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O BIOLOGICHESKIKH I GIDRODINAMICHESKIKH ZVUKAKH IZDAVAYEMYKH RYBAMI

(Biological and Hydrodynamical Sounds Emitted by Fishes)

by

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ABSTRACT

A brief review of the history of studies dealing with sounds produced by fishes is followed by a discussion of sounds emitted by some of the fishes inhabiting the Black Sea. The observations and tests had been conducted in aquariums and in the sea in the Batumi and Odessa (Chernomorka) areas in 1951. The biological and hydrodynamic sounds produced by various species of fishes in different conditions are briefly described, pointing out frequencies, intensity, duration and other characteristics. The list of species includes Trachurus trachurus, Engraulis encrasicholus, Scomber scombrus, Atherina hepsetus, Belone belone, Mullus barbatus, Gobins niger, Corvina umbra, Trigla lucerna, Smaris smaris, Hippocampus hippocampus, etc.

TRANSLATOR

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Introduction.

The fact that some fishes are capable of emitting sounds was known in times of yore. Dobrin points out that the Phoenician fishermen in the Mediterranean Sea found schools of drumfish by listening to their sounds. Malayan fishermen have looked for fishes by listening to their sounds up to the present time; for this purpose, the leader of the crew bends over the side of boat and submerges his head, keeping it in water until he hears the sound of fishes; afterwards, the nets are placed in the water [6]. The great scientists of the XIX century, such as Humboldt, Kewje, Zhorzhua Saint-Iler knew well that fishes can emit sounds, and they paid considerable attention to the phenomenon [6].

By the middle of the last century the investigators already had data on many fishes that emit sounds and on the nature of the sounds. Thus Landois [11] lists 24 species of fish that emit sounds; the information is based on a report by Miller of the Berlin Academy of Sciences in 1856. In a similar list, Jonson [9] mentions, in addition to the character of sounds emitted by fishes, the mechanism of sound emission, the main frequency of a sound, and the duration of sonic vibrations in seconds.

During recent years, owing to the expansion of marine investigations, many new fishes and other marine organisms have been added to the list of animals that emit sounds. As a result of studying the materials it has been possible to determine the areas inhabited by the animals. Thus, Fish [7] points out that the Marine Laboratory of the Naragansett University (University of Rhode Island) (USA) has during 7 years recorded sounds emitted by hundreds of species of marine organisms. On the basis of the distribution of the sounds, a chart has been constructed which presents many areas of the western portion of the Pacific Ocean. Similar investigations conducted in the waters surrounding the islands of Japan aided the identification of numerous sound-emitting organisms inhabiting the waters [9].

Of interest are the attempts to find schools of fishes by the sounds they emit, which were conducted in 1952 and 1953 in the Gulf of Maine (USA). Several sound recordings of concentrations of bluefin tuna and mackerel were made [13]. The second report on these studies points out that the investigations of tuna and mackerel with the aid of hydrophones continue and that if the results would appear to be positive for fishermen, a special instrument may be constructed [12].

There is very little information in the literature on the use of data on sounds emitted by fishes [10, 14, 5]. Of considerable interest are the reports by Westenberg and Bottemanne concerning the attraction of fish in Indonesian waters by means of sounds and the methods of catching the fish. Many fishes, including tunas and sharks, are the objects of such catches. Bottemanne reports that in the waters around the Island of Java alone about 40,000-50,000 tons of fish are caught annually. Regrettably, the very interesting method of attracting fishes by sounds in Indonesian waters has not yet been adequately explained. /273

Of the Soviet literature I can mention a study be Ye. V. Shishkova [4], which contains a list of Black Sea fishes (11 species) that emit sounds and which presents a spectrogram of frequencies of the sounds.

Resuming the data listed in the literature, one may say that many species of fishes and other marine organisms that inhabit various seas are capable of emitting the most diverse sounds typical of the given species. However, the finding of fishes by sounds has been little practiced and the final results are not known (except for primitive methods of searching for fishes by the inhabitants of Malayan Islands).

