

The Effect of Sound Stimulus on the Behavioral Disturbance of Red Sea Bream, *Pagrus major*

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The behavioral changes of the young red sea bream, *Pagrus major* TEMMINCK *et* SCHLEGEL, were examined experimentally to clarify the effect of sound stimulus to the fish. The fish and the food reservoir to record feeding activity were kept in the central portion of a resin tank, partitioned into three parts by black cloths spread, which were used to separate the fish from the sound source.

Sound stimuli applied were pure tones which generated electrically, and projected from underwater speaker set in the experimental tank. Frequencies were 200, 300, 500, 700 and 1000Hz, and projecting times were 100, 200 and 400 ms. Sound pressures ranged from 40 to 70 dB.

The number of the experiments in which the fish frightened was observed by eye observation were counted. The number of the feeding activity per minute was recorded at the time, when the sound stimulus was projected.

The rate of the occurrence of fish frightened increased with increasing sound pressure and the response was most sensitive at 200 Hz. The feeding activity was also disturbed at higher sound pressure and at the frequency of 200 Hz. However, the response was not so sensitive as behavior disturbance. Duration of sound projection had little effect on the behavioral disturbance so far as the present experiments are concerned.

Many informations concerning the acoustic physiology of the fish has been accumulated in the past few years (HAWKINS 1981). It is confirmed that certain fishes are able to hear and respond sensitively to the sound in water.

It is obvious that the fish is affected by underwater sound and vibrations in various ways. In the extreme case, fishes were found to die through the impulsive pressure produced by the underwater blasting and the crushings in building bridge or constructing harbor. Some apprehensions have also been pointed out that weaker impulsive sound presumably influences fish behavior which in turn causes economical loss in fisheries production because of the escapement of fish from the fisheries ground as well as the decrease of feeding activity.

The present study intended to examine the effect of underwater sound stimulus on the

Received October 22, 1985. Contribution No. 176 from the Nansei Regional Fisheries Research Laboratory, Ohno-cho, Hiroshima-ken, 739-04, Japan

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behavioral disturbance of the fish with physiological experiments, through observations of fright behavior and feeding behavior.

Materials and Methods

Experimental animals and conditions

The red sea bream, *Pagrus major* TEMMINCK *et* SCHLEGEL, was obtained from Nomi-Suisan Co., Hiroshima, and was maintained in 1-ton concrete tank where filtered running sea water was supplied. The size of specimens ranged from 8.5 to 11.0 cm in fork length and they were fed pieces of oyster meat twice a day. The fish was transferred to the experimental tank three days prior to the experiment and then trained to feed oyster meat from food reservoir for a period of an hour per day. The experimental tank, 800 l in total capacity, was separated into three compartments by black cloths in order to avoid the contact of fish with underwater speaker and to observe the behavioral response at precise position (Fig. 1). In one experiment, 30 specimens are usually contained in the central section of the tank. The natural sea water filtered by sands was poured gently from the inlet and discharged through the outlet to maintain

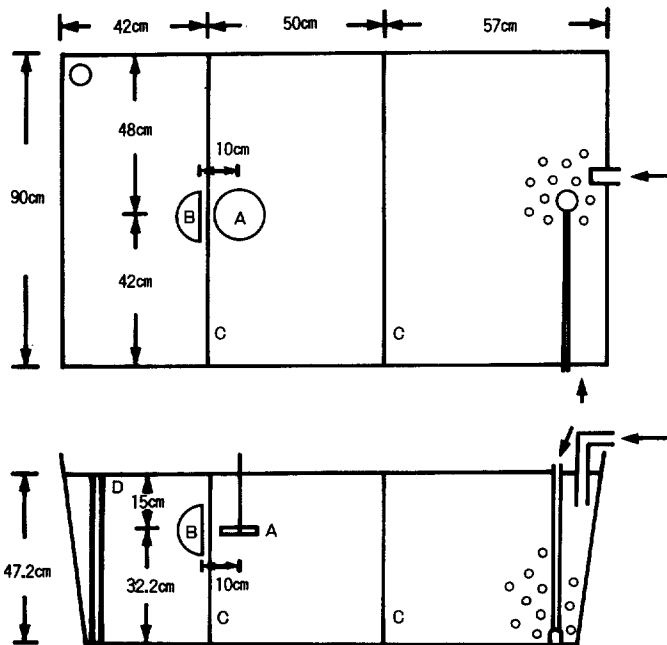


Fig. 1 Surface(top) and side(bottom) views of the experimental tank. The fish were kept in the central portion.

