生捕リシイルカの飼育と音響学的調査

Feeding Trial and Acoustic Studies on Dall's Porpoise Captured Alive

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イシイルカの飼育は、鴨川シーワールドの島羽山、清水、平塚らが担当し、音響学的調査は水産工学研究所の畠山、石井と日本大学の矢島が行った。

1. 飼育実験

1984年春の日本の太平洋岸は異常に水温が低く、5月になってもイシイルカは北上せずに茨城県沖合に遊泳していた。イシイルカの生捕りを依頼していた漁業者が、漁場から帰港する途中に茨城県沖合でイシイルカを発見し、漁網でイシイルカを生捕った。生存した1頭を短期間ではあるが飼育することができたので、死亡するまでの飼育経過をここに報告する。

1.1 イシイルカの生捕り

1984年5月7日AM8:30、図1に示した茨城県日立市会瀬津10マイルの海域において二艘旋漁船（金見目丸14.5トン）が20頭のイシイルカ型イシイルカの群を発見し、AM9:00にサバ網を用いて3頭を捕獲した。そのうち2頭は死亡したが、残る1頭が生存していたので急いで日立市久慈浜港に入港した。AM10:00には陸路で大洗に向けて久慈浜を出発し、AM11:35に大洗水族館の飼育水槽（7m×5m×水深3m）へ搬入した。

1.2 飼育経過

捕獲したイシイルカの体長は160cm、体重は76.5Kg、性別は雄であり、ただちに冷凍のイワシ、サバで飼付けを試みたが食べたかった。

5月9日に水産工学研究所によって音響学的実験が行われた後、十分な飼育管理が困難であるため鴨川シーワールドに移送することにした。PM6:35から輸送準備を開始し、PM8:35には大洗水族館を出発することができた。陸路で輸送し、5月10日AM0:50に鴨川シーワールドに到着し、図2のマリンシアター飼育水槽（12m×8m×水深3m）に搬入した。同日、再び水産工学研究所により音響学的調査が行われた。

他の色々な刺激に対する反応行動観察を行うと共に、飼育に関する基礎資料を得る必要があるので、表1の飼育記録に示したように継続して飼育し、生かす努力がなされた。

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5月10日から12日まで他種のイルカ（カマイルカ1頭）と混養し、仲間関係などを保たせ孤独から来るストレスの解消を試みたが、他種間の仲間関係は生じなかった。

活イワシ、活イカなどの飼料を5月17日まで継続して与えたが食べないので、5月10日以後は強制給餌も每日実施した。

5月11日以後は抗生剤と副腎皮質ホルモンを毎日投与した。飼育7日目の5月18日に腰尾椎部の腫曲が認められ始め、栄養状態の悪化と共にそれが徐々に進行した。飼育12日目の5月18日AM7:56、突然遊泳が困難となり死亡した。死体は解剖検査を行うため、日本大学農林医学部へ標本として提供した。

Ridgwayはサバとアジの飼育で18カ月という長期間にわたり飼育することに成功しているが、今回の飼育実験では飼育させることができず12日目に死亡させてしまった。

またRidgwayは、水槽の壁に衝突して外傷となり死んだ事例と遊泳速度を制限した狭い空間のためなのか皮膚がはがれた事例を報告しているが、今回の飼育実験ではそのような現象が見られなかった。

サバ魚種でイシイワシを生捕れることが分ったので、機会があれば網を使い、また従来の捕獲器具を改良して生獲実験を継続し、仕切網を入れたイシイワシについて実験を行いたいと考えている。

2. 音響的調査

イシイワシのエコロケーション能力の評価や混獲防止技術の開発のため、水槽に飼育されているイシイワシのクリックスを録音分析し、系・ロープなどの物体や超音波パルスに対する反応を観察した。

5月9日（飼育3日目）には大洗水族館でイシイワシの反応観察と同時にクリックスの録音を行い、5月10日には鴨川シーパークでクリックスの録音を行った。

通常状態では時計回り方向に約0.7m／Sの遊泳速度で1周に17秒かかり、直径4mの円を描きながら呼吸回数7回／分でゆったりと泳いでいた。

2.1 投入イワシに対する反応

イワシを投入して物体と音で刺激を与えた時、イシイワシは驚くのか、飼われてやって来た食べ物のか、またエコロケーションクリックスを発生するのかなどについて、TVカメラで反応行動を録画すると共に、水中マイクロホン（B＆K 2685、8103）によりクリックスを監視しながらテープレコーダ（ティアック R410）に録音した。

カタクイイワシを投入した時の水中音圧は1mの距離で40～50dBであり、スペクトラムのピククは1～3kHzに存在した。

(1) カタクイイワシ投入……1回目

体長7cmのカタクイイワシが15尾を水中へ投げ入れると、水面で「ポチャン」という音を発生し、除除に底の方へ静かに落下した。イシイワシは投入直後の水中音に驚くこともなく図8(a)に示した回遊を
続け、投入後約4秒してからイワシのところを通過したが無関心であった。

(2) カタクチイワシ投…2回

図3(b)に示すように、イワシを投入してから14秒後に投入箇所に接近したが、沈んでいくイワシの存在を意識して、イワシとコンクリート壁の間で直径約1.5mの回遊を18秒間続けてから近来の遊泳パターンに戻った。