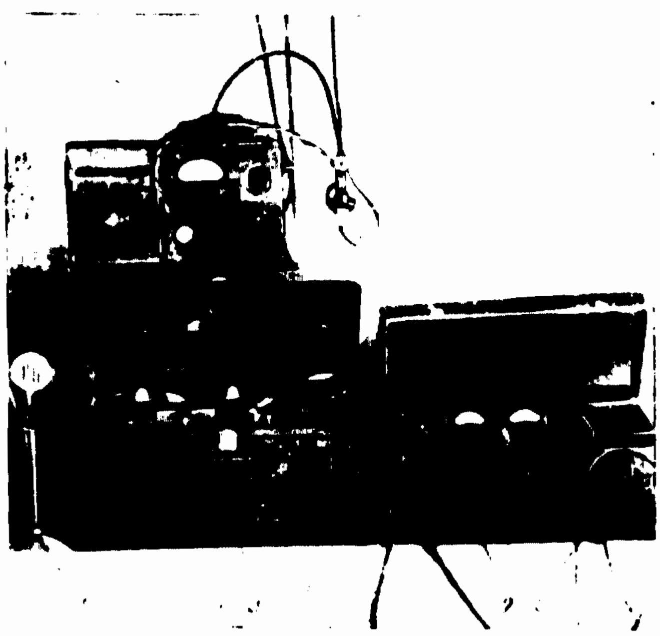

Figure. Apparatus for listening to and recording of sounds emitted by fishes: 1- cable with hydrophones; 2 - amplifier; 3 - tape recorder; 4 - microphone; 5 - automatic transformer; 6 - telephone.

The results of studies in the sounds emitted by some of the species of Black Sea fishes are presented in this paper. The investigations were conducted from July through November 1951, mainly in Batumi and Odessa (Chernomorka) areas. The observations were conducted in a glass aquarium having the capacity of 100 l and in a net tank having the dimensions of 8 x 4 x 2 m; the aquarium was placed 50 m off the coast, and the tank was placed at a stake net 300 m off the coast. In the aquarium and the net tank the fish was obtained from the stake net. The sound of fishes was observed in Gudauta area near Batumi by a study group in the expeditionary vessel S R T of Chernomorka. In addition, the investigators listened to the sounds emitted by fishes that were accumulated at an underwater source of light (when fish were caught with the aid of light) and to the sounds emitted by fishes when the source was cut off. The listening and recording of the sounds was made possible by a special equipment consisting of highly sensitive broad-band hydrophones (piezoelectric hydrophones made of Seignette salt prepared by VNIRO), measuring amplifier, microphone, telephone, automatic transformer and tape recorder (see the figure). V. A. Glinkov, mechanic of VNIRO operated the equipment.

In Chernomorka the study group consisted of the author, T. Ye. /274
Saf'yanova, N. Ye. Aslanov and S. G. Zusser. In Batumi the investigations were carried out by the author and V. A. Glinkov.

In Chernomorka we observed the following species of fish: Trachurus trachurus L., Engraulis encrasicholus L., Scomber scombrus L., Atherina hepsetus L., Belone belone eccxini günther, Mugil sp., Mullus Carbatus ponticus Essipov, and gobius niger L. The fish was obtained with the aid of a fishing boat and metofeluga.

At Batumi the composition of fishes was somewhat different: Atherina hepsetus L., Trachurus trachurus, Pomatomus saltatrix (L), Motella tricirrata B., Mullus barbatus ponticus Essipov, Corvina umbra L., Trigla lucerna L., Smaris smaris L., Pleuronectes flesus luscus, Hippocampus hippocampus L., Syngnathus sp., Trachinus draco L.

Altogether 171 observations were carried out, and a sound film was prepared from the recorded sounds emitted by fishes; the film was demonstrated to the personnel of fisheries in Batumi.

The recorded sounds can be divided into two main categories. To the first category pertain the sounds closely associated with the functions of marine animals and, consequently, they are typical of the organisms and their biological characteristics. These sounds we assign to the category of biological sounds or simply sounds.

The other category contains sounds resulting from the movement of marine organisms, from mechanical impact of external organs on water and on objects in it (swimming, leaping, strokes with fins, friction against sand, stones, plants, etc.). These are the hydrodynamic sounds or noises.

All the other sounds and noises that are heard in sea water are assigned to the group of disturbance sounds (waves, surf, rain, noise of vessel motors, etc).

Biological sounds.

The sounds emitted by fishes were recorded in various environmental conditions and in various circumstances of tested fishes: with free-swimming fishes in the sea and in an aquarium; with fishes disturbed in the aquarium and with fishes taken out of the aquarium, as well as with fishes feeding in the aquarium.

The following fishes did not emit sounds either in the sea or the aquarium, although we do not think that they are completely mute: Motella tricirrata B., Gobius niger L., Pleuronectes flesus luscus, Syngnathus sp., Trachius draco L., Scomber scombrus L., Belone belone euxini günther, and Engraulis encrasicholus.