A: Food reservoir B: Underwater speaker
C: Cloth septum D: Outlet of seawater

Effect of Sound Stimulus on Fish Behavior

water temperature constant. The temperature rose from 20.9 to 24.3 °C during experiments, which were carried out from August 11 to October 8, 1981. Details of respective experimental condition are indicated in Table 1.

Table 1. Size of red sea bream and other experimental conditions

No. of Exp.	Period	No. of fish	Fork length (cm) mean \pm s.d.	Body weight (g) mean \pm s.d.	Range of temperature (°C)
1	Aug. 11-27	29	8.9 \pm 0.71	17.0 \pm 3.87	21.8 - 23.5
2	11-27	20	9.5 \pm 0.72	20.7 \pm 4.81	22.0 - 23.6
3	Sep. 1-12	30	10.5 \pm 0.79	26.5 \pm 6.48	22.0 - 23.4
4	1-12	30	10.8 \pm 0.63	28.8 \pm 4.80	22.0 - 24.0
5	1-12	20	10.7 \pm 0.56	— *	22.3 - 24.1
6	1-12	20	10.7 \pm 0.51	— *	22.3 - 24.1
7	Sep. 8-10	20	— **	— **	22.9
8	8-10	20	“	“	22.9
9	Sep. 13-20	30	9.3 \pm 0.71	18.9 \pm 4.05	23.1 - 24.4
10	13-20	30	9.9 \pm 0.76	22.8 \pm 5.03	22.3 - 24.1
11	Sep. 15-Oct. 2	30	10.0 \pm 0.59	22.9 \pm 4.04	21.4 - 22.8
12	15-	2 30	10.3 \pm 0.65	24.9 \pm 4.90	20.9 - 22.8
13	Oct. 6-Oct. 8	30	9.4 \pm 0.60	18.6 \pm 3.56	23.9 - 24.5
14	6-	8 30	9.5 \pm 0.68	19.6 \pm 4.21	23.5 - 24.2

*: Weight was not determined.

**: Troubles in water flow system

Sound projection system

The system used for sound projection and measurement of sound pressure is shown in Fig. 2 as a block diagram. The model of sine wave projected is also shown in the figure.

Frequencies (f) of sounds used in the experiment were 200, 300, 500, 700, and 1000 Hz and their pulse width (t) were 100, 200, and 400 ms. The pulse intervals (T) were determined by observer's own free will.

Stable burst wave was obtained with gating signal generator by fixing T and t , because the function generator applied could not produce shorter range of width pulse and the width of burst wave was changed following the alteration of pulse intervals. We could set T ($T=N \times 10^n$, $n=0, 1$) sec., and t ($t=M \times 10^m$, $m=-2, -1, 0$) sec. by observer's will when M and N were assumed as an integer from 1 to 9.

The function generator (EXACT electronics, Inc. type 519) was a type for AM/FM function which projected continuous, burst, AM and FM waves. This instrument was also controlled by the external gate signal. Output impedance was 50 Ω , frequency accuracy was within $\pm 2\%$ of setting, distortion was below 0.5%, and amplitude stability

