音波発生器の効果試験

Test of sound generator

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音波発生器3台をサケマス流網に取り付け、操業期間中に混獲されるイシイルカの水平・垂直位置を調べ、一般網の混獲イルカの水平・垂直分布と比較し、その違いから有効性を調べた。

1. 試験期間

１９８６年６月９日～７月１４日

2. 試験船

野島丸船団所属の独航船　　第５３長久丸

3. 方　　法

３・１　音波発生器

今回使用した音波発生器は１９８５年度に試作したもので、２０～５０kHzの周波数のパルス波とＦＭ波をランダムに発生し、最大音圧は１*m*の距離で１８６dBである。

電池と電子回路をブイの中に収納入し、送波器はブイの下部に取り付けられ、水平方向に無指向性で音波が発射される。装置の作動時間は１２時間にセットされ、使用後翌日の使用にそなえ充電される。

詳細な仕様は前年度のINPFC，ドキュメント（畠山１９８６）[1)]に述べてある。

３・２　音波発生器の取付け位置

図１に示すように３３０反の流網の端から５５、１１０、１６５反目の３ヶ所に、５５反間隔で音波発生器を各々１個取り付けた。

３・３　データの採集方法

混獲イシイルカの種別、生死、頭数、混獲位置などを米国側へ報告する用紙をそのまま利用し、日本人オブザーバー（竹村氏）にデータを記入して貰った。

4. 結果及び考察

４・１　混獲イルカの分布

表１に示すように試験期間中の操業は３４回で、そのうち音波発生器を使用したのは３２回であった。混獲イルカは全てイシイルカで合計８頭であり、生存していたイルカが３頭、死亡して船上に揚げたイルカが２頭、揚げる途中に脱落したイルカが３頭であった。音波発生器を使用し

ている時の試験船のCPUEは0.250であり、一般船全体のCPUE(0.331)の76%に、また中空系船全体のCPUE(0.262)の95%に相当する。

野島丸船団の隣接船のうち最もサンプル数の多い中空系船のCPUE(0.349)と比較すると、試験船のCPUEはその72%に相当する。

混獲イルカの位置を図1、2に示した。流網全体を水平9区分、垂直3区分に分割して音波発生器を使用した時の混獲分布を計算し、1986年の一般網のデータと比較しながら表2、3に示した。音波発生器は水平区分5の中央、水平区分6と7の境目、水平区分8の中央に取り付けられたことになる。

垂直分布については試験網と一般網の間に大差がないが、水平分布については音波発生器から離れた水平区分1～4に約90%の混獲が集中している。

試験船は1隻であり、試験回数と混獲数が少いので統計的な効果判定ができないが、音波の弱くなる片側に集中的に混獲される傾向が見られ、今後とも検討していく必要がある。

4・2　機器の使用状況

投網直前の音波発生器の作動テストでは、32回ともテストランプが点灯し空中発振音が確認された。揚網直後のテストでは異常が1回あり、6月20日の電池No.4の音波発生器のテストランプが消えたままで空中発振音も聴こえなかった。予備の電池でテストすると正常に作動したので、それ以後は予備の電池を使用した。

電池は充電開始より5～6時間で通常チャージランプが消え充電完了となるが、充電に16～48時間必要としたことが5回あった。その長時間充電の電池でも揚網時の音波発生器のテストでは正常に作動しており、チャージランプの輝度が低かったことから判断し充電器のコネクターの一時的接触不良と思われる。

音波発生器を投入する時船速をストップかスローにしたこと、音波発生器の取付位置の前後2反目に赤い布で目印を付けて、それが見えたら笛を吹いて甲板員に知らせ、舷側への衝突などのトラブルを避けたことは前年度と同じである。

音波発生器の上部をオレンジ色に塗装し視認し易くして欲しいという乗組員の要望があったので今後改善する必要がある。音波発生器の下部のナットはビニールテープで覆ったので、網糸にからまり横倒しになることはなかった。

4・3　音波発生器の有効距離

音波発生器と混獲イルカの間の最短距離は、1985年で750 m[1)]、1986年で1050 mであった。イルカが音波に無関心でそのまま遊泳を続け羅網したのか、音波を聴いて何らかの反応を示す途中で羅網したのか不明である。また、イルカの聴覚には受波指向性があるので、イルカの遊泳方向、音波発生器とイルカの位置関係などによりイルカの受ける刺激の度合が変り、音波発生器の有効距離も変る。

