Observation of bottlenose dolphin's behavior to salmon gillnet

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ハンドウイルカの対網行動の観察

Observation of bottlenose dolphin's behavior to salmon gillnet

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通常のエコロケーションを行っているイルカは、流網を充分認知していると考えられるので何故る網をするかについて、その混獲機構を解明していく必要がある。そのため捕獲したハンドウイルカ3頭を仕切網の中に入れ、その中央部に流網を張り、自然遊泳状態における昼夜連続の対網行動、驚かして追い越す時の対網行動、流網に餌を付けた時の捕食行動を観察した。

以前にイルカの流網の認知について、反射損失を一定の値に仮定して大まかな検討を行ったが、実際にイルカと流網の間の距離が増加すると、エコロケーションの超音波ビーム内の反射に寄与する物体の面積が増加するので、今回それを考慮してハンドウイルカの流網認知可能最大距離を求めてみた。

1. 対網行動の観察
1.1 実験日程
1986年2月20日…仕切網の設置。ハンドウイルカ3頭の撤入。
21日…1頭のハンドウイルカに発光標識の取付け。流網の設置。
22、23日…平常時の対網行動観察。
24日…威嚇時の対網行動観察。
25日…威嚇時の対網行動観察。流網に付けた餌の捕食行動の観察。

1.2 実験場所
長崎県壱岐郡勝本町のイルカパークの一部を図1、2のように網で仕切り、その中央部に長さ1反、網丈3m、目合115mmの流網を張って遊泳場所をA、Bに2分割し、流網に対するイルカの行動を観察した。仕切網と流網の配置は、網の端のラインをしなる物（木、船、桟橋、コンクリートブロック）の位置から図のように決めた。桟橋は浮いているのでイルカはその下を自由に通過できた。また、桟橋の端から向岸まではこの流網の長さより長いので、桟橋側11mに向岸側5mには流網がなく、イルカはその部分を通過できた。桟橋と流網の間の距離を0mから10mまで変えて、イルカの行動に与える影響も調べた。実験場の水深は4〜5mで沈下桟は底から離れていることが多いので、イルカは流網の下を潜って反対側へ行くこともできた。

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1.3 実験イルカ

1986年1月28日に捕獲したハンドウイルカ20頭がイルカバークに観光用として飼養されていたので、2月20日にそのうち3頭を図3に示すように仕切網の中に入れた。図4のように1頭のハンドウイルカには、夜間の遊泳行動を観察し易くするため発光標識を付けた。

捕獲後一週間位で飽餌がでるようになり、一日に10箱（約100kg）のサバ、イワシ、サンマを生か又は冷凍のままで投げ与えていた。

1.4 発光標識

図5に示すようなフラッシュランプを光源として使用した。電源は単1アルカリ電池（1.5V）1個であり、電池と制御回路の間5Ωの抵抗を入れて初期の発光間隔を0.9秒から3秒に変更し、約1週間点滅するようにした。但し、電池の消耗と共に少しつつ発光間隔が長くなる傾向があった。

フラッシュランプを赤いセロファン紙で2重に包み、図6に示した長さ15cm、直径7.5cmの白いポリ袋に入れ、間隔をパッキング材で包み強い衝撃に耐えられる構造とした。ポリ袋はビニール紙で編んだ袋に入れ、長さ60cmの紐で締め付けた。

銅をアルミパイプの先端に取り付け、発光標識をアルミパイプの横に弱い紙テープで張り付け、イルカに銅を打ち込んだ衝撃でパイプから外れる仕掛けとした。

1.5 対網行動の記録

日用の明るい時には、普通のテレビカメラを使用し、夜は星明り程度の明るさでも物体が観察できる暗視眼鏡（FUJINON, Night scope, FNS-P101）を使用し、ビデオテープレコーダで録画した。暗視装置の仕様は以下の通りである。

◇ 光の増幅倍数 ……… 50,000倍
◇ 視 認 距 離 ……… 月明り（0.01 ～ 0.1 lux）で約1,000m先の人間、星明り（0.001 lux）で約400m先の人間。
◇ 暗 視 管 ……… 3段増幅型静電受光方式（自動輝度調整回路付）。
◇ 同 と ……… 重量約5.4kg, 全長465mm, 最大高さ182mm, 最大径146mm

T V カメラは図1に示すように柵橋の少し高い陸地の道路に設置した。

1.6 実験結果

(1) 平常時の対網行動

2月23日～24日の平常時の対網行動を分析した。

昼間は標識イルカと他の2頭のイルカを区別して、モニターT V の画面からイルカの呼吸浮上地点と流網の間の距離を計算し、頻度分布を調べた（図7, 8）。夜間はナイトスコープの映像から標識イルカと流網の間の距離を調べた（図9）。

標識イルカの浮上回数と発光標識の発光回数を1時間毎に計数し、表1に示した。発光標識は一定間隔で発光し、イルカが水面近くにいる限りナイトスコープにより発光が録画されるので呼吸回数と
は関係がない。

(2) 威嚇時の対処行動

イルカの多い区域の方へポイントを入れ、水面を竿で叩いたり、石を投げ入れたり、ポイントで接近したりしてイルカを威嚇した時、イルカがどういう逃げ方をするのか観察した。図1はA区域にイルカが多い場合の実験である。桟橋から流網主にはロープのみが存在し、その距離（R）を0〜10mまで変えた。威嚇時の対処行動の観察結果を表2に示した。