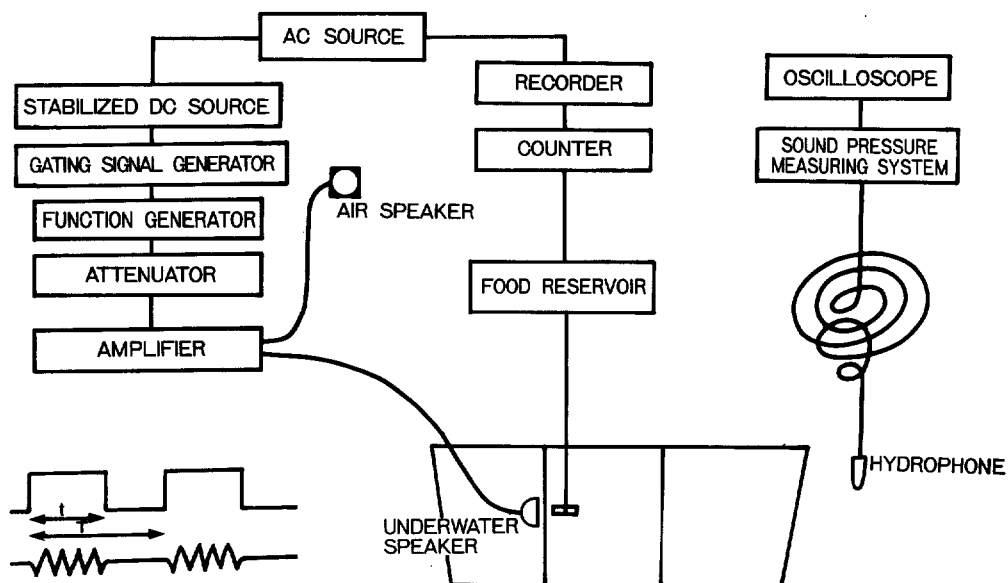


Fig. 2 Block diagram of the experimental system used for sound projection and measurement of sound pressure. Time intervals of the sound impulse were also illustrated.

was 0.25% for 24 hours.

In the attenuator (TOKYO-KOON-DEMPA Co. STA-113 type), circuit structure, variable range of attenuation, impedance, frequency range and maximum power input were un-equilibrium, 91 dB, 600Ω, from DC to 150 kHz, and 30 dBm (1W), respectively.

In the power amplifier (SONY Co. TA-1120A type), rated output, input impedance, S/N, dumping factor, and distortion were 35W×2 (16Ω load), over 100kΩ, over 90 dB at AUX input, over 360 (16Ω load) at 1 kHz, and below 0.1% at rated power respectively. The frequency characteristic was flat at the range from 10 Hz to 100 kHz.

In the underwater speaker (PIONEER Co. UL-3 type), voice coil impedance, minimum

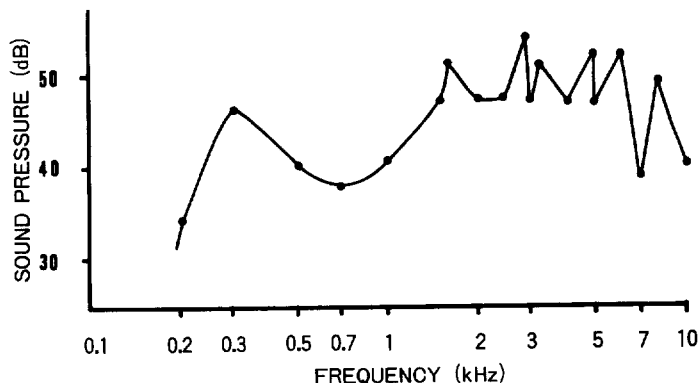


Fig. 3 Characteristics of sound frequency produced by the underwater speaker. (Input voltage was 2 V p-p.)

Effect of Sound Stimulus on Fish Behavior

resonance frequency, maximum power input and maximum depth were 16Ω at 450 Hz, 300 Hz, 30W on pulse wave and 5m, respectively. The frequency characteristic is shown in Fig. 3. The characteristic of sound frequency was measured at 25 cm distant from the sound source when the input of power to the underwater speaker was 2 V p-p.

The hydrophone (OKI electric industry Co. ST1001 type) to measure sound pressure and sound wave form was omnidirectional up to 30 kHz and provided the maximum operating depth of more than 500 m.

The frequency characteristic of sound pressure meter utilized was flat at the range from 20 Hz to 50 kHz. It was accurate within ± 2 dB at the range from 20 Hz to 1 kHz, and measurable sound pressure range was from 0 to 80 dB re 1 μ bar.