イワシを投入してから16秒後と31秒後に一連のクリックスを発生していた。

(3) カタクチイワシ投…3回

イシルカが呼吸のため湧出してくる時、鼻先にイワシを投げ込んだが、通常の遊泳状態を続け驚いた様子を見せなかった。

(4) マイワシ

体長20cmのマイワシを1尾ずつ2回投げ入れたが、無関心で驚かなかった。

以上の実験により、イワシを投入した時の水中衝撃音程度では驚かなく、解凍イワシでは鰭としての興味も示さないことが分った。（1）〜（4）の実験中にクリックスを監視したが、2回目の投穂時のみ一連のクリックスを2回発生し、そのクリックス発生時にはイワシの存在を意識して遊泳パターンを変えていた。

Ridgwayの報告では、1965年1月8日に捕獲した1頭のイシルカは26日の生存期間中に全く音を発生しなく、鰭に対する反応も1日目にイカを与えたが見向きもしなく、2日目には口にくわえて水槽の周辺を引っ張り回したが食べなく、3日目からイカとアジョを食べようになったとある。同じく4月21日に捕獲した2頭のイシルカは最初の2日間は沈黙を続け、3日目から20kHz以下の低い周波数のクリックスを活発に発生し、摂餌に関しては2日目からサバとアジョを食べ始めたと報告している。

今回の調査では、1頭で鰭メ 3日目に頻度が少しずつクリックスを発生していた。解凍した鰭のためか摂餌開始の前兆と反応する「鰭をくわえる行動」が見られなかった。その後も見えたイカ、イワシ、ニジマスを投げ入れているが、自ら摂餌することが無かった。

2.2 ハンマーの打撃音に対する反応

ハンマーでコンクリート水槽の内壁（図3(a)のD地点）を叩いて水中衝撃音の刺激を与え、イシルカの反応行動と鳴き声を調べる実験を行った。

壁から1mの距離で水深50cmの位置における音圧は71dBであり、スペクトルは2〜2.5kHzにピーキがあった。

表2にイシルカの反応の観察結果を示した。経過時間は最初のハンマー打撃から測った時間を記入した。

ハンマーの打撃音の音圧は大きいのに驚いた反応を示さないところを見ると、低周波には鰭の感覚がイシルカと考えられる。最初の2回の打撃ではクリックスを発生していないが、3回目以降は1打撃につき1回クリックスを発生している。
2.3 ロープに対する反応

図4に示すように直径10mmの白いナイロンロープを水槽の中央（EP）に張り、それに対するイシイルカの反応行動を観察した。

ロープを水面上50cmに張っている時は、Gの点線の円を描き従来の遊泳パターンに変化がなかった。次にイシイルカがEFを通過してECD内に入ったら、ロープを水面に付けて58秒間イシイルカの反応を観察した。図4に示すようにECDの狭い範囲で半径1mの同遊（H）を5回続け、その後1→Jと方向を変えたが、ロープの下を潜って反対側へ行くことはしなかった。通常は呼吸のため浮上する以外は水面下に潜って回遊するが、ロープを水面に張ると頭部を上げて放しになり、「ばしゃばしゃ」と音を立て、激しく息を吹き上げながら回遊するようになった。

次にロープを水面上2mの高さにすると、38秒で元の遊泳パターンに戻り、水面上10cmにロープを下げても遊泳に変化が見られなかった。再びロープを水面に張ると、前と同じくECDの範囲内で小さな半径で回遊するようになった。最初にロープを水面から上げた時クリックスを1回発生したのみであり、眼で水面のロープを認知してその存在を強く意識している様子だった。水槽という狭い空間における反応なので今後とも検討する必要がある。

2.4 一定間隔で吊り下げた糸、針金に対する反応

図5に示すように一定間隔（70cmまたは35cm）で吊り下げた透明色ナイロンフィラメントや銀色に光る針金に対するイシイルカの反応行動を観察し、同時にクリックスの発生についても調べた。

糸などを吊り下げるとイシイルカは警戒し、図5（b）のKで示した遊泳パターンをとるので、EFに最も接近する時の距離（t）と時刻（T1）を調べた。また、イシイルカの身体の一部が糸に接触する時は、その場を図5（a）に示した番号（1～6）で示し、身体の部分は頭、胴体、尾びれを各々H、B、T、Dで示した。次にイシイルカが吊り糸に慣れて、図5（b）のLで示した遊泳パターンのように糸と糸の間を通過するようになると、EFを通過した時刻（T2・T3）と通過場所（①～⑦）を調べた。吊り糸の間隔を35cmとした時は、吊り糸の番号は右から1～13に、通過場所は①～⑪とした。

0.6mmのナイロンフィラメント6本を70cm間隔で竹竿から吊した場合のイシイルカの反応を例として表3に示した。糸の長さは3mとし、鈍魚の鯨を下につけ、水槽の壁（AB）から中央（EF）まで約1分間で移動させた。T1～T3は、移動開始から測った経過時間である。

実験を開始してから待々に接近距離が小さくなり、35秒経過後の3回目の回遊では頭部と尾びれが糸に接触し、糸の存在をあまり気にしていないことが分かる。一度身体に糸が触れられた後は、②と⑥を通して遊泳パターンを続けているが、周波周期は10～19秒で変動が大きい。水中マイクロホンを水槽のA付近に吊り下げクリックスを監視していたが、吊り糸を移動させる5秒前にクリックスを1回発生したのみで、実験中のクリックス発生はなく、糸の確認は目視によるものと思われる。