1. R = 10m  …… 3回の実験とも、威嚇されたイルカは簡単に図1のaのようにロープの下を通過し、他区域へ移動する。移動後直ぐに元の領域へ戻ることが2回観察された。

2. R = 5m  …… 威嚇するとイルカは図1のcのようにポイントの横を通じ逃げることが3回あったが、ロープの下を通って他区域へ移動することが5回観察された。

3. R = 2.5m  …… 威嚇されたイルカがロープの下を通り他区域へ移動したのが2回、ポイントの横を通じ逃げたのが15回であった。

4. R = 0m  …… 威嚇されたイルカがポイントの横を通じ逃げたのが5回、図1のbのように網の下を通じ、他区域へ移動したのが1回であった。

3. 流網に付けて餌の捕食行動

体長25〜28cmのサバの尾部を弱い留糸でしばり、浮子棚からB区域側へ吊して水深0.5〜1mのところに餌があるようにした。あとはイルカが捕食し続け張れば簡単に切れるものを使った。

流網は桟橋のところまで残り、餌を1m間隔で原則として4尾吊りし、桟橋から一番近い餌までの距離を3mと5mに変えて捕食行動を観察した。イルカに毎朝与えている餌を実験日には与えないで餌飽し状態にし、B区域側にいた2頭のイルカについて実験を行った。

接近回数、実験開始から捕食までの経過時間、どの餌を捕食したかなどに留意して、実験結果を表3にまとめた。

1.7 考察

(1) 平常時の対処行動

夜間の標識イルカと流網の間の距離は3〜5mの範囲が多く、昼間の標識イルカでは5〜10mの範囲に、他のイルカで4〜9mの範囲に多い。いずれにしろ流網に0〜1mの距離で接近することは殆どなく、夜間にこの距離で接近することがあっても離網していない事実からイルカは充分流網を認知していると考えられる。

呼吸浮上回数については、11〜15時の範囲ではוד定であるが、これ以後18時まで徐々に減少していく傾向が見られる。発光回数については、21〜1時の範囲で少なく、1〜5時の範囲で時間と共に増加していく傾向があり、イルカは夜中より明け方近くに水面に漂って睡眠遊泳していると考えられる。

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(2) 威嚇時の対鯨行動

平常時にはイルカが桟橋と流網をつなぐロープの下を通る場合にA→Bの移動を行っていることが多い。

桟橋と流網の間の距離（R）が10mの場合、威嚇するとイルカは桟橋を通るロープの下を通ることで他区域へ移動した。R = 5mではイルカが桟橋の横を通る場合が少なく、ロープの下を通ることで他区域へ移動する方が多く、桟橋と流網の間の空間をあまり通過せずにいると考えられる。R = 2.5mではイルカが桟橋の横を通る場合が多くなり、その空間をあまり通過せずにいることが多い。R = 0mでは桟橋の下を通って流網の下を通ることで他区域へ移動している。

威嚇されてパニック状態になっているイルカでも、桟橋と流網の存在を無視して通ることで通ずる場合はある。流網を認知し避けていることが分かった。

(3) 流網に餌を付けた時の捕食行動

イルカは鏡食状態にあっても流網の存在を認識し、頭部を左右に振りながら慎重にエコロケーションをし、羅網することなく餌を食べることが分かった。

表3に示すように桟橋から一番遠い餌が最も捕食までの時間が長く、遊泳接近して捕食行動をする時桟橋の存在が強力になっていた。桟橋から遠い面で流網から離れてすら下っている餌を一番早く捕食する傾向があがった。また、流網が潮流によりイルカ側へぶかれて餌が網の上にのっている状態では捕食しにくかった。

イルカが流網に対峙し斜め方向や直角方向から接近し、餌のところでお互いに発動して捕食することを二度して、羅網しそうになることが数回あった。頭部が流網の方へ向いている時は羅網しそうになることはなかった。

今後の問題としては、夜間に流網に餌を吊し下ろしたり、流網の外に餌を投げ入れたりして、暗い所での捕食行動を観察する必要がある。

2. ハンドウイルカの流網の認知距離

流網とイルカの間の距離が増加すると、エコロケーションの超音波ビーム内に含まれる浮子の数、浮子欄と沈子欄の長さ、流網の面積が増加し、反射波の合成に寄与する部分が増える。

以降の報告では大まかな目安を得るため、1mの距離の反射損失に距離増加の補正値を加えて、浮子欄、沈子欄、網地の反射損失を各々20、25、45dB の一定値としてインシルカの認知距離を求めて各々40、30、11mを得た。

今回は流網の位置を考慮しながら、距離によるターゲットサイズの変化とイルカの受波エコロケーションレベルを計算し、認知距離を求めた。

2.1 認知距離の求め方

一般的にイルカのクリックスの音源レベルをS(dB)、イルカと反射物の間の距離をr(m)、水平
伝搬の吸収損失係数を \( \alpha (\text{dB/m}) \)、反射物のターゲットサイズを \( TS (\text{dB}) \) とすると、イルカが受波するエコーレベル \( EL (\text{dB}) \) は次式で表わされる。

\[
EL = S - 40 \log r - 2 \alpha r + TS
\]  
(1)

また、1mの距離における反射物のターゲットサイズを \( K (m^2) \) とすると、\( TS \) は次式で表わされる。

\[
TS = 10 \log KNr^n
\]  
(2)