The oscilloscope (SONY TEKTRONIX Co. 564 B type) could memorize a momentary pulse, and measured the sound pressure by keeping the pulse wave still on a Braun tube. Writing speed, initial luminance, storage time, erase time and frequency range were 100 cm/sec., 6fL, an hour, 250ms., and from DC to 10 MHz, respectively. The underwater sound waves on the Braun tube of the oscilloscope was taken by a Polaroid CR-9 camera.

The feeding activity recorder has been described in detail elsewhere (ISHIOKA 1976).

Experimental procedure

The experiments on the change of fish behavior and feeding activity under sound stimulus were carried out simultaneously. Ordinarily, they have been carried out twice a day, from 9:30 am and 3:30 pm, for a period of 1 hour using the fish sufficiently trained for feeding of oyster pieces kept in the food reservoir.

When sound stimulus was projected from the underwater speaker, an observer sitting beside the experimental tank recorded the number of fishes swimming around the food reservoir. Thus, the number of fishes frightened was directly counted and peck signals produced by fishes were recorded every 1 minute by the feeding activity recorder. The sound stimulus was projected at an interval of 3-5 minutes. During the experiment the experimental fishes received a single species of sound stimulus at one time.

Data analysis

Rate of frightened behavior: The percentage for each sound stimulus was expressed as:

$$100 \times (\text{Number of experiments observed the fish frightened}) / (\text{total number of experiments}) \%$$

Rate of feeding activity disturbance: Number of peck per minute soon after sound

stimulation (A) was compared to that (B) based on a straight line regression calculated by 3 variables for 3 minutes immediately before sound impulse. The effective rate was calculated by the following equation and negative value was estimated as 0.

$$\text{Effective Rate} = 100 - 100 \times (A)/(B)$$

Results

I. Characteristics of projected sound

(1) Wave form of the sound: The wave form of the sound projected from the underwater speaker is generally deformed by the mechanical properties of instruments. The wave forms shown in Fig. 4 correspond to those obtained with the burst wave of 200, 300, 500, 700, 1000, 2000Hz in frequency, which was projected for about 10 ms from the speaker in the experimental tank. Damped oscillation of the resonance frequency of 300Hz or 1.6 kHz of the underwater speaker was lasting for about 20 ms following the cessation of input pulse.

Within the range of pulse width of 100-400 ms, the energy density of the output signal was mostly subjected to that of the input sound signal. Therefore, it was considered that the effects of reflected waves and transient waves of damped resonance oscillation of the speaker were negligible.

(2) Distribution of sound pressure in the experimental tank: The sound pressure projected into the tank was measured by the hydrophone at the distance of 25, 50, 75 and 100 cm away from the underwater speaker suspended 30 cm below the surface of water. The result was shown in Fig. 5. Calculated attenuation coefficients were 12.5, 13.2, 10.5, 8.0 and 6.5dB/D.D. at 200, 300, 500, 700 and 1000Hz, respectively. The results of this experiment revealed that the sound pressure is most influenciable by the position of the fish perceiving the sound. To avoid distance error, the experiment was made so that the sound was exactly projected to the fish swimming around the food reservoir.

II. Behavior changes of the fish

(1) Influence on fright: The fish swimming around the food reservoir stopped immediately after the sound emission and then turned their way to get away from the underwater speaker. These behaviors were noticed clearly. The sound pressure was measured precisely at a fixed position close to the food reservoir. As shown in Fig. 6, the sound pressure indicated the strong effect on the behavior of fright. Thus, the slope of the response increases with increasing sound pressure of respective frequency.

