AN ULTRASONIC DEVICE IN BIOTELEMETRY AND ITS APPLICATION TO TRACKING A YELLOWTAIL*

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INTRODUCTION

The behavior of fish in the open waters has been hardly examined from the past to the present days. Ordinary tags of various types applied to the fish body have been only one clue to examine the movement of fish in the horizontal plane. The migratory direction is roughly estimated by movement of tag carried by fish and expressed as the linear course from the location of the tag release to that of the tag recovery. This implies that the ordinary tag in any type has a limited value in the study of migratory behavior of fish.

The fish inhabits the wet space of three dimensions and its swimming behavior which is controlled by fish itself is simultaneously affected by the various environmental factors. When the technique of the ultrasonic telemetry is applied for the study on the movement of the unrestrained fish, it is possible to examine the navigating orientation through the continuous tracking, and to measure the swimming speed, the diurnal activity and the relation between these behaviors and environmental factors. Objective measurements are indispensable for both the basic and applied study on the behavior of fish in the future.

Recent development of technology in electronics has enabled us to make the transmitter of small size and explore unsolved fields in the marine biology. Trefethen (1956), Johnson (1960), Novotny et al. (1962), Bass (1965), Henderson et al. (1966), Poddubny et al. (1966), Yuen (1970) and Mitson et al. (1971) report the characteristics of their ultrasonic telemetering devices and the application to some kinds of fishes, using transmitters containing no sensor. Utilizing the simple computer to plot the location of fish, Kuroki et al. (1971) introduce a telemetering apparatus to measure the environmental factors.

In this paper, a biotelemetering system of ultrasonic type which has been successfully developed by us since 1968 is described. Ichihara (1971 a) partially refers to this system under development, reviewing the general problems in relation to the ultrasonic and radio telemetry applied to marine animals. Our prototype instruments comprise four components; ultrasonic transmitter, receiving transducer, receiver and analogue data recorder. After the effectiveness of this system was confirmed through tests in the fresh waters, it was applied to track the yellowtail, *Seriola quinqueradiata*, in the adjacent waters to Goto Islands of

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the western Japan in May of 1971. Several fixing methods of the transmitter to the yellowtail also were examined in an oceanarium of Tokai University.

TRANSMITTER

For tracking fishes, Kuroki et al. (1971) and Mitson et al. (1971) developed transponding ultrasonic tags which respond to the call signal from the base station. Our transmitter is the pinger type to emit the signal from the fish to the base station. In order to escape from the prevailing ambient noises derived from the turbulence of the ocean traffic, the surface agitation and the marine organisms which Wenz (1962) states, and to obtain the propagating range of signal as wide as possible in the sea, the sonic frequency of 50 KHz is selected for the underwater telemetry. The beam transmitted from the ring-transducer of pinger is of non direction. The life of battery is effectively extended by utilizing the pulse signal. It is characteristic that this pinger contains the sensor to detect the environmental temperature or the swimming depth of the target fish and that it transmits one information in one channel to the base station through the modulation of pulse interval. The pinger of this type is called here the information pinger. The magnetic reed switch turns on by the removal of a magnetic tape on the outside of the pinger. The slight deviations of freqency in the transmitter is inevitably caused by the variable water pressure or temperature in the field. Therefore, the pass band-width in the receiver is slightly expanded to cover the range of these deviations, although it is essentially needed to make the band-width as narrow as possible to elevate the sensitivity in the receiving apparatus. A kind of beed type thermister is applied for the temperature sensor and the electric conductive rubber for the pressure sensor. The propagating range of signal in the sea depends on both environmental and topographic conditions, but it usually covers 2 km for the signal and our recorder can distinguish informations within the distance of 1 km from target. This implies that the possible range of tracking is within 2 km from the base station in the sea. The external shapes of the pingers made in 1971 and their specification are shown in Fig. 1 and Table 1 respectively.

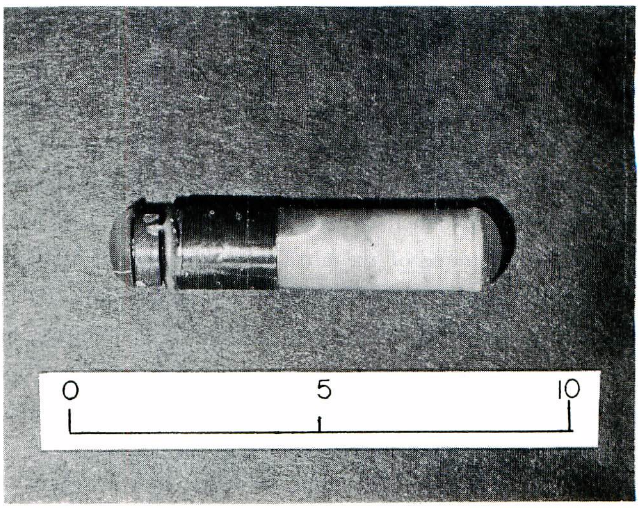

Fig. 1. External shape of an ultrasonic transmitter made in 1971.

The circuit diagram of the information pinger is presented in Fig. 2. The resistance of sensor (S) which varies with the change of environmental factors, shifts the pulse

Table 1. Characteristics of pinger

Shape	Cylindrical epoxy capsule	
Transducer	Ring-type lead zirconium titanate, 50 KHz	
Maximum pule interval	4 s	
Pulse width	20 ms	
Output electric power	100 mw	
Battery	Silver oxide, 6 v	
Life span	120 hours	
Size	Temperature-pinger	17 φ × 84 mm
	Depth-pinger	17 φ × 91 mm
	Tag-pinger	17 φ × 80 mm
Weight	Temperature-pinger	30 g in air 10.5 g in water
	Depth-pinger	32 g 〃 〃 〃
	Tag-pinger	26 g 〃 9.0 g 〃
Submergible pressure	30 kg/cm^2	
Range of measurable temperature	5°∼30°C	
Range of measurable depth	10∼100 m	

interval. It is the most important in the telemetering to obtain rapidly the accurate and stabilized information without waste. After the basic experiment, Ichihara (1971 b) recommends that the pulse interval modulation (PIM) satisfies the above conditions and valid for the underwater telemetry in one channel. Figs. 3 and 4 show the relationship between the duration of the pulse interval and the level of the environmental factors ; ambient water temperatures or diving depths. The pulse interval of pinger changes from 1.0 to 4.0 sec in accordance with the shift of the level of environmental factors. When the resistance of sensor is removed, Fig. 2 indicates the circuit of the ordinary pinger in which the pulse interval is constant. In the general statement, the pulse interval of 2.0 sec is appropriate for tracking fishes which move actively. In both the ordinary pinger and the information one, the pulse width is constant and determined as 20 ms.

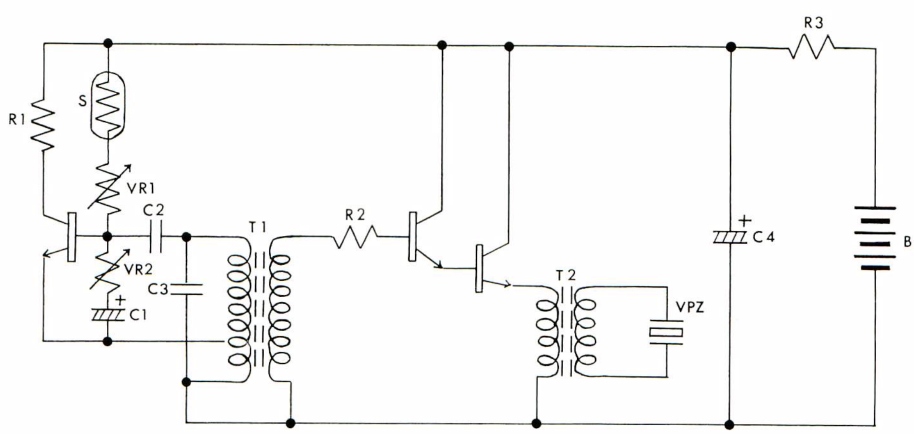

Fig. 2. Circuit diagram of the information-pinger
S indicates the sensor.