上式で \( n = 0 \) とすると浮子などの物体がN個ある場合の\( TS \) であり、\( n = N = 1 \) とするとロープなど長さのある物体の\( TS \) であり、\( n = 2, N = 1 \) とすると網など面積を有する物体の\( TS \) である。

イルカのエコーロケーションのビームが流網に直角に入射するとし、浮子棚と沈子棚ではビームの中心がそれらの上を通り、網地ではビームの中心が網地の中間を通るとして、反射波の発生状況を考えることにする。

パルス由 \( T \) のクリックスの超音波パルスが薄くて広がるのある物体にあたる時、イルカの位置に同時に入射して一つの反射波として合成されるのは、一番近い反射物までの距離が \( r \) の時 \( r - (r + cT/2) \) の範囲にある反射物の反射波である。但し、\( c \) は水中の音速である。上から見た状態を表わす図10において、\( O \) をイルカ、\( XY \) を網地とし、\( OP_1 = r \)、\( P_1P_2 = P_2P_3 = cT/2 \) とする。

超音波パルスが網地の方へ伝播していきその先端が \( P_2 \) まで到達した時、直径 \( Q_1R_1 \) の円内にある網地が1つの反射波の合成に寄与し、次にその先端が \( P_3 \) に到達した時 \( Q_1R_1 \) を内径、\( Q_2R_2 \) を外径とするリング内の網地が反射波の合成に寄与する。超音波パルスが伝播するにつれて、そのリングは外側へ広がっていく。

図11はイルカの位置から流網の方向を見た状態を表わす。\( EFGH \)を網地とし、リングの内径や外径が網丈より大きくなると、反射する部分は網丈で制限されリングのうち斜線で示された面積となり、外側のリングほどその面積が小さい。

イルカのエコーロケーションのビーム角度を \( \alpha \)、沈子棚の反射指向角を \( \beta \)、網地の反射指向角を \( r \) とする。

沈子棚の反射部分は時間と共に \( Q_1P_1 + P_1R_1, Q_1Q_2 + R_1R_2, Q_2Q_3 + R_2R_3, \ldots \) と外側のリングへ移行していく。反射部分の長さは、超音波パルスの後端が \( P_1 \) に達した時最大となり \( Q_1R_1 \) であるが、近距離では \( \alpha \) や \( \beta \) の小さい方で制限された値となる。

リングの面積は中心から離れる程大きくなるが、近距離では \( \alpha \) が \( \gamma \) の小さい方で制限され、かなりの遠距離では網丈で制限される。反射に寄与する最大面積は、近距離では上記の角度できまる面積であり、遠距離ではリングの外径が網丈となる時の面積である。かなりの遠距離では \( Q_1R_1 \) を直径とする円が網丈で上下を切断された形の面積で最大となる。

浮子については、浮子棚のロープを除いて残った浮子の配列で反射を考えることにする。浮子の反射指向角 (\( \varepsilon \) ) はかなり小さいので、近距離の \( TS \) は半径 \( r \tan \varepsilon \) の円の中の浮子の数で決まり、遠距離
のTSは半径P1Q1の円の中の浮子の数で決る。

浮子の取付間隔をlとし、2P1Q1が(N-1)l～Nlの範囲では、イルカの超音波ビーム内の浮子のうちN個が反射波の合成に寄与する。

沈子棚の場合、反射に寄与する長さがより長くなると、TSの変化量は10 log y' yとなる。また、網地の場合、反射に寄与する面積がS'からSに変化すると、同じくTSの変化量は10 log S/Sとなる。

認知距離はイルカの聴覚閾値をTHとすると、EL = THとなる距離として求められる。イルカの聴覚閾値は連続波が短い時間中のパルスについて測定されているので、短いパルスについては補正する必要がある。

2.2 認知距離の計算結果と考察

ハンドウイルカのクリックスの波形特性は、Auら（1974）のデータなどを参考にし、パルス巾（τ）50μs、周波数120kHz、ビーム角度（α）を10°とした。音源レベルについては、今回の実験場所が狭く浅い海域なので16に〜180dB（0dB = 1μPa）とした。反射指向角についてはPence（1986）のデータなどを参考にし、β = 10°、γ = 6°、κ = 3°とした。

イルカと海藻までの距離（r）とそれぞれの角度（α = β, γ, κ）から得る半径を各々y1, y2, y3とし、図12, 13に示した。τ = 50μs とするときτ / 2 = 3.8cmとなり、その時の距離とP1Q1 (y)の関係を図12, 13に示した。

反射に関与する浮子の数が最大となる時の半径は距離115mまではy3で決まり、それ以上ではyで決まる。沈子棚では反射に関与する長さが最大となる時の半径は、距離10mまではy1, 0で決まり、それ以上ではyで決る。網地では反射に関与する面積が最大となるのは、距離55mまではy3で決まり、それ以上では網状で決る。浮子の数とy3と距離の関係を表4に示した。

以前の測定結果3)により、浮子、沈子棚、網地の1mの距離のTSを各々-25, -33, -55dBとし、反射に関与する個数、長さ、面積の最大値の距離による変化を補正して各々のTSを図14に示した。2倍の距離をDDと表わすと沈子棚のTSは10mまで3dB/DDで増加し、それ以上では1.5dB/DDで増加している。網地のTSは30mまで6dB/DDで増加し、30〜55mの範囲で増加の割合が少しずつ減少し、55m以上では3dB/DDで増加している。