音波発生器の周波数が２０～５０ kHz で比較的低いのは、イルカの受波指向性が広くなるので、どちらの方向を向いて遊泳しているか分らないイルカに音刺激を与えて注意力を喚起させる意味においては有利である。

今回はイシイルカが音波発生器の方を向いているという条件で、音波発生器の有効距離を検討することにする。

音波発生器の周波数は２０～５０ kHz の範囲にあるが、送波器の周波数特性により３５ kHz 近辺の周波数で最大音圧となるので使用周波数３５ kHz として有効距離の計算パラメータを決めた。水平方向の伝播の吸収損失係数を１６ dB／kmとした。

雑音のある環境でイルカが音波を聴く時、周囲の雑音のスペクトラムレベルをNJ、臨界帯域巾をBW、受波指向性利得をDIとすると、その雑音中の聴覚閾値THは次式で表わされる。

$$TH = NJ + BW - DI \qquad (1)$$

NJについては深海の平均雑音スペクトラムのデータから、海況１で29 dB（０dB＝１μPa／$\sqrt{HZ}$）、海況３で３６ dB、海況６で４５ dBとした。BWについてはイシイルカのデータがないので、Johnson（１９６８）[2]が測定したハンドウイルカのデータから３３ dBとし、DIについてもAuら（１９７４）[3]のハンドウイルカのデータを参考にして１５ dBとした。以上のデータからTHを計算してみると、海況１で４７ dB、海況３で５４ dB、海況６で６３ dBとなった。Awbreyら（１９７９）[4]の解剖所見による聴覚閾値の推定では、３５ kHz の値が５１ dBであり、それ以下になることはないので海況１のTHを５１ dBとした。

生捕りイシイルカの音響学的実験（畠山ら１９８７）[5]では、同じような送波方式の音波発生器の音圧を１０ dBステップで変えて威嚇実験をし、外見上イシイルカが反応を示し始める音圧として126 dBの値を得ていて、真の値（Pt）は１１６～１２６ dBの範囲にあることが分っている。THはイシイルカにようやく聴こえる音圧であり、Ptはイシイルカが驚き外見上の反応を示す音圧であり、それらの丁度中間にイシイルカへ音刺激を与えて注意力を喚起させる音圧（Pc）を仮定した。

図３で音波の距離減衰と上記の各設定値との交点から有効距離を求め、表４に示した。

今回の音波発生器と同じような送波方式の音波で洋上のイシイルカの威嚇実験（武富ら1985[6]、石井ら１９８６[7]）では、最大７００*m*まで発射した瞬間飛びはねて逃げる反応を観察し、全く同じ音波発生器を使った実験（畠山１９８６）[1]では１０００*m*の距離の種不明イルカが徐々に遠ざかった反応を観察している。

洋上イシイルカの威嚇実験及び混獲イシイルカと音波発生器の間の最短距離から、少くとも７００*m*位まではイシイルカが驚いて逃げる反応を示す範囲であることが分る。Ptによる有効距離は４４０～７４０*m*の範囲にあり、最大値の方が上記の値に近く、生捕りイシイルカは洋上イシイルカに比べ聴覚が少く悪くなっている可能性がある。