Effect of Sound Stimulus on Fish Behavior

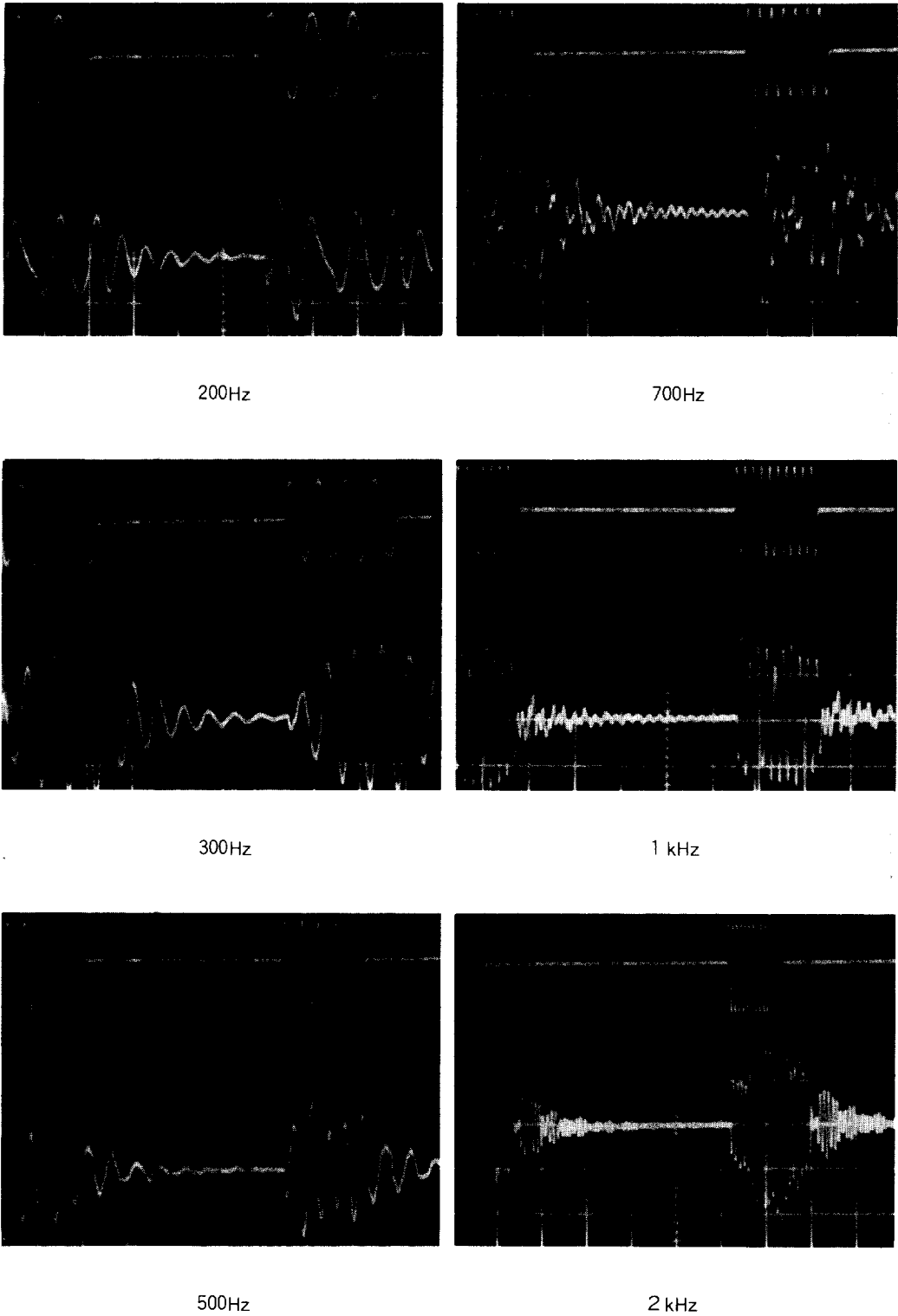


Fig. 4 Wave forms of the electrical input signal (top) and projected underwater sound (bottom) from the underwater speaker at respective frequency.

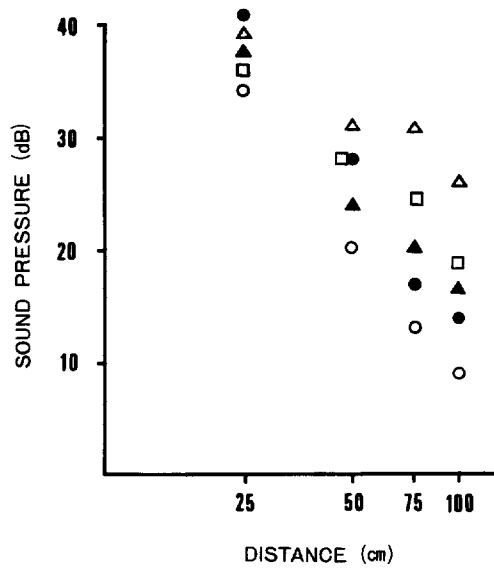


Fig. 5 Distribution of sound pressure in the experimental tank.