120kHzの水平伝播の吸収損失係数を0.03dB/mとした。

(1)式に各パラメータの数値を代入してELを計算して図15に示した。120kHzの連続波に対するハンドウイルカの聴覚閾値はJohnson（1966）のデータでは約60dBとなっているが、パルス巾50μsの補正値（30dB）と網地の反射波の時間的広がりによる補正値を加える必要がある。

ビームの中心部が最も早く網地に到達し、中心から外れて遅れて到達し反射するので、反射波に時間的広がりが生じ、距離と共にその広がりが増加する。例えば図12において、イルカのビームは100mの距離で半径ACの円となる。ACとy, 網状のy1, y2, との交点を各々B, D, Eとする。
反射に伴うリングの外側がBからDの間にある時は、Dに近い方がリングの面積が大きいのが大きな差がなく、TSもほぼ一定である。リングの外側がDからEの間では網目で反射物の面積が制限されるので、TSが減少し、リングの外側がEからAの間では網地の反射指向性で層に反射波が減少するので、TSの減少が激しい。
反射波の合成に寄与する部分の長さと面積の時間的変化を10、30、100mの距離について調べ、反射波の時間遅れとTSの関係を図16に示した。例えば、距離100mにおける網地、沈子網のTSを各N（100）、L（100）とし示している。
L(100)のグラフにA、B、Dの位置を、またN(100)のグラフにEの位置を示しておいた。各グラフ共反射物の反射指向性により反射波が減少し始める位置を大きいマークで示した。網地のTSでそのマークは距離10mで0μs、30mで5μs、100mで125μsのところであり、沈子網のTSでは距離10mで10μs以下、30mで100μs、100mで450μsのところにある。
エネルギー積分機関による聴覚閾値の補正値は、網地の場合の10mと30mで0dB、100mで-4dB、沈子網の場合の10mで0dB、30mで-3dB、100mで-5dBとした。浮子では反射指向性が薄く、反射波の時間的広がりが距離100m位では期待できないので、その補正値を0dBとした。浮子、沈子網、網地の認知の場合の聴覚閾値を各々TH(F)、TH(L)、TH(N)として図15に記入し、各々の認知距離を160dBと180dBの音源レベルについて求め表5に示した。
音源レベルが180dBでは、認知距離が34m以上であり充分認知できることを示している。但し、音源レベルが160dBとなると認知距離が急に減少し、早い遊泳速度では羅網の危険がある。
流網に対し斜め方向からイルカが接近する時、TSは減少し、反射波の時間的広がりは増加する。
前の現象はイルカにとって流網の認知を難しくし、後の現象はその認知を容易にするので、どちらの影響が大きいか調べなければならない。沈子網と網地の反射指向性を今回は単純な形にして認知距離を計算しているが、実際は複雑であり検討の余地を残している。また、実際に投網された流網は一直線でなく3次元的に複雑に変化しているので、今後とも流網の反射と認知について研究する必要がある。

Reference

3) Hatakeyama, Y. 1984: On Reflection Loss of Gillnet and Maximum Detectable


Fig. 1 Diagram showing layout of dolphin, nets, pier and boat.
Fig. 2 Experimental site

Fig. 3 Three bottlenosed dolphins swimming in the net enclosure
Fig. 4  Swimming bottlenose dolphin marked with a flashing buoy

Fig. 5  Flash bulb and 1.5V long life alkaline dry cell
Fig. 6 Spear and polypropylene pot in which a flush bulb and a dry cell were put.

Fig. 7 Distribution of distances between a dolphin with a flushing buoy gillnet in the daytime.

* Distances ranging from $(N-1)$ (m) to $N$ (m) are regarded as $N$ (m).
Fig. 8 Distribution of distances between two dolphins without a light mark and gillnet in the daytime.

Fig. 9 Distribution of distances between a dolphin with a light mark and gillnet at night.

...Distances ranging from \((N-1)m\) to \(N(m)\) are regarded as \(N(m)\)
Fig. 10  Successive positions of a supersonic pulse wave front and reflecting parts. (Top view)

Fig. 11  Successive spreads of reflecting parts (Front view).
Fig. 12 Changes of $y$, $y_3$, $y_6$ and $y_{10}$ at a long distance.
Fig. 13 Changes of $y$, $y_3$, $y_6$ and $y_{10}$ at a short distance.
**Fig. 14** Target size as a function of distance.

**Fig. 15** Echo level as a function of distance and detection threshold.
Fig. 16 Target size as a function of delay time of reflected wave

* 1 ··· Target size of lead line 100 m apart from dolphin

* 2 ··· Target size of net 100 m apart from dolphin
Table 1. Number of surfacing of a dolphin with a flushing buoy and flushing of its buoy

<table>
<thead>
<tr>
<th>Time</th>
<th>No. of surfacing</th>
<th>Time</th>
<th>No. of flashing</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 ~ 12</td>
<td>184</td>
<td>21 ~ 22</td>
<td>68</td>
</tr>
<tr>
<td>12 ~ 13</td>
<td>183</td>
<td>22 ~ 23</td>
<td>96</td>
</tr>
<tr>
<td>13 ~ 14</td>
<td>171</td>
<td>23 ~ 24</td>
<td>113</td>
</tr>
<tr>
<td>14 ~ 15</td>
<td>176</td>
<td>24 ~ 1</td>
<td>119</td>
</tr>
<tr>
<td>15 ~ 16</td>
<td>163</td>
<td>1 ~ 2</td>
<td>210</td>
</tr>
<tr>
<td>16 ~ 17</td>
<td>150</td>
<td>2 ~ 3</td>
<td>282</td>
</tr>
<tr>
<td>17 ~ 18</td>
<td>143</td>
<td>3 ~ 4</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 ~ 5</td>
<td>424</td>
</tr>
</tbody>
</table>
Table 2. Behaviors against gillnet when intimidated