Pcによる有効距離は1,900 mとなっているが、これは仮定による計算であり、イシイルカに注意力を喚起させる音圧を測定し、正しい有効距離を求める必要がある。

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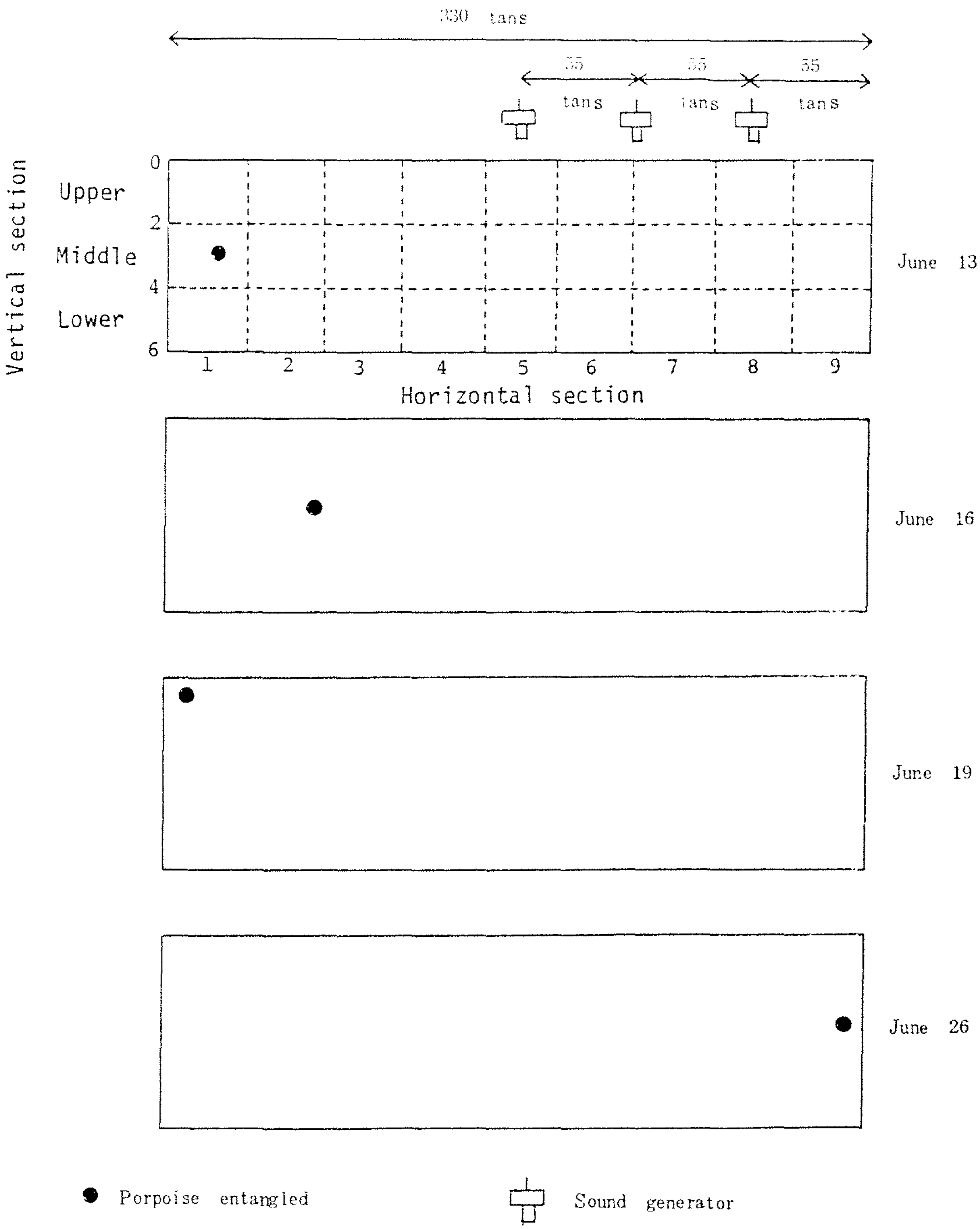

Fig. 1 Positions of sound generaters and distribution of Dall's porpoises entangled