- Open circle: 200Hz
- Closed circle: 300Hz
- Closed triangle: 500Hz
- Open square: 700Hz
- Open triangle: 1000Hz

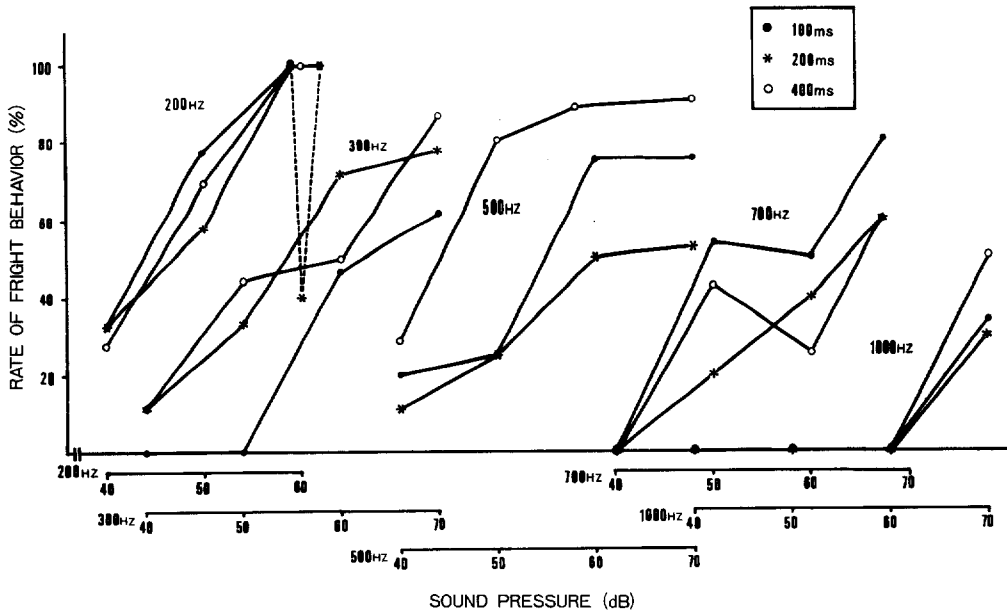


Fig. 6 The relation between the rate of experiment where the fish was frightened and sound pressure.

Effect of Sound Stimulus on Fish Behavior

It also reveals that the response of the fish was affected by sound frequency. In this experiment, one third of the experiments was effectively responded even at 40dB in 200 Hz although the response was observed at 70dB in 1000Hz.

The duration of sound impulse seems to have little effect on the fish response over the range of 100 ms.

(2) Influence on feeding behavior: The experiment was carried out after the end of initial burst feeding, because the measurement of the number of feeding activity by using the feeding activity recorder are limited mechanically as reported previously (ISHIOKA 1976).

Generally, the effect of sound impulse to the feeding behavior was temporary, and further no fish was influenced for a longer period. The relationship between the calculated average effective rate and sound pressure was shown in Fig. 7. This indicates that the feeding activity was affected by the sound pressure and frequency, although the magnitude of the response was not so large as in the case

of behavior change by fright. The effect on feeding activity increased with the increase of sound pressure. The sound of low frequency (200 Hz) was most effective to create the response of the fish. However, these tendency is not always statistically significant since quite ineffective responses were observed in a high rate at weak sound pressure as well as at higher frequency above 300 Hz. At 1000 Hz, the significant behavior changes did not appear in the range from 40 to 70dB.

Duration of sound impulse had unexpectedly little effect on the feeding behavior. A short impulse (100 ms) seems to be more effective to generate the response.