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Distance (m)</th>
<th>Intimidating method</th>
<th>Distribution of dolphins before experiment</th>
<th>Time elapsed (m:s)</th>
<th>Moving direction (No. of dolphins moved)</th>
<th>Passing place</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>P</td>
<td>A:B</td>
<td>0:143</td>
<td>A → B(2)</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td></td>
<td>1:2</td>
<td>0:43</td>
<td>B → A(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>S</td>
<td>1:2</td>
<td>0:12</td>
<td>A → B(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>P,S</td>
<td>1:2</td>
<td>0:57</td>
<td>B → A(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>S</td>
<td>3:0</td>
<td>0:22</td>
<td>A → B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>P</td>
<td>3:0</td>
<td>0:31</td>
<td>A → B(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>P,S</td>
<td>1:2</td>
<td>1:05</td>
<td>B → A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>S</td>
<td>1:2</td>
<td>0:33</td>
<td>B → A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>P</td>
<td>1:2</td>
<td>0:21</td>
<td>B → A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>S</td>
<td>2:1</td>
<td>1:19</td>
<td>A → B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>P</td>
<td>0:3</td>
<td>0:15</td>
<td>B → A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>P,S</td>
<td>0:3</td>
<td>0:25</td>
<td>B → A(1)</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>P,S</td>
<td>3:0</td>
<td>0:19</td>
<td>A → B(2)</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0:41</td>
<td>B → A(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0:57</td>
<td>A → B(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0:60</td>
<td>B → A(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>S</td>
<td>1:2</td>
<td>0:13</td>
<td>B → A(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>5</td>
<td>P</td>
<td>3:0</td>
<td>0:41</td>
<td>A → B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0:26</td>
<td>A → B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1:01</td>
<td>A → B(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1:18</td>
<td>A → B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1:53</td>
<td>B → A(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2:37</td>
<td>A → B(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2.5</td>
<td>S</td>
<td>1:2</td>
<td>B → A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#1 Distance between pier and gillnet.
#2 P-pole. S-stone
#3 Time elapsed after beginning of experiment.
#4 R-under the rope between pier and gillnet. N-under the gillnet.
Table 3. Eating behaviors against preys attached to the gillnet

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Time elapsed</th>
<th>Distance (m)</th>
<th>No. of approach</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3min 5sec</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3min 37sec</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7min 3sec</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9min 14sec</td>
<td>5</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6min</td>
<td>4</td>
<td>1</td>
<td>Preys were thrown into waters as they didn't approach to attached preys till 5min.</td>
</tr>
<tr>
<td></td>
<td>6min 24sec</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6min 27sec</td>
<td>(3)*5</td>
<td>25</td>
<td>They couldn't eat prey. Prey dropped from net. At 10min 28sec experiment was stopped.</td>
</tr>
<tr>
<td>3</td>
<td>49sec</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1min 28sec</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4)*5</td>
<td></td>
<td></td>
<td>At 3min 57sec and 13min, preys were thrown into waters. Although they approached to preys 101 times, they couldn't eat preys, at 22min 14sec experiment was stopped.</td>
</tr>
<tr>
<td></td>
<td>(3)*5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4*4</td>
<td>1min 36sec</td>
<td>9</td>
<td>1</td>
<td>At 1min 15sec preys were thrown into waters.</td>
</tr>
<tr>
<td></td>
<td>2min 23sec</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

*1 ...... Time elapsed from beginning of experiment to eating prey.
*2 ...... Distance between pier and prey eaten.
*3 ...... No. of approach to prey till eating it.
*4 ...... Two preys were attached to gillnet at this experiment only.
*5 ...... The number in the parenthesis indicates distance between pier and prey not eaten.
Table 4. Number of float in the beam

<table>
<thead>
<tr>
<th>No. of float</th>
<th>Diameter of beam (m)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 ~ 1.1</td>
<td>0 ~ 21</td>
</tr>
<tr>
<td>2</td>
<td>1.1 ~ 2.2</td>
<td>21 ~ 42</td>
</tr>
<tr>
<td>3</td>
<td>2.2 ~ 3.3</td>
<td>42 ~ 63</td>
</tr>
<tr>
<td>4</td>
<td>3.3 ~ 4.4</td>
<td>63 ~ 84</td>
</tr>
<tr>
<td>5</td>
<td>4.4 ~ 5.5</td>
<td>84 ~ 105</td>
</tr>
<tr>
<td>6</td>
<td>5.5 ~ 6.6</td>
<td>105 ~ 141</td>
</tr>
<tr>
<td>7</td>
<td>6.6 ~ 7.7</td>
<td>141 ~ 200</td>
</tr>
</tbody>
</table>