1.2mmのナイロンフィラメント6本を70cm間隔で吊り下げた場合、1分後の4回目の回遊で糸の間を通過するようになり、0.6mmの場合と同じである。しかし、5回目の回遊でも糸の間を通した
が、6～13回目では0.2～0.3 mまで接近しても通過することはなかった。0.6 mmの糸より1.2 mmの糸を強く意識していることが分る。

1.2 mmナイロンモノフィラメント10本を35 cm間隔で吊り下げた場合、3分38秒後の21回目の回遊までに尾びれや筋体に6回接触させる程に接近しながら糸の間を通過しなかった。22回目と24回目の回遊で糸の間を通過したが、その後6分44秒後の40回目の回遊まで糸の間を通過しなかった。

糸の直径が大きくなり間隔が狭い程、インシイタが糸を意識し、通過の妨げになっている。糸ワイヤが水槽中央部にある時のインシイタのクリックス発生は1回のみであり、糸の確認を始んだ目視で行っている。

2.5 擬似エコロケーション・クリックスに対する反応

20 〜 50 kHzの超音波パルスを、その周波数、パルス巾、間隔をランダムに変えながら発生する装置を用い、短時間インシイタに向けて放射し、その反応を観察した。この装置の仕様については、今年度のドキュメントに説明している。

実験前は、図6の点線で示すように約1 m / Sの遊泳速度で直径約3 mの円周を11秒で時計回りに一周する遊泳パターンをとり、呼吸周期は7 〜 8秒であった。図6に示すように水槽のA Bの中間点で送波器を手で持って方向を定め、水深30 cmに沈めた。イルカが回遊して送波器の方向へ向き、距離が3 m位になった時に超音波パルスを発射した。発射時と停止時のイルカの位置を各々ON、OFFで示した。ONの位置における最大音圧は78 d Bである。

(1) 1回目の超音波発射（23秒間）

発射した瞬間「ゴホッ」と空気を呼き、従来の円を描く遊泳パターンがくずれ、図7のように頭部を水面上に持ち上げ直しになり、呼吸周期を2秒に早め、図6(a)のようにフラフラと方向を定めずに泳ぎ続ける反応を示した。その後27秒でようやく呼吸周期が通常の値になり、円を欠く遊泳パターンに戻った。しかし、その直径は約1.5 mで通常の1/2であり、強い後遺症が残った。発射6秒前に1回クリックスを発生したが、発射後にはクリックスが発生しなかった。

(2) 2回目の超音波発射（51秒間）

発射後の反応は1回目と同じであり、発射時間が長いので図6(b)のようにフラフラした経路が長く複雑になった。超音波の停止後20秒で直径1.5 mの小さい半径でゆっくり遊泳し始めた。発射後1分19秒と2分11秒で各々1回のクリックスを発生した。

2回の実験結果から、呼吸回数が4倍に増え、超音波パルスが受からないよう頭部を水面上に上げて放しにした反応は、強いショックと逃避行動を示していると考えられる。

2.6 クリックスの分析

図8に測定と分析のブロックダイアグラムを示したが、測定システムは今までの報告と同じであり、水中マイクロホンと增幅器はB & K 8108型と2635型であり、テープレコーダーはTEAC製R 410で
60 inch／S のテープ速度で録音し、測定システム全体として 200 kHz まで録音可能である。

分析パラメーターを従来と同じく圧力、周波数、パルス巾、次のクリックスまでの間隔とし、一連のパルス列については全パルス数、最大音圧、最大パルス間隔を調べた。以前は波形写真から最大値を示す付近の 3 〜 5 ケの波形の平均周期を計算し周波数を求めたが、今回は高速フーリエ変換（FFT）により相対的なエネルギー密度スペクトルを計算し、主な周波数成分を求めめた。FFT のサンプリング数は 1,024、クロックレートは 0.5 μS／W であり、周波数分解能は 1.95 kHz である。

大洗水族館と鴨川シーワールドにおけるクリックス発生状況を表 4 にまとめたものである。クリックスの発生回数、その実験と前後の発生回数を合計したものである。大洗水族館で水槽内に異物を入れた実験では、それは観察するためのエコーレコーダーはわずか』目視による観察が多かった。10号テープ 1 巻の録音時間は 12 分である。鴨川シーワールドへ送るため、イシルカの健康状態を診断したが、捕獲して 1 秒後と傷を受けて発生したクリックスを各々 1 回発生した。

鴨川シーワールドの水槽に搬入した直後に水中マイクロホンを降してみても明瞭なクリックスが認められず、それから 10 時間後の 5 月 10 日現在 11 時頃に再び水中マイクロホンを入れると、図 2 に示した回遊パターンで約 1 m／S の速度で遊泳しながらクリックスを発生していた。

大洗水族館の実験の中からロープを水面から上げた時のクリックス （A）と健康診断のため捕獲した直後のクリックス （B）、鴨川シーワールドで自然遊泳中のクリックス（C）を分析して、その結果を表 5 に示した。一連のクリックスの中から A では 0、20、40 番目のクリックス、B では 90 と 100 番目のクリックス、C では 10、20、40、50、60 番目のクリックスを分析している。1 つのクリックスが更に小さいパルスの合成があるものについては、そのパルスを a、b、c で表示した。代表例として A と C の一連のクリックスを図 9 に、A の 10 番目のクリックスと C の 60 番目のクリックスの波数分析結果を図 10、11 に示した。スペクトルがいくつかの極大値を有する場合、ピーク値の右肩に 「*」印を付けた。

