from the sound source.

The second experiment showed that the sound of HORN has the most frightening effect. The PHASER sound is somewhat inferior to it in this indicator. The WAIL and YELP sounds have a reduced fish deterrent effect.

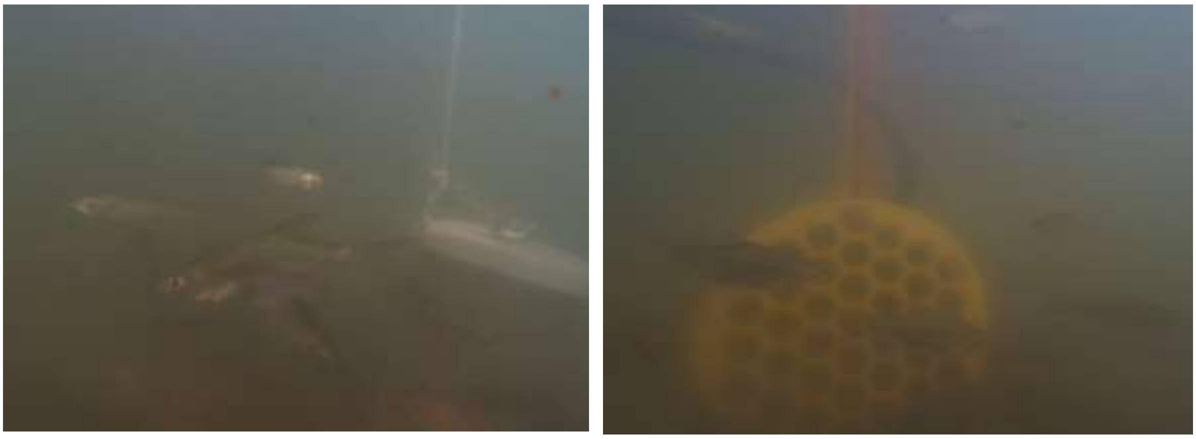

Fig. 1. Fish at the feeder (left); at the turned-off underwater speaker (right).

In the course of the third experiment, the efficiency of fish frightening was studied under acoustic exposure in the range from 55 to 95 dB. The underwater acoustic speaker OCEANEARS DRS-8-003/SA430 Mod 2 was used as a sound source. The visual results of the experiment were recorded by the Action GoPro Max (CHDHZ-201-RW) video camera and the Giadius mini S underwater drone, with a 4K Ultra HD 12MP camera. The effectiveness of acoustic fish frightening was carried out both under normal background conditions and under conditions of attraction. Fishing bait was used as an attraction. This made it possible to collect fish at the point where the underwater speaker was installed and to trace their reaction to a loud sound (Fig. 2).

Fig. 2. Fish behaviour before turning on (left); the underwater acoustic speaker, and after turning it on (right).

Table 2 shows the data on the efficiency of fish frightening under acoustic exposure in the range from 55 to 95 dB, in conditions of attraction. From the analysis of Table 2, it follows that sounds with a loudness of 95 dB are most effective in scaring away fish. High deterrence efficiency is maintained at a distance of up to 3 m. A sound with a loudness of 85 dB significantly affects fish at a distance of no more than 1 m.

Table 2. Data on the efficiency of fish frightening at different distances, in conditions of attraction, with acoustic exposure in the range from 55 to 95 dB.

Sound volume (dB)	**Efficiency of fish frightening at different distances (%)**									
	1 m	**2 m**	**3 m**	**4 m**	**5 m**	**6 m**	**7 m**	**8 m**	**9 m**	**10 m**
55	2	2	1	0	0	0	0	0	0	0
65	18	7	2	0	0	0	0	0	0	0
75	58	29	8	2	0	0	0	0	0	0
85	91	43	26	7	2	0	0	0	0	0
95	100	100	97	52	11	8	2	0	0	0

Under background conditions without attracting elements, the reaction of fish to sound was more sensitive. Table 3 shows the data on the efficiency of fish frightening under acoustic exposure in the range from 55 to 95 dB, in background conditions, without attraction.

Table 3. Data on the efficiency of fish frightening at different distances, in background conditions, with acoustic exposure in the range from 55 to 95 dB.

Sound volume (dB)	**Efficiency of fish frightening at different distances (%)**									
	1 m	**2 m**	**3 m**	**4 m**	**5 m**	**6 m**	**7 m**	**8 m**	**9 m**	**10 m**
55	6	4	2	1	0	0	0	0	0	0
65	21	10	4	2	1	0	0	0	0	0
75	64	37	5	3	2	0	0	0	0	0
85	97	63	38	19	7	5	2	0	0	0
95	100	100	100	72	29	14	5	1	0	0

The task of the fourth experiment was to determine how long the effect of a single acoustic scare is fixed in the behaviour of fish. The experiment was carried out both under normal background conditions and under attraction conditions. Since the most effective loudness (95 dB) was established by the third experiment, it was decided to use this loudness range.

Fishing bait was again used as an attraction. After a group of fish gathered near it, the underwater speaker turned on with a volume of 95 dB.