Table 5. Detectable range of gillnet for bottlenosed dolphin

<table>
<thead>
<tr>
<th>Source level (dB)</th>
<th>Detectable range (m)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>Float 60</td>
<td>Lead line 62</td>
</tr>
<tr>
<td>160</td>
<td>Float 13</td>
<td>Lead line 16</td>
</tr>
</tbody>
</table>
OBSERVATION OF BOTTLENOSE DOLPHIN'S BEHAVIOR TO SALMON GILLNET

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Observation of bottlenose dolphin's behavior
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17 p. Fisheries Agency of Japan, Tokyo, Japan.
Summary

Behavior of three bottlenose dolphin to salmon gillnet was observed. Three dolphins were held in a net enclosure which was partitioned equally with a salmon gillnet. Observations were made for three categories of situations; when they were swimming under ordinary conditions, when they were struck with panic, and when they were feeding on fish attached to the gillnet. For all these categories, they fully detected the existence of the gillnet and did not get entangled in the gillnet. However, it was observed several times that their flukes almost grazed the net when they changed their swimming direction trying to feed on the fish attached to the gillnet.

Maximum detectable ranges of salmon gillnet by bottlenose dolphin were determined to be 34 m for the net and about 60 m for the float and leadline by assuming the source level of clicks is 180 dB and considering the breadth of the gillnet. These findings indicated that bottlenose dolphin can detect salmon gillnet at a considerably long distance.
It is necessary to clarify the mechanism of entanglement of porpoise and why porpoise get entangled in gillnets although they are considered to fully recognize the existence of gillnets by echolocation. For that purpose, using three bottlenose dolphins captured alive and held in a net enclosure which had a gillnet partition in the middle, observations were made on their behavior to the gillnet while they were swimming under ordinary conditions (day and night), and while they were intimidated by being chased. Feeding behavior was also observed when food (fish) were attached to the gillnet.

A previous study\(^1\) reported a rough estimation on the recognition of gillnets by dolphins by assuming that the reflection losses of the elements of gillnet are constant. However, practically, as the distance between the dolphin and gillnet increases, the total area of the objects which are included in the reflection from the supersonic beam also increases. Therefore, in this study, taking this fact into consideration, maximum detectable range of salmon gillnet by bottlenose dolphin was calculated.

1. **Observation on behavior to gillnet**

1.1 **Period**

1986 February 20  
The net enclosure was set in place.  
Three bottlenose dolphins were carried into the enclosure.

1986 February 21  
A flashing buoy was attached to one of the dolphins. A salmon gillnet was set in the middle of the net enclosure.

1986 February 22 and 23  
Behavior to the gillnet was observed under ordinary conditions.

3134--3
1986 February 24

Behavior to the gillnet was observed when the dolphins were intimidated.

1986 February 25

The same as on February 24. In addition, observations were made on feeding behavior when fish were attached to the gillnet.

1.2 Location

In a cove called "Iruka(Dolphin) Park", Katsumoto-town, Iki, Nagasaki Prefecture, a net enclosure was set up with two sheets of net which were set across the cove, as shown in Figs. 1 and 2. In the middle of the net enclosure, a sheet of salmon gillnet (length: 1 tan, depth: 3 m, mesh size: 115 mm) was set to divide the enclosed space into two areas (A and B) and the behavior of the dolphins to the gillnet was observed. Arrangement of the enclosure and gillnet was determined as shown in Fig. 2 based on the locations of the objects (tree, boat, pier, and concrete block) to which the ropes of the ends of nets were tied. Since the pier was floating, the dolphins could pass under it without difficulty. The distance between the edge of the pier and the opposite shore of the cove was longer than the length of the gillnet. There are spaces between the end of the gillnet and the edge of the pier (11 m) and between the other end of the gillnet and the shore opposite the pier (5 m). The dolphins could freely pass through these spaces. The effect on the dolphin's behavior by the varied width of the space between the pier and gillnet was also examined for a range of 0 to 10 m. Since the depth of the cove at the location for this experiment ranged from 4 to 5 m, and the leadline of the gillnet was often off the bottom, the dolphins could also move to the other area by passing under the gillnet.
1.3 Dolphins used

Twenty bottlenose dolphins were captured alive on 1986 January 28 and thereafter kept in "Iruka(Dolphin) Park" for a tourist attraction.

Of those, three dolphins were carried into the enclosed space on February 20 (Fig. 3). As shown in Fig. 4, for easier and better observation of dolphins behavior at night, a flashing buoy was attached to one of them.

It took about one week after the capture until the dolphins began to feed. They were fed with a total of some 100 kg of fresh or frozen (with thawing) mackerel, sardine, and Pacific saury per day.

1.4 Flashing buoy

A flash bulb, shown in Fig. 5, was used as a source of light. Power supply was an alkaline dry cell size D (1.5 V). Connecting a resistance of 5 \( \Omega \) between the cell and electronic circuit in series to adjust the interval between flashes to 3 seconds (originally 0.9 second) enabled the flash bulb to keep flashing for about a week. However, with consumption of the cell power, the interval had a tendency to increase gradually.

The flash bulb was double wrapped with red cellophane paper and put in a white polypropilene pot (15 cm tall, diameter 7.5 cm). Packing material was put around the bulb and cell to reduce jarring. The pot was put in a bag made of woven vinyl strands and tied with a 60 cm string to a tiny spear.

The spear was attached to the end of an aluminum tube and the flashing buoy was tied along the tube with weak paper tape. It was designed so that they would come off the pipe as a result of the shock when the spear was shot into the dolphin.
1.5 Recording of behavior to the gillnet

Records of the behavior of the dolphins were made on a video tape recorder using an ordinary TV camera under bright conditions in the daytime or a night scope (FUJINON, Nightscope, FNS-P101) with which objects can be observed even under low light conditions such as starlight.