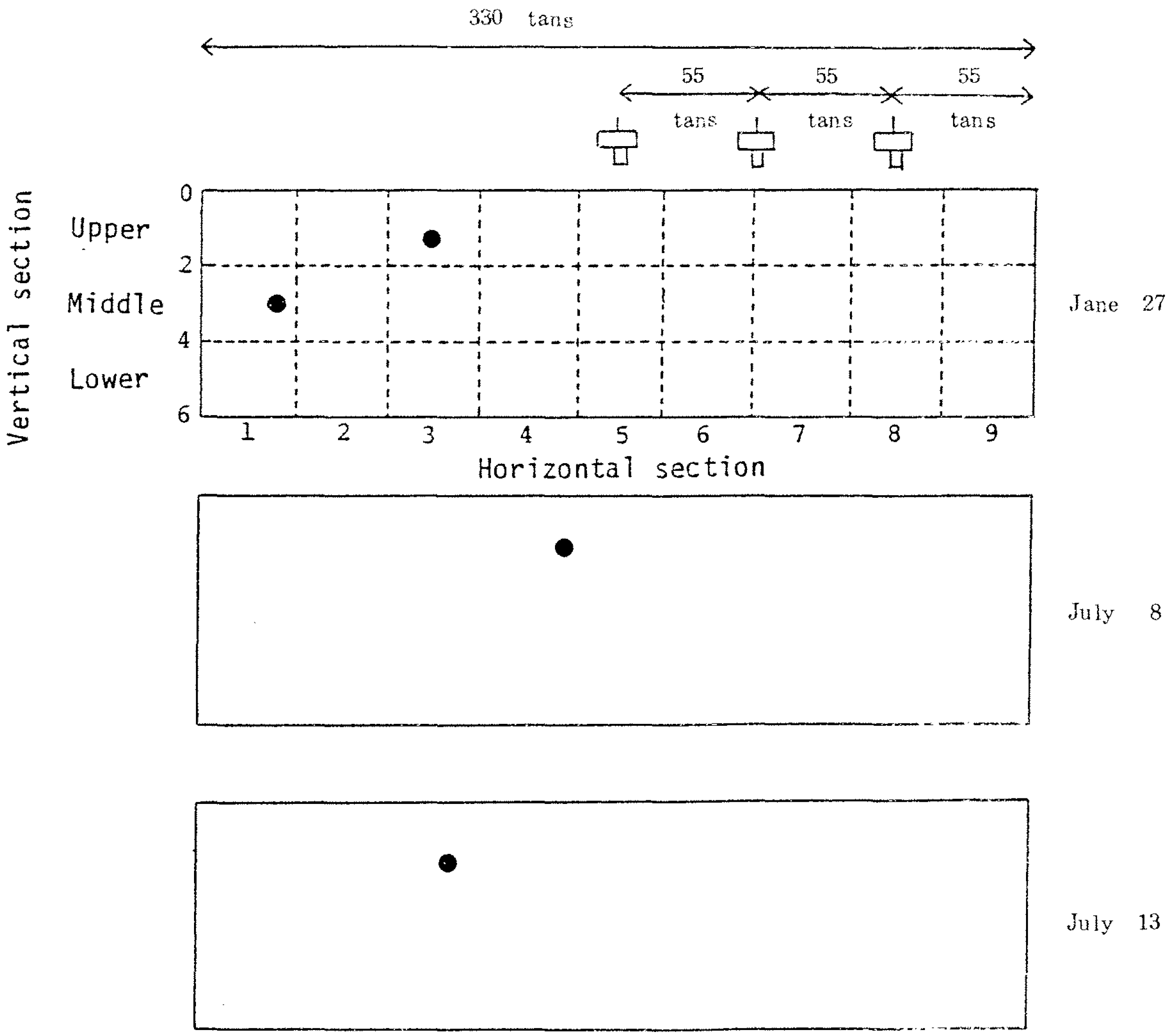

Fig. 2 Positions of sound generators and distribution of Dall's porpoise entangled