The observations conducted in the sea disclosed various submarine sounds among which sounds emitted by Trachuras trachuras L. could be singled out. Once we perceived clear sounds emitted by Mugil sp. at the stake net, but most often and in many places we heard the typical drumming sounds of fishes (the species of the fishes were not determined).

Tr. trachuras L. emitted soft barking sounds which lasted for 5 seconds. The sounds emitted by Mugil sp. were observed at night; on the background of gentle splashing of waves we heard at times clicking sounds. The sounds of "drummers" were repeatedly heard at the stake net (Chernomorka) and in the Gudauta area. They differed sharply from the sounds produced by T. trachuras and Mugil sp.

At night in the Gudauta area we succeeded in analyzing the sounds of "drummers" in great detail. They were clearly pronounced, reminding us now of the beating of drums, now of a distant thud of a hammer. It is noteworthy that the initial sounds created responses which were followed by a period of silence until a new "call" of a fish was heard /275 and a "response" by the other one in about 1-1.5 seconds. Sometimes the initial call was emitted simultaneously by two fishes.

The sounds lasted for 1-7 seconds, the average duration being 3.5 seconds. The sounds emitted by a fish consisted of 23 signals. The first sounds were very frequent, but the subsequent ones were emitted after longer pauses, yet they were more clearly pronounced.

The sounds of "drummers" were less frequently heard and they were weaker. Between 2300 and 2400 they were most frequent and loud, but after 0200 they attenuated and ceased. The investigations made it possible to clarify the known diversity in the sounds of "drummers" (differences in duration, frequency, force and character). As many as six types of sounds were detected: containing now multiple accents, now two to four accents, now sharp or soft attenuances, now followed by long or short pauses. Some of them were soon interrupted, which was evidently the result of fear or other causes. We are bent on admitting that these diverse drumming sounds are emitted by the same species of fishes.

It can be assumed that the character of the sounds produced by the "drummers" depends upon sex and the biological condition of fishes; the sounds vary with males, females, young and mature fishes, as well as with hungry or satisfied, quiet or frightened fishes.

When fishes were freely swimming in the aquarium, we heard sounds emitted by two species of fishes - T. trachurus and P. saltatrix. The former very seldom produced sounds and they were of short duration (not exceeding 2 sec.).

In Batumi we observed horse mackerels (T. trachurus); the length of non-commercial individuals was about 8-10 cm, but the length of commercial individuals was 14-16 cm; besides, there was one individual 38.5 cm long. The character of sounds of all the fishes was rather similar, but the pressure of the sound increased with the length of fishes, reaching its maximum in the large individual. In horse mackerels having the same length the pressure of the sound corresponded to physiological conditions of each individual. As a rule, the loudest sounds in the aquarium were emitted by fishes which were physically more active.

Of certain interest are sounds produced by the tailor fish (P. saltatrix). When listening to the sounds in the Batumi aquarium we noted that, in contrast to other fishes that were quietly swimming, the tailor fish was continually swimming for many hours with a constant speed (0.17 m/sec) in a definite direction (counterclockwise along the walls of the aquarium) without stopping, not even for a second.

During swimming the tailor fish emitted very weak gradually fading sounds reminiscent of brief tinkling signals "tsits tsits-tsits-tsi-tsi-tsi."

The sounds lasted for about 3 seconds. Up to six brief signals could be distinguished in each sound. The interval between the sounds was more or less constant, lasting from 45 seconds to 1 minute. The character of the sound signals and their intensity in subsequent soundings did not change at all. The sounds continued no matter whether the aquarium was lit or dark. They could be perceived when the acoustic disturbances were minimal.

Of all the fishes which were disturbed in aquarium (caught and gently held in the hands), horse mackerel appeared to be the most "talkative." Especially frequently the fish emitted typical barking sounds when it was caught and held in the hands. These sounds could also be heard by the unaided ear when the fish was taken out of water.

In the Batumi aquarium one could often hear sounds produced by Corvina umbra. The length of the fishes was about 13.5-37 cm. They did not eat. They emitted sounds when attempting to get out of the hands. /276
These quiet rattling sounds lasting for 2-3 sec. were reminiscent of individual signals "tri", "tri", "tri." Corvina umbra when removed from the water emitted similar but slightly coarser sounds which could be heard with the unaided ear. The stomach of the fish showed clearly the effort needed for the production of sounds. We know that fishermen are familiar with the rattling sounds emitted by the fishes when they free themselves from nets. Because of these sounds the fishermen call the fish the "rattling drummer."