On account of the proper characteristics in the individual thermister as well as in the conductive rubber, the pulse interval should be calibrated for each pinger before the field test is carried out. The conductive rubber in which the small carbon particles are scattered is of low price and changes widely the conductivity or the resistance in response to the variation of level in the water pressure. Kavrak (1970) emphasizes the validity of conductive rubber for the fluids research but we could not eliminate the hysteresis coming from the elasticity of rubber. Since the characteristics of the conductive rubber is not stable substantially as the pressure sensor, the other type of sensor should be developed.

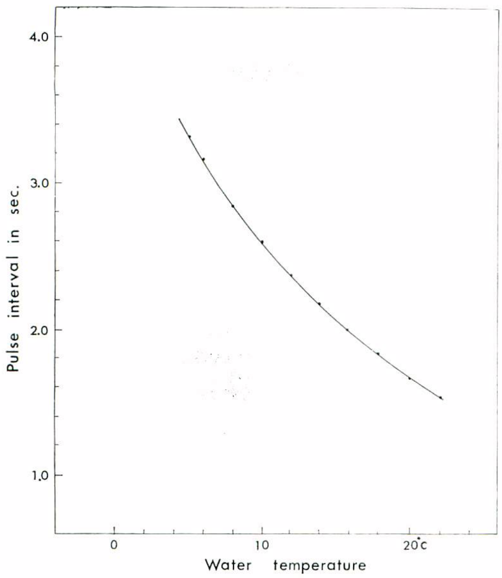

Fig. 3. Relationship between the pulse interval and the environmental water temperature in the temperature-pinger.

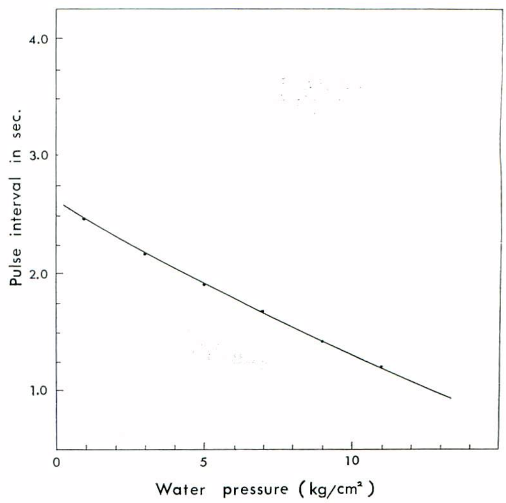

Fig. 4. Relationship between the pulse interval and the environmental water pressure in the depth-pinger.

RECEIVING APPARATUS

The receiving apparatus comprises three components ; receiving transducer, receiver, and recorder. In the underwater telemetering system, the signal of pulse transmitted from the pinger is primarily received by the transducer, then amplified and detected in the receiver, and finally recorded by the recorder as the behavioral informations on the unrestrained target fish. The efficiencies of these apparatuses as well as of the pinger have a direct effect on not only the propagating range of sonic informations but also the accuracy of received informations. The characteristics and operational mechanism of the receiving apparatuses are described as follows.

Receiving transducer : The receiving transducer is made of lead zirconium titanate. As shown in Fig. 5, the angle of declination can be changed readily from 0° to 90° in the vertical plane and the rotating range till 360° is possible manually in the horizontal plane.

The directive characteristics of such a transducer is an important factor to determine the receiving sensitivity and the accuracy in direction finding. Fig. 6 indicates the general pattern of directive characteristics in the transducer, composed of the one main lobe and two side lobes. The receiving sensitivity is represented by the length of main lobe in 0° and the accuracy in direction finding is determined by the width of main lobe. The directive angle of the transducer is generally expressed as the angle which holds between OP_1 and OP_2, and 43° in the present receiving transducer. The length of OP_1 or OP_2 is equal to

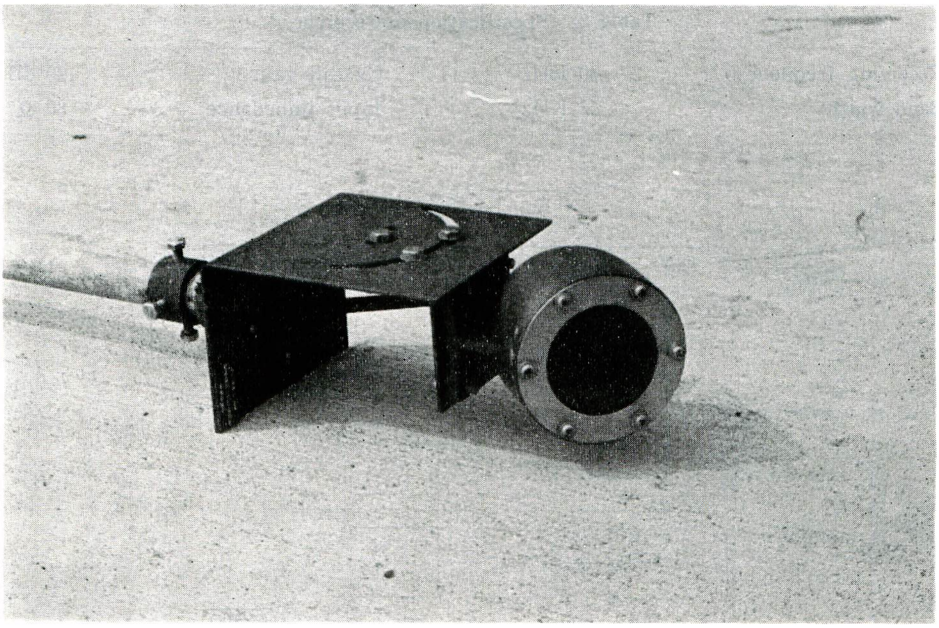

Fig. 5. External shape of receiving transducer.

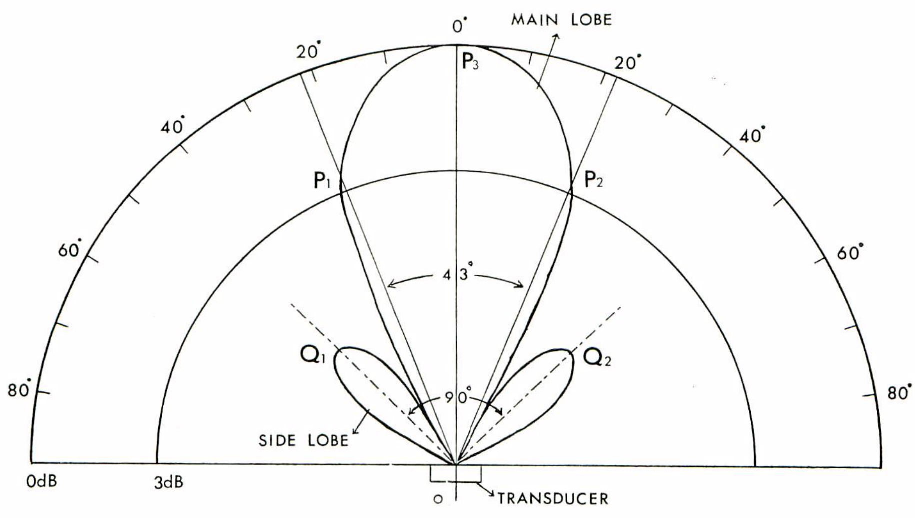

Fig. 6. Directive characteristics of receiving transducer.

the length of $OP_3/\sqrt{2}$, indicating the half power point. When the target pinger is located far from the receiving transducer, the transmitted signal is received within the range covered by the main lobe. On the other hand, the signal from the pinger which is located close to the transducer, is received by the main lobe as well as by the side lobes. The directive angle of side lobes is about 90° as shown in the figure. In the actual operation of the receiving transducer at sea, therefore, it is necessary to recognize whether the signal is received by the main lobe or side lobes.