クリックスを発生した時のイルカの位置と頭の方向からマイクロホンまでの伝達距離を計算すると、A で 7 m、B で 10 m、C で 10 m であり、1 m の距離における音圧を求めたためには表 5 の音圧に、約 20 dB 加える必要がある。大洗水族館と鴨川シーワールドにおける最大音圧は共に 1 m の距離で 54 〜 57 dB であり、洋上のイシルカに比べ約 10 dB 小さい。

今回の騒音の中にもホイスルと 20 kHz 以下の中波音クリックスが含まれていなかった。エコーを正確に検知するためマウスゴウウェは、反射体まで往復伝達時間より 20 〜 50 m S だけ長い間隔でエコーを検知クリックスを発生していると報告されている。大洗水族館のクリックスは、音圧が変化していてもほとんど一定の距離で約 9.5 m S と小さい値であり、エコーレーションの增加が主の目的が無意識に出したものと思われる。

大洗水族館におけるクリックスは単一のパルスであり、そのパルス巾は 15 〜 90 μS、主な周波数成分は約 90 kHz、パルス間隔はほぼ一定の 9.5 m S、一連のパルス数は約 170 である。洋上のイシルカ
References


Table 1  Feeding record of Dall’s porpoise captured alive

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of days</th>
<th>Temperature</th>
<th>Physical data</th>
<th>Length (cm)</th>
<th>Weight (kg)</th>
<th>Feeding amount (kg)</th>
<th>Kinds of foods</th>
<th>Remarks</th>
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<tbody>
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<td>Air °C</td>
<td>Water °C</td>
<td>Respiration rate /min.</td>
<td>Heart beat /min.</td>
<td>Temperature °C</td>
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<td>14.7</td>
<td>4.8 ~ 13.0</td>
<td>60 ~ 80</td>
<td>35.7</td>
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<td>36.6</td>
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<td>17.9</td>
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<td>37.9</td>
<td>3.5</td>
<td>M,K,Sr</td>
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<td>11</td>
<td>18.0</td>
<td>17.6</td>
<td>160</td>
<td>51.0</td>
<td></td>
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<td>0756</td>
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</tbody>
</table>

mM—minced mackerel, Sq—squid, M—mackerel, K—Konosirus punctatus, Ff—force feeding

NRIFE—National Research Institute of Fisheries Engineering
Table 2 Responses to sounds generated by beating tank wall by hummer

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Time elapsed min : sec</th>
<th>Responses</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>No change in swimming. No sound</td>
<td>Beated not so strongly</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>No astonished response. A little slow swimming. No sound</td>
<td>Beated strongly</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>Radius of swimming circle became about 1 m around &quot;D&quot; corner at the tank and swimming speed became a little fast but after 10 seconds he swam in former pattern. 37 seconds after beating clicks were generated.</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>1:19</td>
<td>No change in swimming. 7 seconds after beating, clicks were generated.</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>2:47</td>
<td>No change in swimming. One minute and 45 seconds after beating, clicks were generated.</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>4:49</td>
<td>No change in swimming. In the midst of generating clicks, we beat tank wall by hummer.</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
Table 3 Responses of Dall's porpoise to hunged nylon monofilaments (0.6 mm φ, 70 cm interval)

<table>
<thead>
<tr>
<th>Number of swimming circles</th>
<th>Time elapsed (min:sec)</th>
<th>Approaching distance (m)</th>
<th>Passage interval and contact portion</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T₁ T₂ T₃</td>
<td></td>
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</tr>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>0.2</td>
<td>2 H, T</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>51 54</td>
<td></td>
<td>(2) (5)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1:03 1:07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1:13 1:19</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>1:24 1:32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1:41 1:47</td>
<td></td>
<td>H T</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1:55 2:06</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2:14 2:22</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2:27 2:33</td>
<td></td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2:43 2:49</td>
<td></td>
<td>T</td>
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</tr>
</tbody>
</table>

Hunged filaments were moved to the center of tank slowly.
Table 4 Generation of clicks of captured Dall's porpoise

<table>
<thead>
<tr>
<th>Aquarium</th>
<th>Kinds of experiment</th>
<th>Number of generations of clicks</th>
<th>Recording time (min.)</th>
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</thead>
<tbody>
<tr>
<td>Oarai</td>
<td>Throwing of sardines</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Beating by hummer</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rope</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Checking health condition</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Free swimming</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nylon monofilament</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nylon monofilament and wire</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>False echolocation clicks</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Kamogawa</td>
<td>Free swimming</td>
<td>14</td>
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</tbody>
</table>


Table 5 Results of analyses of Dall's porpoise's clicks

<table>
<thead>
<tr>
<th>Analyzing point</th>
<th>Sound pressure P(dB)</th>
<th>Major frequency components f(kHz)</th>
<th>Pulse width ( \tau ) (( \mu s ))</th>
<th>Pulse interval T(ms)</th>
<th>Max. sound pressure ( P_{max} )(dB)</th>
<th>Max. interval ( T_{max} )(ms)</th>
<th>Min. interval ( T_{min} )(ms)</th>
<th>Number of pulses N</th>
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</thead>
<tbody>
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<td>35</td>
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<td>30</td>
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<td></td>
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<tr>
<td>B</td>
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<td></td>
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* Max. spectrum
Fig. 1 Positions of capture of Dall’s porpoise and experiment aquaria
Fig. 2 Experiment tank of Kamogawa Sea World and swimming course of Dall's porpoise
H--Hydrophone
(a) No.1 and 3 experiment  (b) No.2 experiment