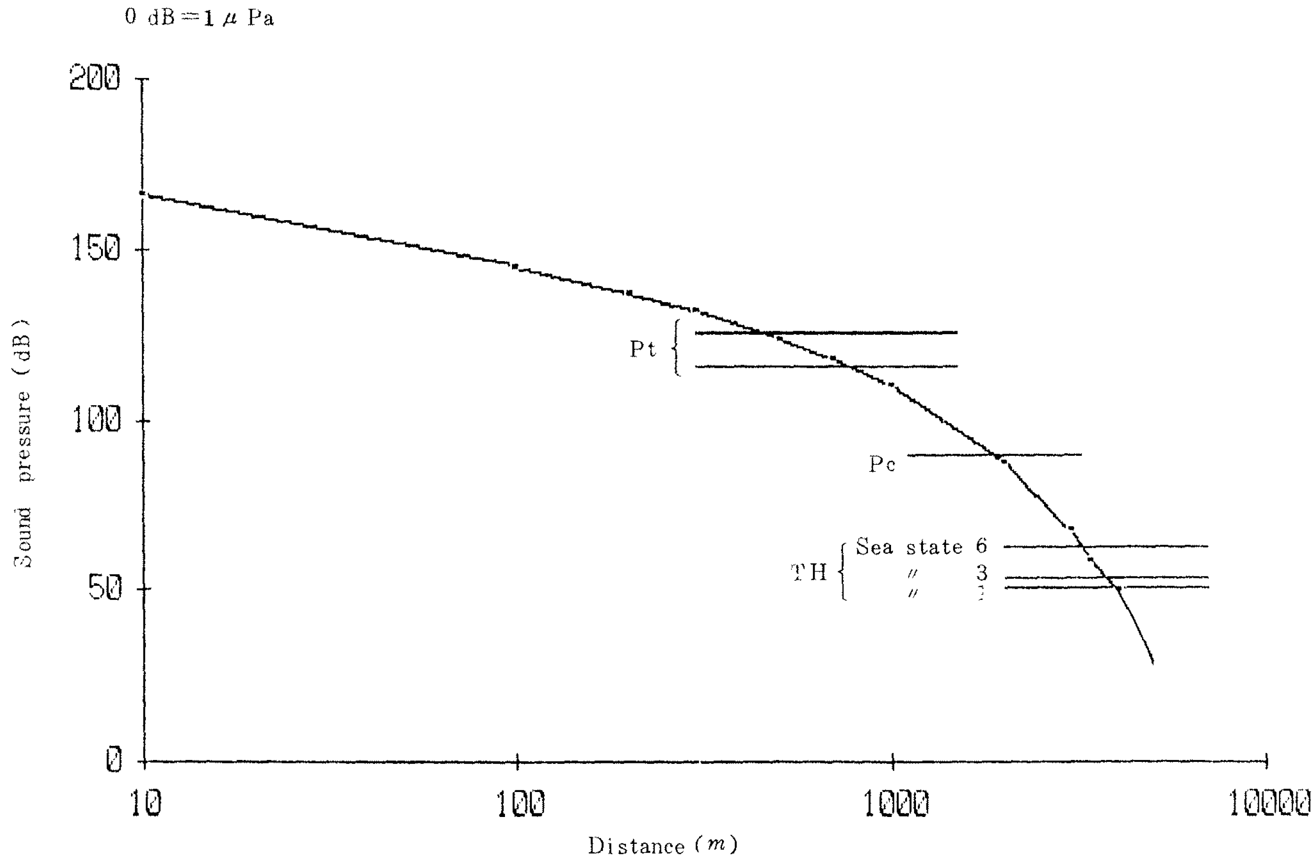

Fig. 3 Sound attenuation as a function of distance and various detection thresholds

Table 1. Entanglement of Dall's porpoise

No. of sound generators used	No. of sets	No. of entanglement	
		One porpoise	Two porpoises
3	32	6	1
0	2	0	0

Table 2. Horizontal distribution of porpoises entangled

		Horizontal section								
		1	2	3	4	5	6	7	8	9
% of porpoises entangled	Standard net	13	13	11	9	10	9	9	12	14
	Experimental net	37.5 (3)	12.5 (1)	25.0 (2)	12.5 (1)	0	0	0	0	12.5 (1)

( ) ……No. of porpoises entangled

Table 3. Vertical distribution of porpoises entangled

		Vertical section		
		Upper	Middle	Lower
% of porpoises entangled	Standard net	44	45	11
	Experimental net	50(4)	50(4)	0(0)

( ) ……No. of porpoises entangled

Table 4. Effective range

Detection threshold		Effective range (m)
TH	Sea state 1	4,000
	〃 3	3,800
	〃 6	3,300
Pc		1,900
Pt		440～740

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TEST OF SOUND GENERATOR

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Summary

Three sound generators emitting random waves of 20 kHz to 50 kHz frequency were attached to a half side of a set of salmon gillnet used by a catcher boat and the distribution of the entanglements of Dall's porpoise was examined. The vertical distribution was almost the same as for standard net operations but horizontally about 90% of the entanglement was concentrated in that half of the set to which no sound generator was attached. This tendency of horizontal distribution was different from that for the standard net operations and thus the effect of the waves produced by the sound generators was observed.

The effective range of the sound generator was calculated to be approximately 700 and 1,900 m for distances at which the effect of intimidation was observed and the porpoise began to pay attention to the sound wave, respectively.. However, further studies are required.

The effectiveness of sound generation was examined by comparing the vertical and horizontal distributions of Dall's porpoise entangled in a set of salmon gillnet, half of which had sound generators attached and the other half were without generators. The data were obtained on Dall's porpoise incidentally taken during the fishing operations.