Table 2. Specification of receiver

Receiving frequency	50 KHz	Overall gain	120 dB
Band width	3 KHz	Input impedance	80 Ω

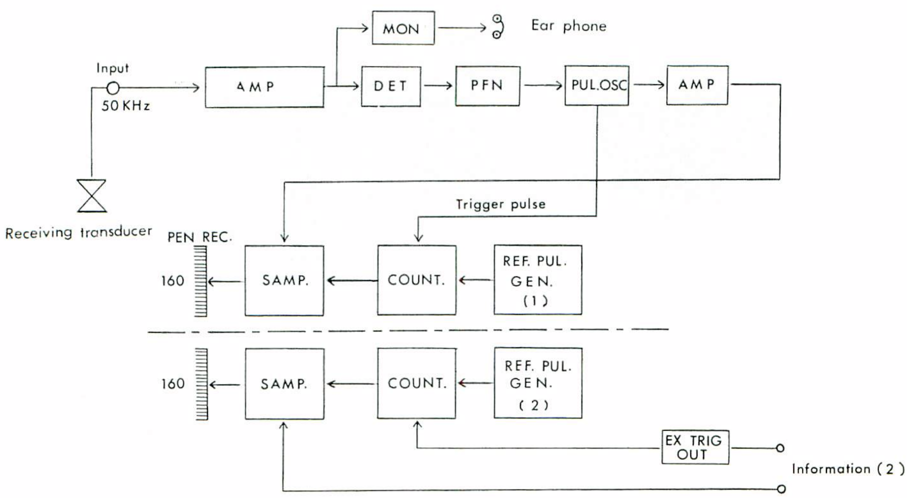

Fig. 7. Block diagram of information receiving system.

A type of hydrophone which is used by Henderson et al. (1966) to receive the sonic signal from fishes, shows wider directive angle and wider band-width than the above receiving transducer does. Consequently, the receiver of hydrophone type gives less chance to miss the signal, but less accuracy in direction finding as well as lower sensitivity than the receiving transducer.

Receiver : The receiver is devised to receive the signal of pulse and the telemetric informations contained in the signal, therefore, the mechanism of receiver is slightly complicated in relation to the operational mechanism of recorder. The specification of receiver is shown in Table 2. When the band-width in the receiver is narrow, the background noise is effectively eliminated and hence the high sensitivity is kept. As the frequency of transmitting transducer shifts slightly with the change of the water temperature or the water pressure, however, the band-width of the present receiver is expanded to 3 KHz to cover the frequency shift.

Fig. 7 shows the block diagram of both the receiver and the recorder. The signal of 50 KHz received by the transducer is amplified through Audio Frequency Amplifier (AMP) and the wave form as indicated in Fig. 8—1 is obtained. Then, the signal is detected through Detector (DET) and the pulse is transformed as shown in Fig. 8—2. The pulse deformed by the ambient noise is arranged to clear one through the Pulse Forming Network (PFN), as shown in Fig. 8—3. The width of amplified signal pulse is spread through the Pulse Oscillator (PUL. OSC) to avoid the wrong record of information. The minimum pulse width from 40 to 60 ms is necessary in this step as indicated in Fig. 8—4. Besides, the Monitor Circuit (MON) in which a part of out-put is supplied to the head phones, is set to check always the sensitivity of the receiver. In this circuit, the audible beat is produced by adding the out-put of Audio Frequency Oscillator to the out-put of amplifier. To use this monitor is convenient for the operator of the transducer which is set on the side of the research vessel.

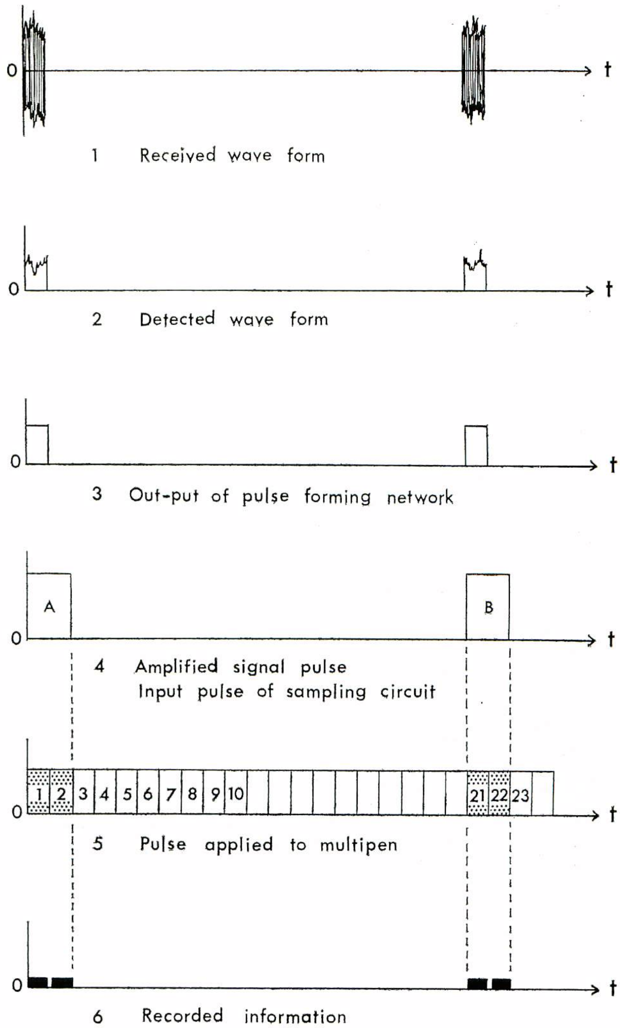

Fig. 8. Information recording mechanism represented by wave form.

Recorder : The recording apparatus is an improved multi-pen-recorder which has been developed by Koden Electronics Co. Ltd. and it can express the telemetric informations as the continuous analogue quantity. As shown in the lower part of Fig. 7, it comprises 320 pens which are independent electrically with each other. In the preliminary improvement, 320 pens are divided into two divisions to record simultaneously two independent informations and hence each division comprises 160 pens. The effective width of recording paper is 60 mm for each telemetric information. The recording paper is optionally rolled up in the speed of 10 mm or 20 mm per minute. The appearance of the recorder is shown in Fig. 9.

The pulse which has the accurate time interval of 1/160 is produced in the Reference Pulse Generator (REF. PUL. GEN) and the individual pulse is distributed to each of 160 pens, through the open-short of the Counter Circuit (COUNT). The signal for the open-short is given by the pulse produced by the trigger circuit. A part of the out-put power in PUL OSC of the receiver is utilized to make the trigger pulse. The signal pulse finally amplified in the receiver is combined with the pulse distributed to each pen and enters into Sampling Circuit (SAMP). At this time, only the signal pulses synchronized with the reference pulse function to keep records. From the viewpoint of the wave form, the operational mechanism to keep records is inidcated in the lower part of Fig. 8. When the trigger pulse which is produced at the standing point of signal A in Fig. 8—4 is applied to COUNT, the reference pulse is applied in turn from the first pen.

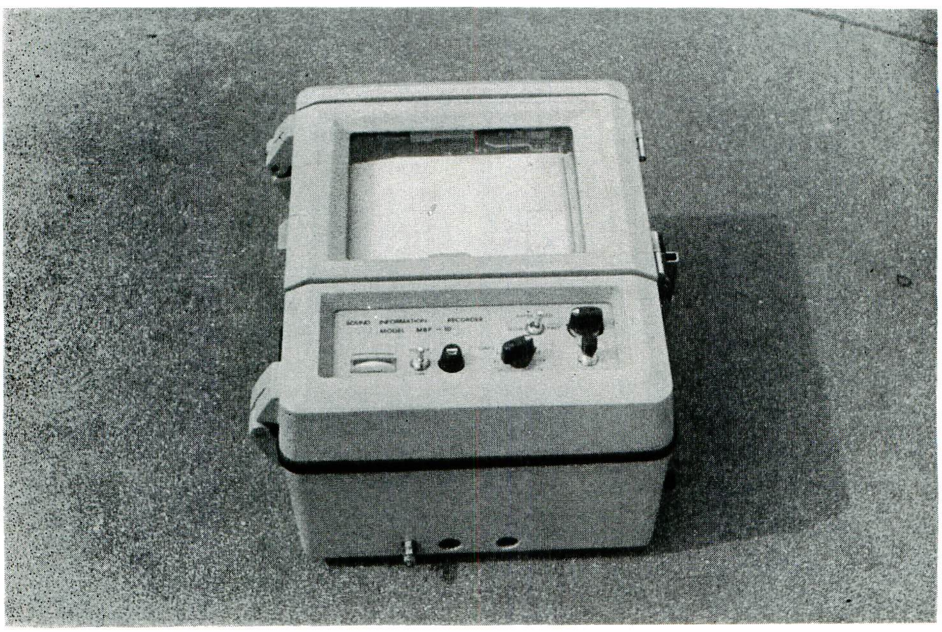

Fig. 9. Multipen analogue recorder for under water ultrasonic telemetry.