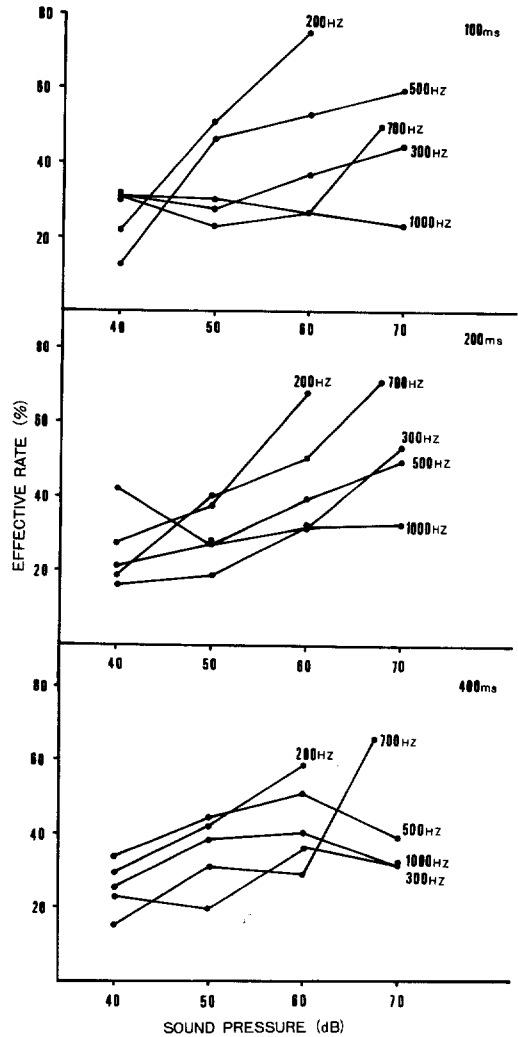


Fig. 7 The relation between the effective rate on restriction of feeding activity and sound pressure of different duration of impulse.

Discussion

The influence of the sound impulse on the behavior of fish has been studied in relation to the fishing methodology (HASHIMOTO and MANIWA 1964, 1966). Thus, some informations have been accumulated in the fields of morphological study for hearing, and also physiological and behavioral aspects. In the latter cases, the most important approaches are determination of the precise sound intensity and the quantification of the reaction of fish. Fortunately, recent development of electronics has rendered the measurement of sound impulse easy and also quantification of fish behavior possible, although the difficulty for standardization is still remained unsolved.

Monitoring of the stimulus sound by oscilloscope revealed that pure tones were produced closely by the projecting system without strong interference of refractive pulse and mechanical distortion, although some deformations of the pattern and a little residual energy were observed. As the duration of impulse was set at the range from 100 to 400 ms, the change of original energy by residual one was not observed in the present experiment.

The fish received the strong sound impulse escaped from the sound source to the most distant position of the bottom of the experimental tank and stayed there for a while, when the color of the body turned to pale. This behavior is spread from one individual to others of a group until all fishes of the group get together to form a crowd. In such condition, the feeding behavior has never been observed and no record on the activity was obtained.

To examine the influence of sound stimulus on the restriction of feeding activity of fish, the multiple regression analysis was carried out to judge statistically the degree of reliance (Table 2). The frequency (Hz), time duration (ms) and sound pressure (dB) were adopted as the independent variables and the rate of response (%) for the dependent variable. Although the value of multiple correlation (R) is moderate, the F-value in the analysis of variance is significant at 1% level. This indicates that the variables clearly contribute to the explanation of variation of the rate of response. Judging from t-value in regression coefficient, duration of sound emission has little influence on Y (rate of response). The regression shown below,

$$Y = 7.0637 - 0.01936X_1 - 0.00314X_2 + 0.75777X_3$$

means that the sound intensity is most effective to cause the change of feeding behavior.

Some informations concerning the relationship between the sound pressure and change

Effect of Sound Stimulus on Fish Behavior

Table 2. Result of multiple regression analysis on the relationship between the properties of sound and feeding behavior disturbance of the fish.