1. Period of the experiment

From 1986 June 9 to July 14.

2. Fishing vessel used

Chokyu maru No. 53, one of the catcher boats attached to the mothership *Nojima maru*.

3. Method

3.1 Sound generator

The sound generators used for this experiment were manufactured in 1985 and emit random supersonic pulses and FM waves of 20 kH to 50 kHz with a maximum sound pressure of 186 dB (at 1 m distance).

Batteries and electronic circuits were placed in a buoy and the transmitter installed in the lower part of the buoy. Horizontal dispersion of the emitted sound waves was omnidirectional. The operation time for the sound generators was set as 12 hours and batteries were charged after each retrieval to prepare for the next operation. Specifications of the sound generator were described in an INPFC document (Hatakeyama 1986)[1] submitted in 1986.

3.2 Locations in the net of sound generators

As shown in Fig. 1, sound generators were attached to the net at three positions with intervals of 55 tans; the 55th, 110th, and 165th tan from the end of a set of 330 tans.

3.3 Collection of data

Data on incidentally taken porpoise such as numbers, species, whether alive or dead during the retrieval, location in the net where the entanglement occurred, etc. were recorded by Mr. Takemura, a Japanese marine mammal observer, using the format in which the data are submitted to the United States.

4. Results and discussion

As shown in Table 1, a total of 34 salmon gillnet operations were made during the period of this experiment. The sound generators were used in 32 operations. A total of eight Dall's porpoise were incidentally taken (3 escaped or released alive, 2 dead and brought aboard, and 3 lost during retrieval). CPUE for a set of gillnets with the sound generators operating was 0.250 which amounted to 76 and 95% of the CPUEs for a standard gillnet operation (0.331) and air-tube thread gillnet operation (0.262), respectively. The CPUE for the Chokyu maru No. 53 was 72% of the CPUE (0.349) for the air-tube thread gillnet operations which were made adjacent to those by the Chokyu maru No. 53 by the catcher boats attached to the Nojima maru. Of all the adjacent gillnet operations, the number of those using the air-tube thread gillnets was larger than those using the standard gillnets.

Locations om the set of nets where the entanglement of the Dall's porpoise occurred are shown in Figs. 1 and 2. The set of gillnets was divided into nine areas horizontally and into three areas vertically for analysis. The distributions of entanglement in the operations where the sound generators were used are shown in Tables 2 and 3 and are compared with data for the operations with the standard nets during the 1986 fishing season. In terms of these net areas, the sound generators were attached to the center of the horizontal area 5, the boundary between horizontal areas 6 and 7, and the center of horizontal area 8.

Vertical distribution of the entanglement did not show significant differences between the experimental net operations and standard net operations. However, horizontally, 90% of the entanglement in the experimental net operation was concentrated in horizontal areas 1 to 4 which were away from the sound generators.

No statistical conclusion can be made since only one catcher boat was used for this experiment and few Dall's porpoise were incidentally caught. However, distribution of the entanglement of Dall's porpoise shows a tendency to be concentrated on the side where the sound waves emitted from the generators were weak. Therefore, further studies are required.

4.2 Operating condition of the sound generators

Just before setting the gillnets, projected sound was confirmed for all the 32 operations.

Although the recharge of the batteries was usually completed in 5 to 6 hours on five occasions it took 16 to 48 hours to complete a recharge. Trouble appeared to result from a temporary bad contact between battery and recharger.

The following procedures during setting or retrieving of the sound generators were the same as in the previous year: the vessel speed was set at "Stop" or "Slow" during setting and pieces of red cloth were attached to the nets ahead of and behind each sound generator and when these markers approached, a whistle alerted the crew that the sound generator was coming to ensure that the generator did not hit the side of the vessel, etc.

The crew suggested that the upper portion of the sound generator be painted orange for easy detection and improved operations. The nut mounted at the lower portion of the sound generator was covered with vinyl tape and no sound generator fell sideways becoming entangled in the threads of the net.