Fig. 3 Responses of Dall's porpoise to sardines which were thrown into water 
+--- position of thrown sardines

Fig. 4 Response of Dall’s porpoise to rope which was put on the surface of the water
(a) Nylon monofilaments or wires hung down from bamboo-pole at 70 cm intervals
1-6 number of filament or wire
0-7 number of interval

(b) Swimming courses of Dall's porpoise and analysis parameters

Fig. 5 Responses of Dall's porpoise to nylon monofilaments or wires
(a) No.1 experiment (23 seconds) (b) No.2 experiment (51 seconds)

Fig. 6 Responses of Dall's porpoise to false echolocation clicks

Fig. 7 Swimming pose of Dall's porpoise when false echolocation clicks generator was turned on.
Fig. 8 Blockdiagram of measuring and analyzing devices
Fig. 9 Photographs of two series of clicks

(a) A 25 ms/DIV 0.2 V/DIV

(b) C 50 ms/DIV 0.1 V/DIV
Fig. 10 Wave shape and spectrum of click (A-20)
Fig. 1. Wave shape and spectrum of clicks (C-60)
TRANSLATION

FEEDING TRIAL AND ACOUSTIC STUDIES ON DALL'S PORPOISE CAPTURED ALIVE

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National Research Institute of Fisheries Engineering
Tokyo, Japan

and

Hiroshi Shimizu
Kamogawa Sea World
Chiba, Japan

1985 January

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Fisheries Agency of Japan, Tokyo, Japan
The feeding trial of the Dall's porpoise was handled by Messrs. Tobayama, Shimizu, and Hiratsuka of Kamogawa Sea World. The acoustic studies were made by Messrs. Hatakeyama and Ishii of the National Research Institute of Fisheries Engineering and Mr. Yajima of Nihon University.

1. **Experiment on holding live porpoise**

On the Pacific Ocean coast of Japan in spring 1984, water temperature was unusually low and, even in May, Dall's porpoises did not migrate towards the north but were swimming off Ibaraki Prefecture. The purse seine fishermen who had been asked to capture Dall's porpoise alive found the porpoises off Ibaraki Prefecture on the way back from the fishing ground to port and caught live Dall's porpoise with the purse seine. Since we were able to hold the Dall's porpoise alive, although for only a short period, we report the procedures until time of its death.

1.1 **Catch of live Dall's porpoise**

At 0830 on May 7, 1984 the *Konpira maru*, two pair purse seiners (14.5 GRT each), discovered a group of 20 Dall's porpoise in an area ten miles off Ose, Hitachi City, Ibaraki Prefecture and caught three Dall's porpoises with a mackerel purse seine. Two were dead on retrieval but the remaining one was alive and brought quickly to Kujiham Harbor, Hitachi City. At 1015 the porpoise was transported by land to a water tank (7×5×3 m) of the Oarai Aquarium, arriving at 1135.

1.2 **Holding procedures**

The body length of the male porpoise captured was 160 cm and body weight was 76.5 kg. Attempts were immediately made to feed him with sardine and mackerel but he did not eat.
After conduct of acoustic experiments by the National Research Institute of Fisheries Engineering on May 9, the porpoise was transported to the Kamogawa Sea World because of the inadequate rearing facilities at Oarai. At 1835 preparations for transport were commenced and at 2035 the porpoise departed from the Oarai Aquarium. The porpoise was transported by land and arrived at Kamogawa Sea World at 0050 on May 10 and placed in the 12x6x3 m marine theater water tank (Fig. 2). On the same day, acoustic studies were again conducted by the National Research Institute of Fisheries Engineering.

As it was necessary to observe further response behavior to various stimuli and obtain basic data on rearing, the porpoise continued to be held, as shown in Table 1, and all efforts made to keep it alive.

From May 10 to 12 we placed a Pacific whitesided dolphin in the same tank in order to relieve the stress resulting from loneliness but this was apparently not successful. We continued to provide food such as live sardine and live squid up to May 17 but as he did not eat forced feeding was also conducted each day from May 10.

From May 11 antibiotics and hyperadrenocortical hormones were administered each day. On May 13, the seventh day of holding, a crook in the lumbar vertebrae was observed which gradually advanced with under-nourishment. At 0756 on May 18, the twelfth day after attempts at holding had started, the porpoise suddenly had trouble swimming and died. The carcass was delivered for autopsy to the Department of Agriculture and Veterinary Science of Nihon University.

Although Ridgway succeeded in holding a porpoise using mackerel and jack mackerel as food for a long period of 18 months, in this holding experiment feeding was not successful and the porpoise died within 12 days.
Ridgway 1) reported an instance in which a porpoise died from an external wound and bleeding resulting from striking a wall of a water tank and another where the skin of a porpoise was peeled because of a narrow space restricting the swimming speed but in this experiment no such phenomena occurred.

Since we could capture Dall's porpoise alive with purse seines for mackerel, we consider that we will carry on the capture experiments using nets if the opportunity is available or remodel the conventional catching equipment previously used and continue experiments on holding Dall's porpoise in cage nets.