Since the signal pulse A is synchronized with reference pulses applied to 1 st and 2 nd pen, only these 2 pens are electrically charged and hence function to keep discharged records on the recording paper. When the next signal pulse B is applied to SAMP, for example, 21 st and 22 nd pens are electrically charged and keep other records. In the descending point of signal B, the trigger pulse stops the function of multipens. Such repeated operations make the continuous analogue records on the recording paper, as shown in Fig. 8—6.

Provided that the maximum pulse interval is 4.0 sec, the reference pulse width for each pen can be given by 4/160 sec, that is, 25 ms. Accordingly, the signal pulse B is recorded in the delay of 500 ms. The interval between signal A and B represents the analogue quantity of the telemetric information and it can be measured directly by the calibrated scale on the recording paper. Fig. 10 indicates 7 levels of the water temperatures recorded by the multipen recorder. It is used as a standard for calibrating the actual records on ambient water temperatures conveyed from the unrestrained fish. The time mark is automatically plotted on the right side of the recording paper every minute. Fig. 11 shows an example of the actual telemetric records of water temperatures from a swimming yellowtail. This yellowtail moves in the different zones of the temperature or the depth during 11 minutes.

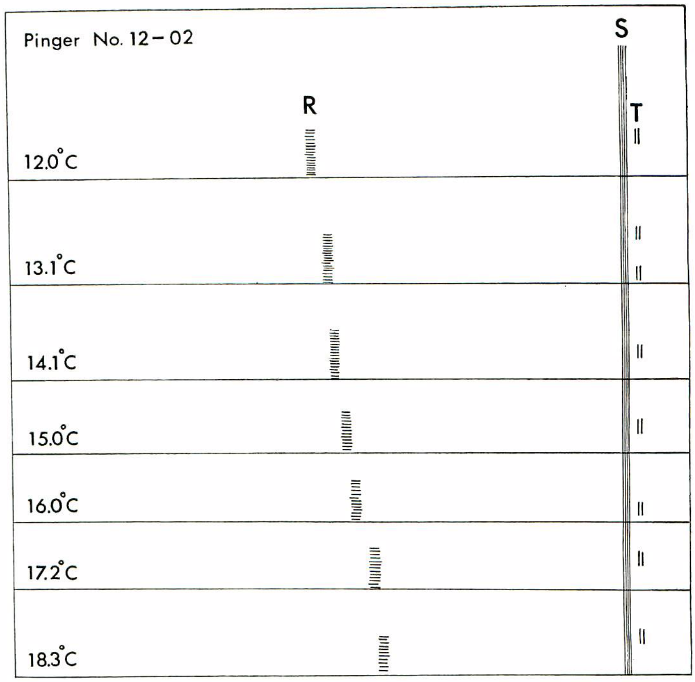

Fig. 10. Records of water temperatures, received by the multipen recorder

R : Record of information
S : Standard level
T : Time mark

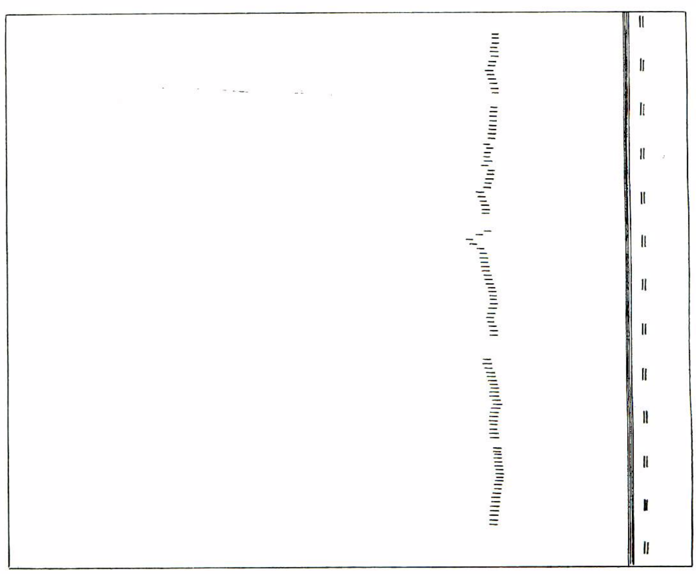

Fig. 11. An example of telemetric water temperature from an unrestrained yellowtail

IMPROVEMENT IN THE FUTURE

Apart from the size of transmitter or the type of sensors, several improvements are necessary for the effective use of the telemetric system mentioned above. How the vessel carries the transducer or what is the effective way in operating the receiving transducer is an important problem to be solved. Equipment of the transducer on the side of vessel is of effective use only in the small vessel, but it is difficult in the large vessel. For the operation of transducer and for the sailing of vessel, the long pipe will be a barrier. The transducer installed at the bottom of vessel helps to escape from these handicaps. Instead of the manual drive, the motor drive is necessary to change the direction of transducer in both horizontal and vertical plane. These improvements save the man power and increase the efficiency in the practical tracking for the target fish at sea.

In tracking fish at the open sea to examine the migratory behavior, it is not very wise to persist in the accuracy of direction finding because the location of vessel is not yet determined with high accuracy. The accuracy of recorded information is preferably required in the future. As one step for this purpose, the multipen recorder was improved so that a total of 320 pens is activated to obtain one information. As an example, this improvement enables us to detect the difference of 0.3°C in the water temperature. The change-over measurement in two steps is necessary to make the error of data least. This implies that the maximum pulse interval of 4.0 sec can be recorded in two steps. It is possible that the signal of pulse interval under 2.0 sec is recorded by the use of 320 pens at first and then the signal of pulse interval of 2.0~4.0 sec is recorded in the next use through the change-over switch.

Several kinds of informations will be needed in the future biotelemetry study, in relation to behavioral, physiological and environmental factors. Telemetering of informations more than 2 factors is very effective in the research work. Standora (1972) devises a 8 channel ultrasonic telemetry system for the study on the shark behavior, utilizng several integrated circuits. He emphasizes that the design of miniaturized sensors is necessary for multichannel monitoring in the future. It seems that his suggestion is not to miniaturize sensors themselves but to make sensors with no supplemental circuits. Compared with the radio frequency, the low frequency ultrasonic under 50 KHz has much difficulty in the multichannel transmission. The multichannel monitoring of ultrasonic should be resolved step by step after the technique of 2 channel telemetry is practically developed.

FIXING METHOD OF PINGER TO FISH

Evaluating the duration which white bass, *Roccus chrysops* carries effectively four kinds of tags ; tags inserted into the stomach, into the body cavity, hooked on the dorsal portion and punched in the dorsal fin, Henderson et al. (1966) conclude that the capsule tag kept in the stomach is well carried by the fish and recovered at the high ratio. On the basis of this test, Hasler et al. (1969) apply the ultrasonic tag in the stomach for tracking white bass to examine the behavior of fish in the orientation at lake Mendota, Wisconsin. The transmitter of pinger type which Henderson et al devised was 9 mm in diameter and 40 mm long. Its weight was 5.8 g in air and about 2.0 g in water. In the same way, Yuen (1970) also successfully tracks skipjack tuna, *Katsuwonus pelamis*, about 44 cm long in Hawaiian waters. He used 8.1 cm long tag of 2.0 cm in diameter and its weight was 62 g in air.