Specifications of the nightscope are as follows--

Amplification of brightness \( \times 50,000 \)

Sightable distance

- In the moonlight (0.01 to 0.1 lux): man apparent at about 1,000 m distance.
- In starlight (0.001 lux): man apparent at about 400 m distance.

Noctovision

Triple step type electrostatic convergence method (with a circuit for automatic adjustment of brightness)

Dimensions and weight

- Total length: 465 mm
- Maximum height: 182 mm
- Maximum diameter: 146 mm
- Weight: about 5.4 kg

A TV camera was set at the road on a little mound on the side of the pier, as shown in Fig. 1.

1.6 Results

(1) Behavior to the gillnet under ordinary conditions

Behavior to the gillnet recorded from February 23 to 24 was analyzed.
For daytime recording, distinguishing the dolphin marked with the flashing buoy from the others, the distances between the gillnet and the location where they surfaced for aspiration were examined from the pictures of the monitor TV and the frequency of distribution was calculated (Figs. 7 and 8). For the nighttime recording, the distances between the marked dolphin and gillnet were examined from the pictures of the night scope (Fig. 9).

The frequencies of surfacing of the marked dolphin and flashing of the buoy were counted by hour (Table 1). The buoy was flashing at constant intervals and the flashings were recorded as long as the dolphin stayed near the surface. Therefore, there was no relation between the recorded frequency of the flashing and that of actual aspiration.

(2) Behavior to the gillnet when they were intimidated

The manner of fleeing was observed when the dolphins were intimidated from a boat put in the area where a larger number of the dolphins were present by hitting the surface of the water with a rod, throwing stones in the water, and letting the boat approach the dolphins. Figure 1 illustrates the experiment where a larger number of the dolphins stayed in area A. There was just a rope between the edge of the pier and gillnet, distance between these (R) was varied from 0 to 10 m. The results of the observations on behavior to the gillnet when they were intimidated are summarized in Table 2.

(a) R = 10

In all (three) experiments, the intimidated dolphins passed easily under the rope to move to the other area as shown by the path marked "a" in Fig. 1. It was observed twice that they returned to the area where they used to stay immediately after they had moved to the other area.

(b) R = 5 m
When they were intimidated they fled passing by the boat as shown by the path marked "c" in Fig. 1 three times and it was observed that they moved to the other area by passing under the rope five times.

(c) $R = 2.5 \text{ m}$

The intimidated dolphin moved to the other area by passing under the rope twice or fled passing by the boat fifteen times.

(d) $R = 0 \text{ m}$

The intimidated dolphin fled passing by the boat five times or moved to the other area by passing under the gillnet once as shown by the path marked "b" in Fig. 1.

(3) Feeding behavior when fish was attached to the gillnet

Weak cotton thread was bound around the tail of mackerels (body length 25 to 28 cm) that were hung on the side of area B from the float line of the gillnet keeping them at a depth of 0.5 to 1 m. The thread used was weak enough to be broken when the dolphin pulled the fish.

For these experiments, the gillnet was stretched to the pier. Feeding behavior was observed by hanging four fish, as a rule, at 1 m intervals and varying the distance between the pier and the closest fish to the pier from 3 or 5 m. No food was given to the dolphins on the day of experiments to make them hungry. They had been fed every morning before. The experiments were conducted for two dolphins staying in area B.

Paying attention to the frequency of approaches, time from the commencement of the experiment to the feeding, which fish was taken, etc. the results were summarized as shown in Table 3.
1.7 Discussion

(1) Behavior to the gillnet under ordinary conditions

At night, the distance between the marked dolphin and the gillnet ranged chiefly from 3 to 5 m.

In the daytime, the main ranges of distance from the gillnet were 3 to 10 m and 4 to 9 m for the marked dolphin and the others, respectively. From the fact that the dolphins seldom got close to the gillnet (within a range of 0 to 1 m) in the daytime and they did not get entangled although they might get close to the gillnet at such distance in the night, it was assumed that the dolphin could fully detect the gillnet.

Frequency of surfacing for aspiration was stable for the period of 1100 to 1500 but showed a tendency to gradually decrease after 1500 till 1800. Frequency of the recorded flashings was low for the period of 2100 to 0100 and increased with time from the period of 0100 to 0500. Therefore, the dolphins are considered to float sleeping at the surface toward daybreak rather than in the middle of the night.

(2) Behavior to the gillnet when they are intimidated

In an ordinary situation, the dolphin rarely moved to the other area by passing under the rope with which the gillnet was fastened to the pier. When the distance between the pier and gillnet (R) was 10 m, the intimidated dolphins moved to the other area easily passing under the rope. When R = 5 m, since they chiefly moved to the other area passing under the rope, although they sometimes took flight passing by the boat, it is considered that they did not find it very difficult to pass through the space between the pier and gillnet. When R = 2.5, the dolphins mainly took flight passing by the boat and apparently felt it fairly difficult to pass through the space. When R = 0, they moved to the other area passing under the gillnet but not the pier.
It was found that the dolphins, even when they were struck with a panic, recognized and avoided the gillnet, judging the manner of taking flight, with an overall grasp of the existence of the pier and gillnet.