Only one sea robin (Trigla lucerna) 39 cm long, which was caught by stake net in Batumi area was at our disposal. The fish, like the large Corvina umbra, could not get used to conditions in aquarium and did not emit sounds even when the fish was disturbed. Only when removed from the water the fish began to emit rather loud and short sounds lasting 1-2 seconds and interrupted by long pauses; the sounds were reminiscent of an individual rattle "trrrek", "trrrek." The sounds were not associated with the intake of air and they could be heard with the unaided ear.

The sea horse (H. hippocampus) was most unadaptable to conditions in the aquarium. They could be held there for 15 and more days. But neither the free-swimming individuals, nor those which were caught and held gently in the hands, emitted any sounds. Only when removed from the water did the sea horses begin to emit rattling sounds which were very monotonous reminiscent of a continuous "khrrrr", "khrrr." In order to record these sounds, the snout of the fishes was held directly in front of microphone. The emission of sounds was felt by fingers holding the fish, which attented to the tension of the organism that was followed by a weak snoring sound emanating from the organism.

When the fishes were fed in the aquarium, some of them took food willingly, which made it possible to record on tape the sounds produced during eating. This behavior was typical of Atherina hepsetus, Trachurus trachurus and Smaris smaris.

Prior to the tests the fishes were kept hungry for a while and therefore when the food was put in aquarium the fishes attacked it right away.

Atherina hepsetus fed on insects (midges, mosquitoes, flies), small zooplankton and demersal crustaceans (isopods and gammarids). When fed on insects, the species emitted gurgling sounds as they caught the food items from the water surface; the swallowing of food was accompanied by champing sounds. When eating zooplankton, the fishes emitted expressive champing sounds. The loudest crackling sounds were recorded when A. hepsetus was fed on crustaceans. Lengthy observations made it possible to determine the type of food swallowed by A. hepsetus by the character of the sounds.

The horse mackerels, 7-15 cm long, were held in the aquarium for a long time period. The fish was fed on isopods, gammarids and small mullets (2 cm long). The live food together with water was poured into the aquarium; at first, the horse mackerel devoured the small fishes, then the isopods and gammarids.

Also champing and crunching (crackling) were heard when the horse mackerel was eating, and these noises were more clearly pronounced than in the case of Atherina hepsetus. The catching of food was accompanied by champing, while the swallowing was accompanied by a brief crunching. Evidently, in order to facilitate the swallowing the horse mackerel must paralyze the motions of its prey, which is achieved by a peculiar "chewing", i.e. by compression of prey and by directing it into the throat. The crunching was especially clearly pronounced when the horse mackerel was fed on mullets.

By studying the functions of the pharyngeal apparatus of a number of vertebrate Black Sea fishes, A. P. Andriyashev [1] concluded that the pharyngeal apparatus of fishes is adapted not only for swallowing /277
but also for a preliminary preparation of food in the mouth.

When we perceive champing and crunching of feeding fishes, we can naturally assume that the fishes must hold, paralyze and direct into pharynx the prey. In certain fishes this function is performed by teeth. This is the preliminary processing of food in the mouth, which is confirmed by conclusions drawn by A. P. Andriyashev on the basis of his experiments.

As was mentioned before, Smaris smaris also was kept in the aquarium. It was fed on crumbs of fishes (Engraulis encrasicholus, Atherina hepsetus) and shrimps. The sounds characterizing the catching of prey from the bottom of the aquarium were weakly heard, but the crunching of food was clearly heard.

Thus the tests with the feeding of fishes in the aquarium made it possible to determine that at the moment of feeding the fishes produced typical sounds audible through hydrophones. The character of the sounds varies from species to species. It also depends upon the type of food. It appeared that the frequency of sounds produced during eating is similar to the frequency of sounds emitted by fishes at their will (see Fig. 6 in a paper by Shishkova 4 . Consequently, the fishes must hear the sounds produced by feeding fishes as well as the sounds produced by fishes when frightened. Such an assumption makes it possible to explain the causes of concentrations of fishes when they approach the food from adjacent areas before they can see the food.

In Bautino Bay of the Caspian Sea we observed in 1948 the following. The remains of cooked fish cast on the surf (about 0.5 m depth) attracted, first, young and larger individuals of voblas which were previously absent in the place. The fishes could not see the food and, evidently, could not perceive the smell because they were at a distance of several meters from the food where the bottom depth was 1-1.5 m and more.