Whether or not the capsule tag in the stomach is available for the yellowtail was examined in the large tank of 10 m×10 m×6 m at Marine Science Museum of Tokai University, Shimizu, from 1970 through 1971. For this basic test, dummies of the same size as our pinger described in the prevoius chapter were used but their weights were 10 g or 20 g in water. In order to measure the duration which the capsule dummy is kept in the stomach of fish, some different procedures were taken before insertion. Of 20 yellowtails, 12 fishes were anesthetized through MS 222—1/5,000 conc. solution and the effect of anesthesia on the duration was examined. Dummies wrapped by the Sand lance (*Ammodytes* sp.) which was a popular bait of the captive yellowtails, was given to 8 yellowtails and compared with the use of bare dummies.

Table 3. Duration which the live yellowtail keeps the bare dummy of pinger in its stomach.

Weight of dummy		Anesthesia treatment			Weight of dummy		Non anesthesia treatment	
		Fish					Fish	
In air	In water	Total length	Body weght	Duration	In air	In water	Total length	Duration
g	g	cm	kg	hrs	g	g	cm	hrs
29	10	50.1	1.4	3.8	29	10	57.5	12.7
29	10	53.4	1.7	3.4	29	10	56.7	14.8
29	10	49.6	1.9	5.0	—	—	—	—
29	10	52.5	1.6	2.2	—	—	—	—
39	20	53.9	1.9	7.9	39	20	57.0	8.0
39	20	51.8	1.6	3.5	39	20	48.6	14.0
39	20	53.1	1.4	11.1	—	—	—	—
39	20	52.2	1.7	10.2	—	—	—	—
Mean		52.1	1.7	5.9			56.1	12.4

Table 4. Duration which the live yellowtail keeps the dummy wrapped by the Sand lance in its stomach.

Weight of dummy		Anesthesia treatment			Weight of dummy		Non anesthesia treatment	
		Fish					Fish	
In air	In water	Total length	Body weight	Duration	In air	In water	Total length	Duration
g	g	cm	kg	hrs	g	g	cm	hrs
29	10	58.9	2.6	38.8	29	10	56.3	16.6
29	10	60.6	2.7	14.5	29	10	57.0	49.3
39	20	58.6	2.7	7.9	39	20	57.5	22.4
39	20	62.2	2.8	11.8	39	20	56.7	48.9
Mean		60.1	2.7	18.2			56.9	34.3

The time duration from insertion to vomitting is measured for the individual case and shown in Tables 3 and 4. The fish used for this test ranges from 49.6 to 62.2 cm in the total length and from 1.4 to 2.8 kg in the body weight. Regardless of bare and wrapped state, the dummy remains about two times longer in the stomach of untreated fish than in that of anesthetized fish. The tables also show the result that the dummy remains about three times longer in the state wrapped by the Sand lance than in the bare state. There is no relation between the weight of dummy and the duration to be maintained, when the dummies of 10 g or 20 g is inserted into the stomach. It is clear, however, that all dummies are vomitted from 2 to 49 hours after insertion into the yellowtail, although the fish listed in Table 4 is bigger than in Table 3.

Both vagus and sympathetic nerve which runs in the stomach wall of fish function for contracting the smooth muscle of the stomach, and there is no antagoism between two nerves as Burnstock (1959) states. In any species of fish, the capsule tag kept in the stomach will be finally vomitted by the contraction of the smooth muscle, but the duration which the capsule is kept differs much among species of fish. The duration seems to depend on the shape of pinger, the structure and size of stomach, and the stages in the growth of fish. However, the basic test indicates that the method of insertion at least is not valid for yellowtails.

Table 5. Duration which the live yellowtail maintains the dummy in the towing type. Each dummy is fixed to the base of anal fin through the artificial silk-worm gut.

	Fish		Dummy			Treatment before release				Duration	
No.	Total length	Body weight	Weight in water	Length of gut	Colour	Anes-thesia	Rest	Towing duration	Cause of falling off	Duration before normal behavior	Chase by other fishes
	cm	kg	g	cm				day		min	
1			10	25	Green	—	—	5.0	U		Violent*
2	51.7	2.7	10	20	Green	—	—	15.0	M	1,440	Non
3			10	30	Green	—	—	0.2	U		Non
4			20	10	Yellow	—	—	12.0	U		Non
5	56.0	2.4	20	10	Yellow	—	—	9.0	U	180—420	Non
6			20	30	Yellow	—	—	0.9	U		Non
7			40	30	Red	—	—	4.0	U		Non
8	56.7	2.5	40	10	Red	—	—	8.0	M	180—420	Non
9			40	10	Red	—	—	11.0	M		Non
10			20	10	Yellow	+	+	22.0	M		Non
11	59.0	3.3	20	10	Yellow	+	+	16.0	M	10—15	Non
12			20	10	Yellow	—	+	16.0	M		Non
13			20	10	Yellow	—	+	17.0	M		Non
14			20	10	Blue	+	+	14.0	M		Non
15	60.5	3.4	20	10	Blue	+	+	15.0	M	10—15	Non
16			20	10	Blue	—	+	11.0	U		Non

* No ring to prevent the twist of gut was used.
U : Unskillful fixing
M : Muscle was cut off

In the telemetering of environmental factors, the sensor of pinger is necessary to remain out of the fish body. To escape from the serious damages to the fish body and keep the fish in the normal behavior, various fixing methods were tested in an oceanarium. The external attachment of the saddle-type pinger applied for Hime salmon (landlocked form of sockeyes) *Oncorhynchus nerka* var. *adonis*, by Shirahata (1971) needs the anesthesia of the fish. To make the fixing time as short as possible, another practical method was devised for non anesthetized yellowtails by using dummies of pinger. At first, dummies of various weights in water were towed through the artificial silk-worm gut from the back of fish. Penetrating the muscle between the first and second dorsal fin, one end of gut was fixed to the fish body and the other end was connected with the dummy. Such a fixing method was not effective. Even if the weight of dummy was 0 g in water, the dummy fixed descended and touched frequently to the tail region of fish with the advance of fish, and eventually it gave the serious damage to the fish. When the dummy was lighter than 0 g in water, the floating dummy disturbed the behavior of fish in the slow swimming. Finally, the base of anal fin was selected to fix the dummy to fish. Penetrating the muscle between the interhaemal spines of the anal fin, one end of the silk-worm gut was fixed to the fish body. The dummy, in which the center of gravity was placed on the latter half, was connected with the other end of gut through a ring like metal. Rotating itself, the ring prevented the twist of gut. Table 5 shows the experimental result for 16 yellowtails when this towing method was applied. To examine the effect of colour on the sense of sight, dummies were coloured in four types for the test ; red, yellow, green and blue colour. Besides, the weight of dummy and the length of gut were changed to detect the best condition available. After the fish was released, the movement of dummy and the behavior of fish were observed until the dummy fell off from the fish body. The duration from release till the fish shows the normal swimming behavior and enters into the shoal can be shorten by keeping the fish in the quiet condition for about an hour before release. For 7 fishes from No. 10 to No. 16, this duration was from 10 through 15 minutes and compared with the other cases.

Anesthesia was not necessary before fixing, because Nos. 12, 13 and 16 fishes which were not anesthetized at the time of fixing maintained the dummies for 11 days and longer. In most cases of the unskillful fixing, the knot between the dummy and the gut came untied and the dummy fell off from the fish body in the midst of swimming. In the skillful fixing, the dummy fell off with the gut through cutting off the muscle between the interhaemal spines. From release to falling, it took from 8 through 22 days as shown in the table. The damage of muscle gave no serious effect on the fish. Since these periods exceed the life span of battery in the pinger, this fixing method was of practical use.