The speaker was turned on once for 5 seconds, and then the fish return time was measured. The indicators of this part of the experiment are shown in Table 4.

Table 4. Duration of the effect of a single acoustic frightening of fish at a volume of 95 dB and duration of the acoustic signal of 5 seconds.

Experiment indicators	**Time ranges (min)**									
	1 min	**2 min**	**3 min**	**4 min**	**5 min**	**6 min**	**7 min**	**8 min**	**9 min**	**10 min**
The number of fish returning to the point of scare after stopping the signal, under background conditions (%)	2	5	7	17	28	56	64	89	100	100
The number of fish returning to the point of scare after stopping the signal, under favorable conditions (%)	28	57	94	100	100	100	100	100	100	100

Under background conditions, fish begin to return to the point of repulsion 1 minute after the stop of a single acoustic signal. After 9 minutes, 100% return. Under favourable conditions, fish begin to massively return to bait 1 minute after the single signal stops. After 4 minutes, 100% return.

The objective of the fifth experiment was to establish how long the effect of repeated long-term acoustic scaring is fixed in the behaviour of fish. The experiment was carried out both under normal background and attraction conditions. Fishing bait was used as an attraction. Since the most effective volume (95 dB) was set, it was decided to use this volume range.

In an experiment lasting 1 hour, the speaker turned on for 10 seconds every 5 seconds. Then, after 1 hour, the time of the return of the fish to the location of the speaker was measured. The experimental parameters are shown in Table 5.

Under background conditions, the fish begin to return to the start point 30 minutes after the long acoustic signal stops. After 110 minutes, 100% return. In attractive conditions, the fish begin to return to the bait 20 minutes after the signal stops. After 50 minutes, 100% return.

Received:
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Table 5. Duration of the effect of repeated long-term acoustic frightening of fish at a volume of 95 dB, when the acoustic signal is turned on for 1 hour.

Experiment indicators	**Time ranges (min)**														
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
The number of fish returning to the point of scare after stopping the signal, under background conditions (%)	0	0	1	4	9	18	31	48	67	91	100	100	100	100	100
The number of fish returning to the point of scare after stopping the signal, under favorable conditions (%)	0	2	11	32	78	100	100	100	100	100	100	100	100	100	100

CONCLUSION

Scientific fishing in the research area - the waters of the Kirov reservoir showed that pike, bream, silver carp, roach and perch live here. An analysis of the biological parameters of fish showed that there were no deviations from the average values of size and weight in adult fish. The density of fish was 285 specimens per 1 hectare of water area. A study of fish juveniles in the fry stage of development showed that their density was 14,854 ind. Ha^{-1}. Deviations from the average values of size and weight in juveniles were not noted. In general, the background ichthyological indicators in the study area can be assessed as typical for water bodies of the West Kazakhstan region. The volume of sound underwater noticeably weakens when moving away from the sound source. At a distance of 20 m from the speaker, the volume is reduced by an average of 57%. At a distance of up to 3 m, the sound volume is quite high. However, further the volume dynamically decreases by an average of 3% per 1 m. The sound of HORN (rattle) has the most frightening effect. The PHASER sound is somewhat inferior to it in this indicator. The WAIL and YELP sounds have a reduced fish deterrent effect. In conditions of attraction, sounds with a volume of 95 dB most effectively scare away fish. High deterrence efficiency is maintained at a distance of up to 3 m. A sound with a loudness of 85 dB significantly affects fish at a distance of no more than 1 m. Under background conditions, the reaction of fish to sound is more acute. Here, too, 95 dB sounds are the most effective. Moreover, the high frightening efficiency is maintained at a distance of up to 4 m. A sound with a volume of 85 dB significantly affects fish at a distance of up to 3 m, while with 75 dB up to 2 m and with 65 dB up to 1 m. A sound of 55 dB is ineffective. In conditions of attraction, the effect of a one-time fish frightening with a sound of 95 dB is fixed for 4 minutes and in background conditions for 9 minutes. Under favourable conditions, fish begin to massively return to bait 1 minute after the single signal stops. After 4 minutes, 100% of the fish return. Under background conditions, fish begin to return to the point of repulsion 1 minute after the stop of a single acoustic signal. After 9 minutes, 100% return. In conditions of attraction, the effect of prolonged fish frightening by a sound of 95 dB is fixed for 50 minutes and in background conditions for 110 minutes. In favourable conditions, the fish begin to return to the bait 20 minutes after the signal stops and after 50 minutes, 100% return. Under background conditions, the fish begin to return to the start point 30 minutes after the signal stops and after 110 minutes, 100% return. Summarizing the above, we can conclude the following: For effective removal of fish from dangerous areas, a long-term scaring away with a sound of 95 dB is necessary. At the same time, one acoustic device is able to effectively cover an area with a diameter of 6 m. For larger areas, several devices should be used. Or one device is actively moved around the water area by boat. This will allow a limited number of expensive acoustic devices to scare away fish in a large area of a dangerous area for them.

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