2. Acoustic study

For evaluation of echolocation ability and development of technology to reduce the incidental catch of Dall's porpoise, we recorded and analyzed the clicks of Dall's porpoise held in the water tank and observed responses to objects such as thread and rope, etc. and to stimulation by supersonic pulses. Observations on responses and recording of clicks were conducted at the Oarai Aquarium on May 9 (three days after the holding commenced) and recording of clicks was conducted at the Kamogawa Sea World on May 10.

Under normal conditions it took about 17 seconds to swim clockwise around the tank at a swimming speed of about 0.7 m per second. The Dall's porpoise was swimming easily and breathing seven times per minute while moving in a circle of about 4 meters in diameter.

2.1 Response to presence of sardines

Observations were made on response of Dall's porpoise to stimulation by substance and sound by giving them sardines in order to determine whether Dall's porpoises were frightened, approached and ate them as
food, or produced echolocation clicks when the sardines were present. Pictures of the response behavior were taken by TV camera and sounds were recorded with a hydrophone (B&K types 2635 and 8103) and tape recorder (TEAC type R-410) while monitoring clicks.

The sound pressure under water at the time when the anchovies hit the surface was 40 to 50 dB at 1 m and the spectrum had a peak between 1 kHz and 3 kHz.

(1) Response to presence of anchovies -- first observation

When we threw about 15 7-cm anchovies into the water they made a splash on the surface and sank slowly to the bottom. The Dall's porpoise was not frightened by the sound immediately after throwing and continued swimming, as shown in Fig. 3(a), and about four seconds later passed the anchovies but ignored them.

(2) Response to presence of anchovies -- second observation

As shown in Fig. 3(b), Dall's porpoise approached the location thrown 14 seconds later. It was aware of the existence of anchovies sinking, and continued to swim in a circle of about 1.5 m diameter between the anchovies and the wall for 18 seconds and returned to his ordinary swimming pattern.

16 and 31 seconds after throwing the anchovies, he emitted a series of clicks.

(3) Response to presence of anchovies -- third observation

When the Dall's porpoise surfaced for breathing we threw anchovies under his very nose but he continued his ordinary swimming pattern and showed no fright.
We threw one approximately 20 cm long sardine twice, but the Dall's porpoise showed no interest nor seemed frightened. Through the above experiments we concluded that the Dall's porpoise is not frightened at impulsive sound caused by throwing sardine into the water nor has any interest in thawed sardines as food.

Through the experiments (1) to (4), we tried to monitor the clicking sounds of the Dall's porpoise, and observed he emitted two series of clicks only at the second throw. At the time of the clicks he was aware of the sardine, showing a change in swimming pattern.

According to Ridgway's report, a Dall's porpoise caught on January 8, 1965 did not project any sound during his entire period of captivity of 26 days. As for his response to food, squids were given the first day but he paid no attention to them. On the second day he held a squid in his mouth and swam around in the tank but did not eat it. But, from the third day on he began to eat squid and saurel. Similarly, the two Dall's porpoises that were caught on April 21st were silent for the first two days. From the third day they began to actively emit clicks of 20 kHz or lower frequencies. As for food, they began to eat mackerel and saurel from the second day.

During the period of this research the Dall's porpoise was seen emitting clicks even alone, though less frequently, from the third day. Probably because of the thawed feed he was never seen "holding the feed in the mouth", a sign of his own efforts to eat. After that, live squid, sardines, and rainbow trout were thrown in but he never tried to eat them.
2.2 Response to hammer sounds

We hit the inner wall of the concrete water tank (at point D in Fig. 3(a)) with a hammer producing an impulsive underwater sound, and tried to observe how the Doll's porpoise responded and if it would emit the clicks.

The sound pressure at a distance of 1 m from the wall and at the depth of 50 cm was 71 dB, and the spectrum showed a peak between 2 and 2.5 KHz.

Table 2 shows the results of observation. The times recorded are after the first stroke with the hammer.

Judging from the fact that the Dall's porpoise was not frightened at the large sound pressure caused by the hammer, he was thought to be insensitive to low frequency sound waves. He emitted no clicks after the first 2 hammer strokes. But from the third stroke he emitted a series of clicks at every stroke.

2.3 Response to a rope

A white nylon rope, 10 mm in diameter was stretched across the center (EF) of the water tank, as shown in Fig. 4, and the porpoise's response was observed.

When the rope was stretched at a position 50 cm above the water surface the porpoise swam in a circle (as shown by the G dotted line), and there was no change in the usual swimming pattern. Subsequently, the porpoise passed the EF line and entered the ECDF area, and the rope was then lowered onto the water surface, and we observed for 53 seconds how the porpoise responded. As shown in Fig. 4, the porpoise swam five times in a circle with a 1 m radius (as shown by the H line) in the narrow range of ECDF, then changed directions from I to J, but did not attempt
to dive under the rope to the other side. The Dall's porpoise usually swam underwater except when he emerged for breathing. But when the rope was stretched, he began to swim with his head up, made splashing sounds, and breathed hard while swimming.

The rope was then raised to 2 m above the water surface, and he returned to his original swimming pattern in 38 seconds, and even when the rope was lowered to 10 cm over the water surface he made no change in his swimming pattern. When the rope was stretched again on the water surface he began to swim in a circle with a small radius within the ECDF range as before. When the rope was lifted over the surface for the first time he emitted a series of clicks once. It appeared that he saw the rope and was very aware of it. This was the response seen in a rather small water tank, and further observation is probably necessary.