The best length of gut was about 10 cm. The dummy of 20 g in water and 35 g in air was successfully pulled by the yellowtail without pitching. Since the mean length and body weight of fish were 56.8 cm and 2.9 kg respectively, the ratio of such a dummy against the body weight of yellowtail corresponded to 1.2%. Shirahata (1971) concludes that there is no remarkable effect on the behavior of Hime salmon when the ratio of weight of the saddle-type pinger to the weight of fish is less than 8 %. The use of different coloured dummies have no special stimulation on the sense of sight of the yellowtail. The pitching and rolling of towed dummy should be avoided, because it stimulates remarkably other yellowtails in the same shoal. The other fish chased abnormally the moving dummy and hence disturbed the normal behavior of the target fish. In No. 1 fish, the dummy which was not equipped with the ring like metal indicated a strong shake in towing and consequently it was chased violently by other fishes. With regard to the fishes Nos. 2~16, no chase by other fishes was observed after the target fish was released. Only one defect which this fixing method brought forth lay in the fact that the tagged fish could not dash to take food like the other fishes in feeding, but the target fish eventually could succeed in taking food. A yellwtail, 80 cm long, equipped with the pinger is indicated in Fig. 12.

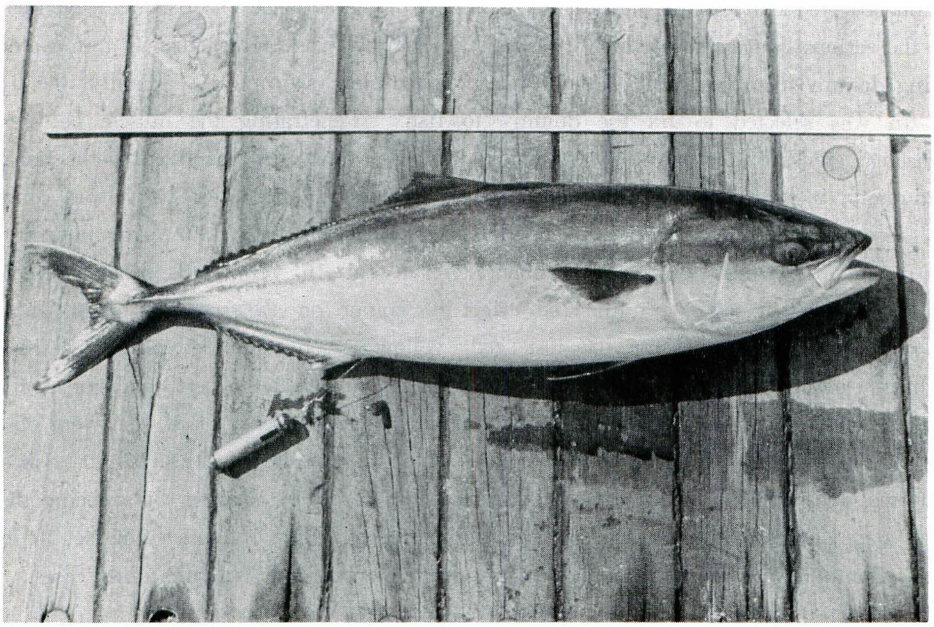

Fig. 12. A yellowtail, 80 cm long, which tows a temperature pinger from the base of anal fin.

TRACKING FISH IN OPEN WATERS

Substantially, the receiving transducer was developed to get the telemetric informations of environmental and physiological factors from the moving fish. Effective beam width of the transducer in the horizontal plane to search for the ultrasonic target is 43° in the long distance and about 90° in the short range as explained in the previous chapter. Rotating the transducer and hearing the audible beat derived from the monitor circuit of the receiver, the operator can recognize whether or not the target is far from the base station. When the target is located beneath the station, the beat can be caught in any direction of the transducer declined to about 15°. Ideally, it is necessary to establish two stations to obtain the accurate location of the target. In particular, it is essential in the fresh waters, because the propagating range of ultrasonic sound is generally wider in the fresh waters than in the salt waters.

In our system, the range to discriminate and record informations is about 1 km in sea. Using the effective beam width of the rotating receiving transducer and confirming the occurrence of clear records, the operator can conduct the course of research vessel within the range of 1 km from the target fish. In such a tracking technique, the location of fish is represented by the location of the vessel equipped with the receiving instruments. Much difficulty in detecting the accurate location of the vessel in the open sea will permit the above practical tracking method by one vessel. An example of successful tracking of the yellowtail is described as follows.

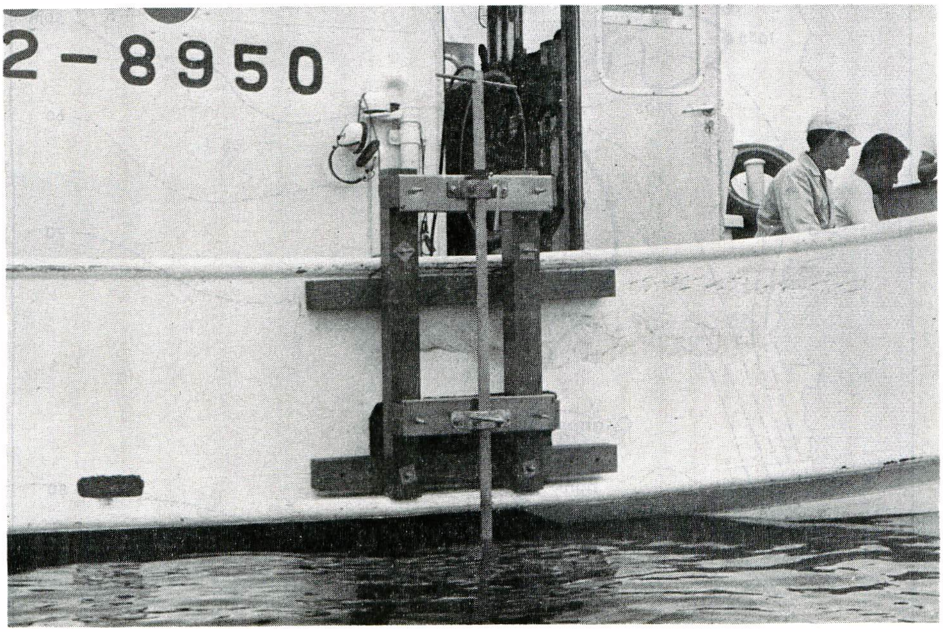

Fig. 13. Receiving transducer equipped on the side of the research vessel, Kakusui, Nagasaki University.

A total of 6 fishes kept in the set net at Danjo Islands for two days was transported to the release point by the container of "Kakusui", 20 gross ton, a research vessel of Nagasaki University. Danjo Islands is located in 45 miles south from the release point. The tracking test in the waters close to Danjo Islands could not be carried out because of the stormy weather. Although the sexes of yellowtails captured by the set net could not be determined from the external shape and the body colour, it was supposed through the observation of thin belly side that these fishes were taken after the main spawning season was over. From the maturing stages of the reproductive organ, Mitani (1959) estimates that the spawning season of yellowtails ranges from April through May in the adjacent waters to Danjo Islands. After the pulse interval was calibrated for the measurement of water temperature, a temperature pinger was fixed to a yellowtail, 80 cm long, in the towing type. At 1152 on May 23 in 1971, the fish was released from the vessel with the other two fishes bearing no sonic tag in the location of 3 miles east off Goto Islands where the sea was 100 m deep. The ιeceiving transducer was set with the wooden frame on the side of the