Previously we thought that fishes concentrate around food because they see other fishes swimming in the direction of the food. Now we can afford to present another explanation of the phenomenon. We consider that the fishes that are near the food approach it first. The eating being accompanied by specific sounds is heard by other fishes that are at a greater distance. We observed that the fishes did not approach directly to the food but in a zig-zag manner, thus possibly determining the direction. Thus, an accumulation of tens of fishes was noted in a brief time around a "food spot." Let us note that at the depth where the food was found only young voblas, 4-8 cm long, were seen. The larger fishes were in deeper sections. We caught part of the fishes that had formed the concentration. The catch consisted of young and larger individuals of voblas 10-17 cm long.

Thus the perception of sound signals by fishes coupled with a good vision aids the fish in finding food and forming concentrations.

It seems to us that a correct interpretation of the phenomenon is very important. This helps us better to understand how individual fishes and schools of fishes find food locations and form concentrations in the areas. We do not discount the significance of vision, smell, sense of touch, etc. in fishes, but consider them to play a significant role. The great significance of vision in the majority of fishes is not to be doubted, we consider that vision is the main factor in explaining the feeding of fish schools on plankton 3 . But by perceiving sound vibrations, in addition to visual waves, the fishes can better orientate themselves in water.

Our observations supplement the findings of A. P. Andriyashev 2 /278
concerning the role of sense organs (vision, smell, etc.) in a number of Black Sea fishes. For a more comprehensive solution of the problem we have to conduct additional special investigations.

Hydrodynamic sounds or noises.

We shall not discuss the noises that are created in an aquarium when fishes touch the ground, walls or cables of hydrophones or when they splash water, etc. Of greater significance are the noises caused by the movement of fishes in water.

We repeatedly succeeded in creating artificial concentrations of fishes (Atherina hepsetus) with the aid of an underwater source of electric light. When the lamp was switched off, the fishes became frightened: at the beginning they leaped out of the water; then they moved rapidly around, mostly in circles, until they became scattered in deeper water.

Besides, a loud typical noise was heard through the hydrophones, which continued for a while and faded gradually out - about 40-50 sec. after the lamp was switched off. Let us note that the leaping out of water lasted not more than 10 sec; the main noise was created by the mass of fishes that moved with great speed into deeper water layers (the observations of the movement of fishes was aided by the luminescense of the water).

Such observations were repeatedly carried out. In order to record the sounds on the tape recorder, a special electrical conduit connected the apparatus with the kettle of the stake net, near which the investigations were conducted. The tape recorded the noises emanating from a free-swimming concentration of fishes near the electric lamp that had been switched on and the noises of frightened fishes after the lamp was switched off.

With the aid of hydrophones placed at the lamp and 10 m from it we recorded the noises produced by Atherina hepsetus. It appeared that the distance of 10 m does not decrease the noise caused by the motion of the same fish school (when the lamp was switched off). The length of fishes we observed was about 5-8 cm. Altogether several hundred fishes accumulated around the light but the noise of their excited swimming was very insignificant.

The spectrogram of noises presented in a paper by Ye. V. Shishkova [4] shows that the frequency distribution of noises produced by quietly swimming fishes and by excited fishes is similar to the pattern determined by us (frequency band being 200-1800 hertzian units) [cps]. But the pressure of sound was in the latter case greater than in the former case.

Thus, hydrodynamic noises are produced when fishes swim quietly or are excited (which could in a sense be compared with a rapid motion of fish school); the frequency of the noises is perceived by other species of fish.

It can be assumed that the migration of commercial populations is accompanied by louder noises than the noises observed by us; these noises propagate to a considerable distance and can be perceived by other populations. The practical verification of the situation may elucidate the presence of a definite sound pattern accompanying the migration and feeding of fish populations.

Conclusions.

1. We distinguish biological and hydrodynamic sounds produced by fishes.

2. Some species of fishes - T. trachurus, Mugil sp., Trigla lucerna, Corvina umbra Pomatomus saltatrix, Hippocampus hippocampus, "drummer" - emit sounds either in the sea or an aquarium, or when they are taken out of water.

Each of the listed fishes emits peculiar sounds having different wave length, frequency, and intensity. The larger and more active a fish, the louder are the sounds produced by the fish. /279

3. The feeding of fishes is accompanied by typical sounds (champing and crunching) created by catching, pressing, and swallowing the prey.

The sounds produced by Atherina hepsetus, Trachurus trachurus and Smaris smaris when eating different types of food have typical features and may in a number of cases differ from one another.

4. Rapid motion of dense fish schools creates loud hydrodynamic noises. With the aid of hydrophones it is possible to find the fish schools.

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