4.3 Effective range of sound generated

The shortest distance observed between the sound generator and Dall's porpoise entangled was 750[1] and 1,050 m for 1985 and 1986, respectively. It is not known whether the Dall's porpoise became entangled in the gillnet while he continued swimming without showing any interest in the sounds or while taking some action after detecting the sounds. On the other hand, since the auditory sense of the porpoise has a receiving directivity, according to the direction of porpoise's swimming, position of the porpoise from the sound generator, etc., the intensity of the stimuli which the porpoise receives varies and accordingly the effective range of the sound generator does the same.

Since Dall's porpoises receiving directivity becomes broader for supersonic waves of lower frequency, it is advantageous that the frequency of sound waves emitted by the sound generator is relatively low (20 kHz to 50 kHz) in order to alert the porpoise under conditions where its swimming direction cannot be specified.

In this study, the effective range of the sound generator was examined under conditions where the porpoise was facing the generator.

For the range of frequency (20 to 50 kHz) emitted by the sound generator, the sound pressure is maximum at a frequency of about 35 kHz due to the frequency characteristics of the transmitter. Therefore, the values of the parameter for calculation of the effective range were determined for that frequency. The absorption coefficient of horizontal propagation was assumed to be 16 dB/km.

Let NJ, BW, and DI imply the spectrum level of the ambient noise, critical band width, and receiving directivity index in the situation where ambient noises exist, the auditory threshold (TH) in the ambient noises is obtained as follows:

$$TH = NJ + BW - DI \quad (1)$$

Based on the data for average deep water ambient noise spectra, NJ was assumed to be 29, 36, and 45 dB (0 dB = 1 μ Pa/ $\sqrt{Hz}$) at sea state 1, 3, and 6, respectively. Regarding BW, since no data have been available for Dall's porpoise, BW was assumed to be 33 dB based on data for bottlenose dolphin measured and reported by Johnson (1968)[2]. Similarly, DI was assumed to be 15 dB based on data for bottlenose dolphin (Au et al.)[3]. Using these parameters, TH was calculated to be 47, 54, and 63 dB for sea states 1, 3, and 6, respectively. The auditory threshold estimated by Awbrey et al. (1974)[4] on dissection was 51 dB with a frequency of 35 kHz. Since this value does not decrease in any condition, TH at sea state 1 is assumed to be 51 dB.

In an acoustic study by Hatakeyama (1987)[5], an experiment was conducted where the Dall's porpoise was intimidated with sound waves emitted by a sound generator which had similar transmitting mode varying the sound pressure of the sound waves by 10 dB and the following findings were obtained: the sound pressure at which the Dall's porpoise appeared to begin showing a response was 126 dB and the true value (Pt) appeared to be in the range of 116 to 126 dB. TH represents the sound pressure at which Dall's porpoise barely hear the sound waves and Pt represents the sound pressure at which the Dall's porpoise is frightened and shows an external response. It was assumed that the sound pressure (Pc) which makes Dall's porpoise pay attention to the sound wave is about the middle value between TH and Pc.

The effective range was obtained based on the points of intersection between the distance attenuation curve of sound wave and above-mentioned parameters as shown in Fig. 3 and Table 4.

In previous experiments by Taketomi et al. (1985)[6] and Ishii et al. (1986)[7], where intimidation of Dall's porpoise was attempted in the sea using sound waves of similar mode to that emitted by the sound generator used in the present study, it was observed that Dall's porpoise jumped and fled when the sound waves were emitted from distances up to 700 m. In the experiment by Hatakeyama (1986)[1] with the same sound generator as used in this study, it was observed that porpoise of unidentified species at 1,000 m distance appeared to respond by moving gradually away from the sound generator.

The experiments conducted at sea where intimidation of Dall's porpoise was attempted and the shortest distances between porpoise entanglement and sound generator attached indicate that the Dall's porpoise are frightened and move away from the sound generator at a range of at least about 700 m. The effective range based on the value of Pt is in the range of 440 to 740 m and the upper limit is close to the above-mentioned value. This fact suggests that the auditory sense of captive porpoise might deteriorate compared with that of Dall's porpoise which are in the wild. Although the effective range based on Pc was calculated to be 1,900 m, this range was obtained using certain assumptions. Therefore, the true effective range should be obtained by continued measuring of sound pressures which make the Dall's porpoise respond.

REFERENCES, TABLES 1 TO 4, AND FIGS. 1 TO 3
ARE IN ENGLISH IN THE JAPANESE DOCUMENT