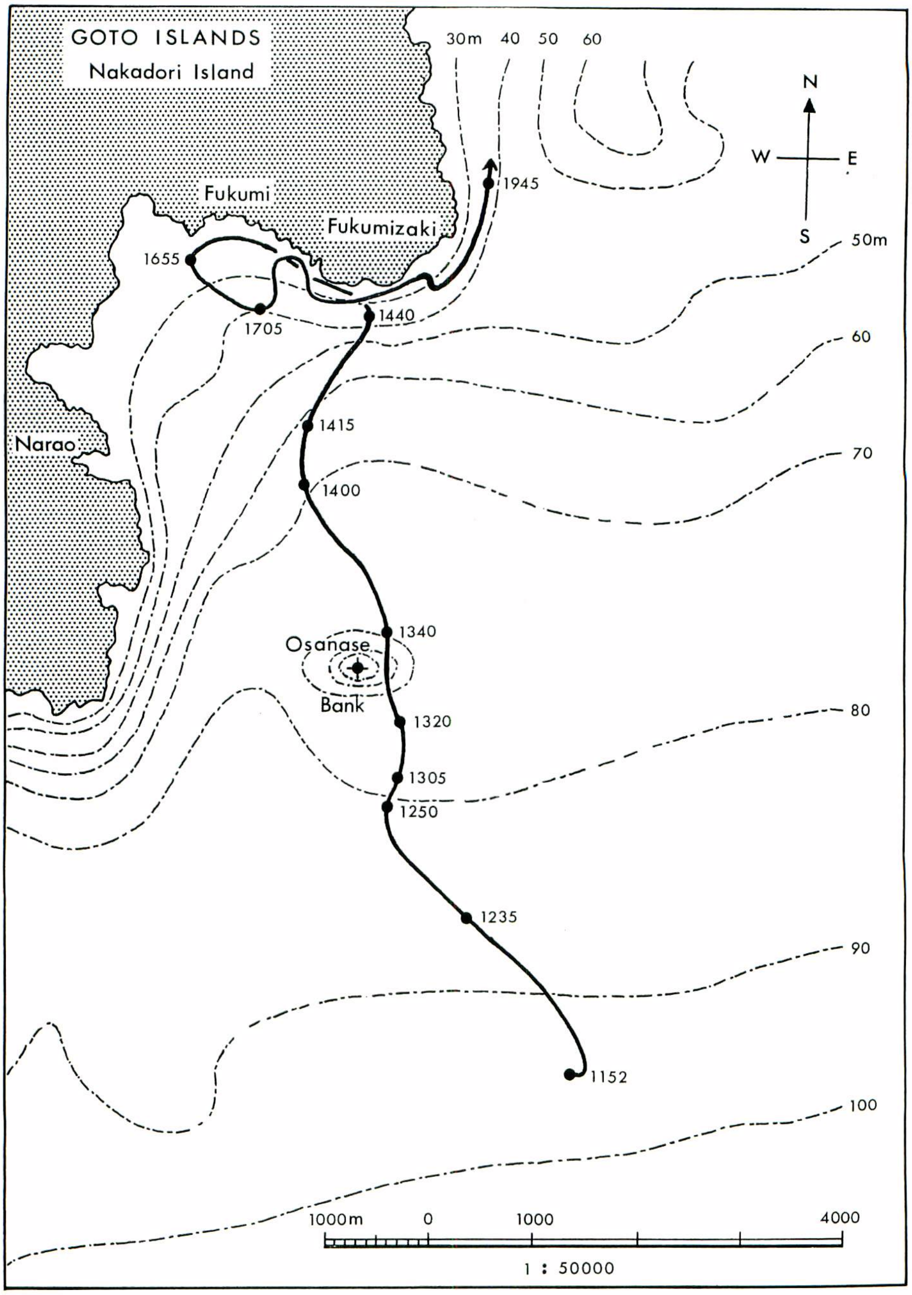

Fig. 14. Horizontal movement course of a yellowtail tracked by the ultrasonic device off Goto Islands in May of 1972.
–·–– Contour line in the sea

research vessel, as shown in Fig. 13. Such an equipment is stable less than the sailing speed of 5 knot and the Beaufort wind force of 3.

For about 20 minutes after release, the fish circulated the release point several times for orientation and then it determined the direction of movement to northwest. There is no relation between the orientation of fish and the direction of the surface wind. The direction of water current was not measured on this chance. The horizontal movement of the fish was tracked by the vessel for about 8 hours and shown in Fig. 14. Throughout the pursuit, the location of the vessel was determined by the bearing and radar, and the vertical distribution of the water temperature was measured by the bathythermograph. During the movement in the deep waters, the fish did not show the extreme change of direction. After swimming in the average speed of 2.8 knot an hour, the fish changed the direction to north at 1250

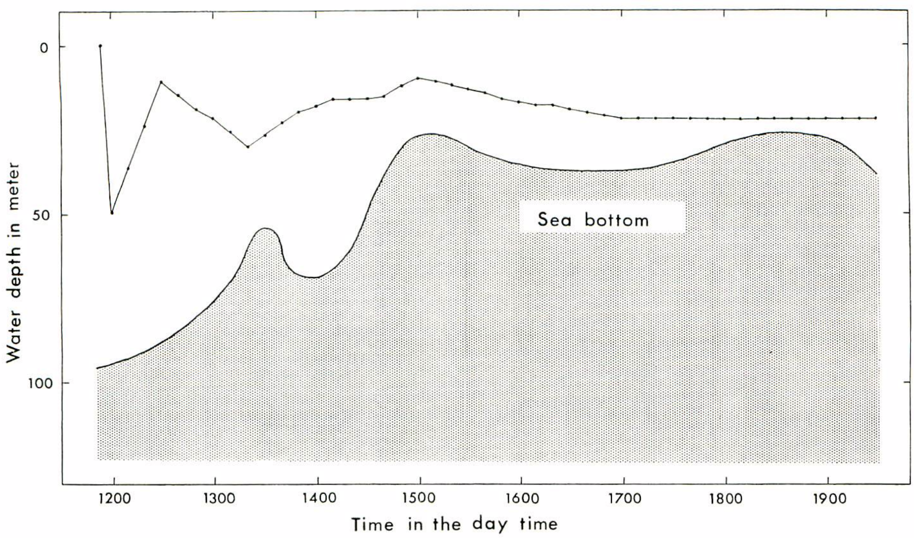

Fig. 15. Vertical movement of a yellowtail tracked by the ultrasonic device
▒ Depth of sea bottom measured by sonar

and approached to Osanase Bank in slowing down the moving speed (1.2 knot). At about 1330, the fish reached the location, 0.1 mile off Osanase Bank and swam around the bank in the very slow speed for about 10 minutes. From 1340, the fish began to move out of the bank and directed to Fukumizaki. It arrived at the shallow waters in front of Fukumizaki at 1440. Then, the fish stayed in the shallow waters and moved around slowly (0.3—0.8 knot) till 1840. In this coastal area, much noises from biological sources often disturbed the records of telemetric water temperature but the signal from pinger was clearly audible and discriminated from ambient noises. Near the sunset of 1850, the fish began to leave for the open waters with the increment of speed (1.5 knot) and took the course to north. At 1945, tracking unfortunately was interrupted because of the accident of radar. Then, the research vessel entered into Narao Port, avoiding the dangerous sail at night.

From 0500 to 1000 in the next morning, the vessel searched for the fish within 5 miles north from Fukumizaki along the coastal line but no beat from the target fish was heard. The topography of this area was complicated, including small bays and inlets. No catch of beat suggests that the fish possibly went out of the coastal region to the open waters at night. It has been known from the past that the nocturnal behavior of yellowtails is active in the coastal region. However, this finding has been derived from experience which the amount of catch by the set net was more abundant in the morning than in the evening (Miyamoto, 1942). The evidence of nocturnal activity will be examined by the direct measurememt of biotelemetry. It was characteristic that the fish swam across the contour line in the course from the release point to Fukumizaki and seemed to navigate from one shallow waters to the other.