Selected groups					
group name	200Hz	300Hz	500Hz	700Hz	1000Hz
analysis group	1	1	1	1	1
sample size	9	12	12	12	12
Selected independent variables (X)					
variable name	Hz	Time	dB		
Selected dependent variable (Y)					
variable name	Response				
Multiple correlation R	0.65883				
Contribution ratio 100*RR	43.40543				
Adjusted cont. 100*RR	40.20197				
Std. error of residuals	11.15355				
Analysis of variance table					
S. V.	D. F.	S. S.	M. S.	F	
Regression	3	5056.75000	1685.58334	13.550	
Residual	53	6593.28955	124.40169		
Total	56	11650.03955			
Regression coefficients					
Variable	Std. B	B	D(B)	T=B/D(B)	
Hz	-0.38384	-0.01936	0.00523	-3.701	
Time	-0.02742	-0.00314	0.01184	-0.265	
dB	0.56908	0.75777	0.13812	5.486	
Constant 1		7.10637	8.38761	0.847	

of behavior of the fish have been obtained. In Ayu, *Plecoglossus altivelis* TEMMINCK *et* SCHIEGEL, Konagaya reported that the lowest threshold level of underwater sound for jumping response was 72 dB at 200 Hz, while this behavior is also considered to be a kind of response generated by the conditioning during ascending migration from the sea in conjunction with sound stress (KONAGAYA 1980). A recent finding indicated that the complex sound impulse by underwater explosion induced behavioral disturbance of fish (YAJIMA *et al* 1979). In the experiment of explosion produced by the underwater sound generator, the cultured red sea bream in the preserving cage did not respond even at 91 dB, while wild specimens showed clear response at 85 to 87 dB. They also reported that the level of sound intensity for the behavioral change by fright was generally higher in cultured fish than in wild ones. In other species, Mugiiwashi, *Atherion elymus* JORDAN *et* STARKS, the fish school was disturbed even at 47 dB (KOYAMA *et al* 1980). It seems that differences in the threshold level of fright depend on the difference of the position of fish perceiving sound impulse, physical conditions of fish, age, and differences in species.

Concerning the frequency of sound, Konagaya reported that Ayu is the most sensitive in jumping behavior to the sound of 200 Hz (KONAGAYA 1980). His result resembles

to our findings, although the behavioral patterns and the species used in each experiment are different.

In the present experiment, distinct feature of feeding disturbance could not be obtained because of dispersed responses of the fish. The behavioral change caused by fright is reflexive and temporary. The influence on feeding activity following the alternation of behavior by sound stimulation is also temporary and less sensitive to the sound impulse, viz. the level of restriction on feeding activity seems to exist only in the higher intensity of sound pressure.

It is usually postulated that the appetite of fish is taken away by the noise generated by construction. However, it is rather difficult to measure the intensity of the loss of appetite, because many complicated factors are involved concerning the appetite of fish and also there is the lack of knowledges on physiological mechanisms of fish appetite. More informations need to be accumulated to analyze the feeding activity under the environmental changes.

The sound stimuli used in this study were pure tones of sine waves. In the future, a complicated pattern of sound impulse similar to that of natural environment should be used in order to ascertain the practical effect of underwater explosion or construction to the fish behavior.

Acknowledgment: We thank Dr. M. Anraku, director of Red-tide Research Division of Nansei Regional Fisheries Research Laboratory, for his valuable comments on this manuscript.

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音刺激に対するマダイの行動変化

石岡宏子・島山良巳・阪口清次・矢島信一

音刺激に対する魚類の行動変化を把握するために、マダイを用いた水槽実験を行った。1トンのFRP水槽を黒布で3つに区切り、その中央部に実験魚と摂餌行動記録器の餌受器を入れた。これは音源に魚が触れるのを防ぎ、音源から正確な位置で魚の行動を観察する為である。

音はサイン波純音を用い、周波数は200, 300, 500, 700, 1000Hz, 放声時間は100, 200, 400ms, 音圧は40-70dBの範囲で実験した。

目視観察により、威嚇された魚の行動の見られた実験回数を調べ、また、放声時には同時にその直後の1分毎の摂餌行動回数を記録した。

行動攪乱の起こる割合は、音圧が増加するほど増加し、周波数では200Hz時に最も鋭敏に反応した。摂餌行動も高い音圧や200Hzで抑制的影響を受けたが、威嚇される行動ほど鋭敏な反応は見られなかった。放声時間は今回の実験範囲では行動変化に影響を与える要因とはならなかった。