2.4 Response to nylon thread and steel wire hanging at fixed intervals

Observations were made on the response of the Dall's porpoise to a transparent nylon monofilament and a silver-colored steel wire hanging at fixed intervals (70 cm or 35 cm) as shown in Fig. 5. Simultaneously, emission of clicks by Dall's porpoise was observed.

When the thread was hung, the Dall's porpoise became cautious and swam in the pattern shown in Fig. 5 (b) K. We observed then his closest distance (l) and the time (T1) of approach to EF. When Dall's porpoise came in contact with the thread, that particular thread is indicated by the number (1-6) in Fig. 5 (a), and touching parts of his body such as head, body caudal fin, and dorsal fin are respectively indicated by H, B, T, and D. Subsequently, as the porpoise became familiar with the threads, he began to pass between the threads in pattern shown in Fig. 5 (b) L, and the time (T2, T3) required
for the porpoise to pass E·F and the points (\(1 \sim 7\)) were observed.

When the interval between the hanging threads was fixed at 35 cm, the threads were numbered from 1 to 13 counting from the right, and the points of passage were (\(1 \sim 14\)).

An example of the Dall's porpoise's responses to the 6 nylon monofilaments 0.6 mm in diameter hanging from a bamboo pole at intervals of 70 cm is shown in Table 3. The thread length was fixed at 3 m, and fishing weights were hung at the ends of the threads, which were moved from the wall (AB) of the tank to the center (EF), which took about 1 minute. \(T_1 \sim T_3\) shows the times counted from the beginning of movement.

As time passed in the experiment the porpoise gradually swam nearer the threads, and at the third round of swimming, which was 35 seconds after the beginning, his head and caudal fin touched thread (2) showing he no longer seemed to mind the threads. After his body touched the thread, he continued to swim passing points (2) and (5) but the time of one round varied greatly from 10 to 19 seconds. We sank a hydrophone near point A of the tank to try to monitor the clicks but the porpoise emitter clicks only once 5 seconds before we moved the threads, and we observed no more clicks during the experiment. His recognition of the threads seemed to have been made visually.

When six nylon monofilaments 1.2 mm in diameter were hung at intervals of 70 cm the porpoise began to pass between the threads after his fourth round, which was 1 minute after beginning the experiment, showing movement similar to the case of 0.6 mm diameter threads.

He passed through the threads on his fifth round, however between the 6th \(\sim 13\)th rounds he came as close as 0.2 \(\sim 0.3\) m from the threads but did not pass between the threads, indicating a greater awareness of 1.2 mm\(\phi\) than 0.6 mm\(\phi\) threads.
When 13 nylon monofilaments 1.2 mm in diameter were hung at intervals of 35 cm, during 21 rounds, which took 3 minutes 33 seconds, his body almost touched the threads six times but he did not pass between the threads. In this 22nd and 24th rounds he passed between the threads but then did not pass between the threads again until his 40th round, which was 6 minutes 44 seconds later. This shows that as the threads got thicker and the intervals shorter, the porpoise became more aware of the threads. This kept him from swimming between the threads. The porpoise emitted clicks only once when the threads were placed in the center of the tank, and we feel he recognized the threads visually.

2.5 Response to false echolocation clicks

Using equipment with a variable frequency, pulse width and intervals, we emitted at random supersonic pulses of 20 ~ 50 KHz towards the Dall's porpoise for a short period of time, and observed how he responded to the supersonic waves. The specifications of the equipment are described in paper\(^2\) submitted this year.

Before the experiment began, the porpoise swam in circles 3 m in diameter at a speed of about 1 m/sec, making a round in 11 seconds in a clockwise direction as shown by the dotted line in Fig. 6. The porpoise's breathing interval\(^{wa5}_{A}\) was 7.8 sec. As shown in Fig. 6, the transmitter was held by hand at a mid-point between A and B in the water tank, and at a depth of 30 cm. The supersonic pulse was emitted to the porpoise when he faced the transmitter at a distance of 3 m. The positions of the porpoise at the time of emission and non-emission are respectively shown with the "ON" and "OFF" signs. The maximum sound pressure at the "ON" position was 78 dB.
(1) The first experiment (duration of 23 seconds)

At the moment when beginning the emission porpoise spewed air making gurgling sounds, changed his usual swimming pattern, stuck his head out of water and kept it up, and his breathing interval decreased to 2 sec, and he began to swim around without a pattern. He regained his normal breathing interval and usual swimming pattern making circle 27 seconds after termination of the sound emission. But, the diameter of circle was about 1.5 m, namely half of the normal diameter, indicating a strong reaction. He emitted clicks one time 6 seconds before the emission but there were no clicks after the emission.

(2) The second supersonic experiment (duration of 51 seconds)

The response to this emission was similar to that in the first experiment, but because the emission lasted longer, the course of swimming cycle became longer and more complicated as shown in Fig. 6 (b). About 20 seconds after stopping the emission, the porpoise gradually began to swim in smaller diameter circles of about 1.5 m. He emitted clicks one time 1 min. 19 sec. and one time 2 min. 11 sec. after the emission.

It is believed from the results of these experiments that increases in breathing rate by up to four times showed that the porpoise was strongly affected, and his attempt to avoid the supersonic beam resulted in his head up swimming style.