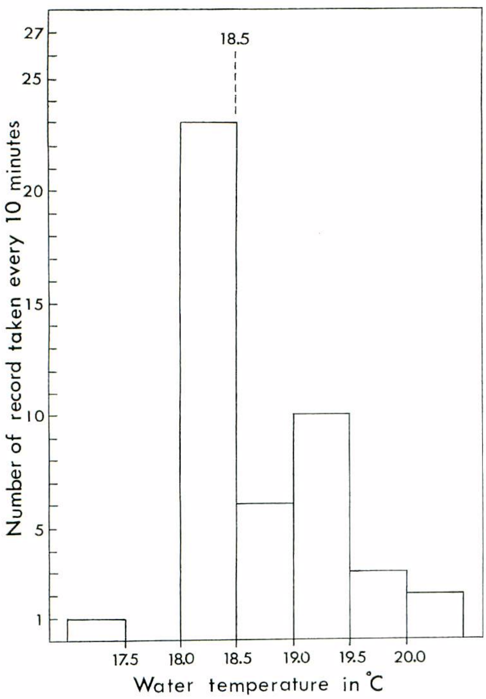

Fig. 16. Swimming temperture of a yellowtail measured by ultrasonic device
---- Mean temperature

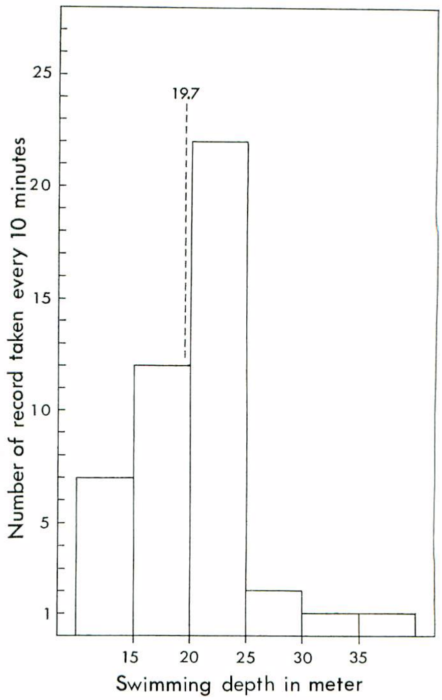

Fig. 17. Swimming depth of a yellowtail measured by ultrasonic device
----- Mean swimming depth

The water temperature sent to the vessel from the pinger was converted into the swimming depth through the frequent measurements of the vertical distribution of water temperature. Along the horizontal movement course of the fish as shown in Fig. 12, the vertical movement of fish can be indicated in Fig. 15. The depth of sea bottom was measured continuously by the sonar of 28 KHz. The relation between the movement of fish and the topography of sea bottom is given in the figure. Immediately after release, the fish dived rapidly to the level of 50 m deep within 8 minutes, and then it turned upwards to come to 11 m deep at 1230. The rapid dive may imply the behavior escaping from restraint.

Thereafter, the fish continued to swim along the topographic change of the sea bottom for about 8 hours. It suggests that the fish itself selected the swimming depth during the movement in this area. On the basis of the measurements every 10 minutes, the frequency distribution of the water temperature in the swimming zone of the fish is presented in Fig. 16 as a histogram. Ranging from 17.0° to 20.0°C in the water temperatuie, the yellowtail inhabited most frequently the zone from 18.0° to 18.5°C. The mean tempera-tuie of water surrounding the fish was 18.5 °C. The frequency distribution of the swimming depth is shown in Fig. 17. Except for the deep dive just after release, the fish kept the depth from 10 to 37 m, staying most frequently in the 20~25 m zone. The mean swimming depth of fish was 19.7 m in the course of tracking.

The swimming speed of fish was estimated from the tracking speed of vessel which sailed to follow the fish. Since the speed varied from the shallow waters to the deep waters, two cases were presented in Fig. 18. The fish moved in the speed of 1.0 knot and less per hour in the shallow waters, while in the speed of 1.5~3.5 knot per hour in the deep waters. The mean speed was 0.6 knot in the former and 1.9 knot in the latter. The combined mean speed was 1.2 knot for the tracked yellowtail. The speedy behavior was indicated when the fish moved across the contour lines in the deep waters.

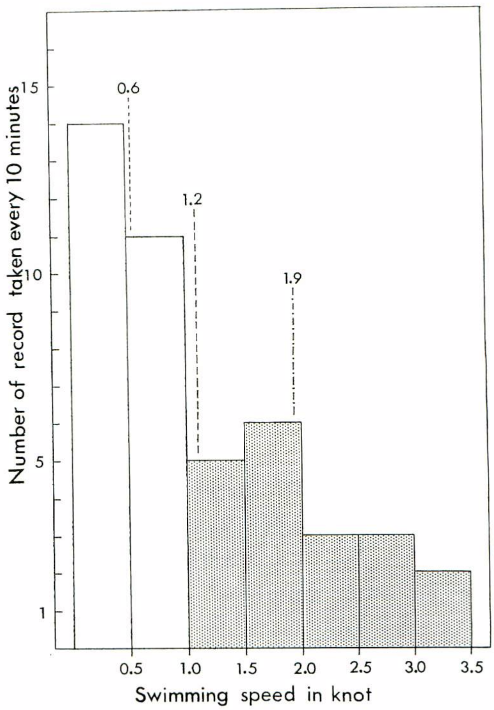

Fig. 18. Movement speed of a yellowtail measured by ultrasonic device
---------- Mean speed in shallow waters
-·-·-·-·- Mean speed in deep waters
– – – – Mean speed in the period of tracking

Suyehiro (1957) and Mori (1958) estimate independently the migiatory speed of yellowtails in the adjacent waters to Japan fiom the sources of tagging and subsequent tag recoveiy, indicating the range from 0.05 to 1.84 knot per hour. On board a fishing vessel, Kurita (1927) chases a shoal of yellowtails and observes that the shoal continues to move in the speed of about 3 knot per hour until it is taken by the vessel. Our measurment covers these past recoid estimated in the rough ways and presents evidence that the moving activity of yellowtail differs in iesponse to the topographic conditions of the sea, even in the day time. Since the tracking was carried out within a limited duration and for only one yellowtail, there were not so many informations obtained with regard to the behavior of yellowtail. However, the successful result suggests that the effective use of underwater telemetric device enables us to measure continuously the activity of fish throughout the tracking in the open waters.

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バイオテレメトリー用超音波機器とそのブリ追跡への応用

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要　旨

ここでのべる海洋生物用の超音波バイオテレメトリーシステムは，1968年度より4ケ年にわたって開発をすすめてきたものである。システムは超音波送信器，受波器，受信器，記録器の4部分から構成されている。周波数 50 KHz を使用した送信器は空中重量32 g，水中重量10.5 g以下であり，平均して2秒の間隔でパルス波を送信し，120時間にわたる送信寿命と水深300 mまでの耐水圧を保持する自発送信ピンガー型であって，情報検出用センサを備えている。システムの特長は，パルス間隔変調により生物の遊泳水温，もしくわ水深を1情報に限って遠隔から受信記録できる点にある。ジルコン酸鉛振動子に受波された信号は，最終的に多ペン式記録器によりアナログ情報として記録され，水温テレメトリーの場合0.3°C差の検出が可能である。信号音の海中伝播距離は平均2 km，情報識別距離は海中で平均1 kmである。

魚類に装着した送信器が魚体に与える負荷の程度，ならびに，遊泳行動におよぼす影響の程度，および超音波標識魚が群に混入する状態を調査するため，大水槽で飼育中のブリを使用して種々の装着法が検討され，最

終的に臀鰭基底の担鰭骨間の筋肉を利用したテグスによる曳航法が採用された。胃内に挿入された送信器は，胃壁平滑筋の収縮により短時間で吐出されるので，ブリに対する装着法としては不適である。

1971年5月，長崎県五島列島，中通島沖で測温送信器を装着したブリを放流し，これを約8時間にわたって受信装置を塔載した船により追跡した。ブリは等深線を横断し，瀬から瀬に移動する水平行動をしめし，また同時に観測された垂直水深分布にもとづくと，ブリは海底地形の起伏に沿う垂直行動をとる傾向が強く，平均潜水深度が 19.7 m であった。この水深は，18.0〜18.5°C の水温層にあたり，平均の遊泳速力は 1.2 ノットであった。遊泳速力は，瀬つきの時と深みに滞在する時でことなっている。

この追跡試験は，開発機器が魚類の行動生態測定用に有効に使用できることをしめすものである。