2.6 Analysis of the clicks of the Dall's porpoise

Figure 8 shows block diagrams of the measuring and analyzing devices. The measuring system was the same as previously reported. The hydrophone and amplifier used were B & K types 8103 and 2635, respectively.
The taperecorder was TEAC type R410 with a recording speed of 60 inch/sec. As a whole the measuring system can record sounds up to 200 kHz. As in the previous analysis, the sound pressure, frequency, pulse width, and pulse intervals of the clicks were taken as parameters for analysis. Total pulse number, maximum sound pressure, and maximum pulse intervals were examined for a series of pulses. Previously, frequency was calculated using an average cycle of 3 to 5 waves around the maximum peak value obtained from a picture of the pulses, but in this analysis major frequency components were obtained from the relative energy flux density spectrum calculated using the Fast Fourier Transform (FFT). The number of sampling points was 1,024. The sampling rate was 0.5 µs/W, and the frequency resolution of the FFT was 1.95 kHz.

Table 4 shows the results of an analysis of the clicks observed in the Oharai Aquarium and the Kamogawa Sea World. The numbers of clicks emission are a total of all emissions observed during, before, and after the experiment. The experiment in the Oharai Aquarium with foreign objects in the water tank showed that there were few clicks for echolocation, and Dall's porpoise recognized it by eyesight. Recording time of used tape is 12 minutes long. The porpoise's health was checked before being brought to the Kamogawa Sea World. He emitted clicks 1 second after being caught and once while the ointment was being applied.

Immediately after the porpoise was placed in the water tank of the Kamogawa Sea World the hydrophone was lowered. But we observed no clear clicks. About 10 hours later, which was about 11:00 AM on May 10th, the hydrophone was again lowered into water, and then we observed clicks while the porpoise was swimming in a circle at a speed of about 1 m/second as shown in Fig. 2.

Table 5 shows the results of analysis of clicks A, which were recorded right after the rope was lifted from water in the Oharai Aquarium,
clicks B, which were recorded immediately after being caught for a 
physical check-up, and clicks C, which were recorded during his swim­
mimg in the Kamogawa Sea World. Out of the series of clicks 0, the 
20th, and 40th clicks out of the A series, and the 90th and 100th 
clicks out of the B series, and the 10th, 20th, 40th, 50th, and 60th 
clicks out of the C series were chosen for analysis. As for clicks 
composed of small pulses, those pulses are indicated as a, b, c.
The series of clicks from A and C are shown in Fig. 9 as typical 
examples. The analysis results of the frequencies of the 20th click of 
A and the 60th click of C click are shown in Fig. 10 and 11. If there 
were several several peak spectrums, the mark "*" is indicated to the 
upper right of the largest peak value.

The distances of sound transmission from the porpoise at the time of 
emitting the clicks to the hydrophone was calculated. In the case of 
A, the distance was 7 m. In the case of B, it was 10 m. In the case 
of C, it was 10 m. In order to obtain the sound pressure at a distance 
of one meter, it is necessary to add about 20 dB to the sound pressure 
given in Table 5. The maximum sound pressure at a distance of 1 meter 
recorded in the Oharai Aquarium and the Kamogawa Sea World was 54 \( \pm \) 57 
dB, which is lower than that of porpoises swimming in the sea by about 
10 dB. The sounds recorded this time did not include whistles or 
clicks with frequencies below 20 kHz. It is reported that a bottlenose 
dolphin emits echolocation clicks \(^5,6\) with 20 \( \sim \) 50 ms longer intervals 
than the double propagation time between himself and the object in 
order to accurately detect the echo. In the case of the clicks recorded 
at the Oharai Aquarium, regardless of variations in sound pressure, 
the clicks were emitted at fixed intervals of approximately 9.5 ms. 
It is believed these clicks were emitted for purposes other than 
echolocation, or just unconsciously.
The clicks emitted in the Oharai Aquarium were of a single pulse. The pulse width was 15 ~ 30 µs. The major frequency components were about 90 kHz and the pulse intervals were more or less fixed at 9.5 ms, and the number of pulses from the series recorded were approximately 170. Compared with the results of pulse analysis of wild Dall's porpoises, the pulse width was less than 1/2, and the frequency was lower by about 50 kHz, but the number of pulses was larger.

The clicks recorded in the Kamogawa Sea World were composed of a maximum of five pulses. The maximum pulse width was 50 ~ 60 µs, and the peak spectrums of many of the clicks ranged from 100 to 115 kHz, but some had frequencies below 100 kHz. The pulse intervals were within a range of 20 ~ 48 ms, and the number of pulses was 64, which were basically normal values. Compared with wild Dall's porpoises, the frequency was lower by about 35 kHz.

It is reported that dolphins in a water tank produce sounds 30 dB lower than wild dolphins 6,7).

It is believed that the Dall's porpoises in the Oharai Aquarium that emit the clicks much different from those of wild porpoises are still confused at the sudden change in environment, and even after they are transferred to the Kamogawa Sea World, their clicks are about 10 dB lower because of the smaller environment.

On the night of May 8th we turned off the lights because we thought they would have to utilize echolocation in the darkness. But, they continued to swim their usual pattern without emitting clicks.

Further, when we suddenly shined a flashlight at the eyes of the porpoises, he was apparently blinded, became disoriented, hit the wall, and soon sank to the bottom.