(3) **Feeding behavior to the fish attached to the gillnet**

It was found that the dolphins, even when they were hungry, fed on the fish attached to the gillnet without getting entangled, apparently being aware of the existence of the gillnet and conducting careful echolocation with a horizontal shake of their heads.

The time that fish remained attached to the gillnet until they were fed was longest for the fish closest to the pier, as shown in Table 3, where the existence of the pier was an obstacle to their feeding effort. The fish hung farthest from the pier and apart from the net had a tendency to be fed on first. The feeding was difficult when the fish were placed on the net which arched into the fish-hung side because of the tidal current in this direction. It was observed several times that the dolphins almost got entangled in the net when they changed their swimming direction at the location where the fish was hung after approaching at a diagonal or right angle and their fluke(s) almost grazed the net. They did not come close to getting entangled when they faced the gillnet.

Observations on the feeding behavior in the night to food hung from a gillnet or to the food thrown beyond the gillnet into the opposite side to the area where the dolphins stay should be included in further studies.

2. **Detectable range of salmon gillnet by bottlenose dolphin**

As the distance between the gillnet and dolphin increases, so does the contribution by the elements of the gillnet to the composition of the
reflected waves by increased number of floats, lengths of the float line and lead line, and area of the net included in a supersonic beam for echolocation.

In a previous report, in order to obtain a rough estimate by adding correction factors for increases in the distance to the reflection losses at 1 m distance, and assuming that the reflection losses for the float line, lead line, and net were constant, i.e. 20, 25, and 45 dB, respectively, the detectable ranges of these elements by Dall's porpoise were calculated to be 40, 30, and 11 m, respectively.

In this study, taking the depth and width of the salmon gillnet into account, the detectable ranges were obtained by calculating the change in the target size and the received echo level to the dolphin with the distance.

2.1 Method for calculating the detectable range

In general, putting the sound source level of the clicks of the dolphin as $S$ (dB), distance between the dolphin and the object by which the sound waves are reflected as $r$ (m), absorption coefficient for horizontal propagation as $\alpha$ (dB/m) and target size of the object as $TS$ (dB), the echo level the dolphin receives $EL$ (dB) is formulated as follows:

$$EL = S - 40 \log r - 2 \alpha r + TS$$

Furthermore, putting the target size of the object as $K$ (m$^2$), $TS$ is formulated as follows:

$$TS = 10 \log KNr^n$$

where $n = 0$ it means that there are $N$ individual objects, such as floats, which contribute to $TS$; $n = N = 1$ means there is an object
which has a length such as a rope; \( n = 2 \) and \( N = 1 \) means there is an object which has area such as a net.

In the following, the occurrence of the reflected waves are considered on the assumption that the beam for the echolocation by dolphin incidence on the gillnet at a right angle, the center of the beam incidence on the float line and lead line where the reflected waves from these lines are considered and it incidence on the midpoint of the depth of the net where the net is considered.

Where the clicks with a pulse width of \( T \) hit an object which is thin and has breadth, and the distance between the dolphin and closest object is \( r \), the reflected waves which returned to the location of the dolphin at the same time were composed of the waves which were reflected by the objects within a range of \( r \) to \( (r + C\frac{T}{2}) \), where \( C \) (m/sec) means the velocity of sound in the water. Figure 10 illustrates an overhead view, \( O \) and \( XY \) imply the location of the dolphin and the length of the net respectively, and it is assumed that \( OP_1 = r \) and \( P_2P_3 = C\frac{T}{2} \).

Where a supersonic pulse is propagating toward the net, when the pulse wave front reaches \( P_2 \), the portion of the net included a circle with a diameter of \( Q_1R_1 \) will contribute to the composition of one reflected wave and successively, when the front reaches \( P_3 \), the portion of the net included in the ring with the inside diameter of \( Q_1R_1 \) and outside diameter of \( Q_2R_2 \) will contribute to the composition of the reflected wave. As the supersonic pulse propagates, the ring related to the composition of reflected wave spreads toward the outside of the net.

Figure 11 illustrates a view from the location of the dolphin toward the gillnet. Regarding EFGH as a net, where the outside and/or inner diameters of the ring become larger than the depth of the net, the
portion of the net contributing to the reflection was limited by the depth of the net to the shadowed area of the ring, which becomes smaller as the ring formed farther from the center of the net.

Putting the angle of the beam of the dolphin as $\alpha$ and reflection directivity angles of the lead line and net as $\beta$ and $\gamma$, respectively. The portion of the lead line moved in time from inner to outer rings consecutively; in this order:

$$Q_1P_1 + P_1R_1, Q_1Q_2 + R_1R_2, Q_2Q_3 + R_2R_3 \ldots$$

The total length of the portion which contributes to the reflection is maximized when the tail-end of the supersonic pulse reaches $P_1$ and amounts to $Q_1R_1$ but restricted by a smaller value between $\alpha$ and $\beta$ at a short distance.

The area of the ring becomes larger as it is formed farther from the center but restricted by a smaller value between $\alpha$ or $\gamma$ at a short distance and by the depth of the gillnet at a considerably long distance. The maximum areas contributing to the reflection for three distance range categories are as follows: the area determined by the above-mentioned angles at a short distance, the area where the outside diameter of the ring becomes equal to the depth of the net at intermediate distance, and the area of the net when encompassed by the arches of the circle with a diameter of $Q_1R_1$ on the net and the upper and lower ends of the net which form chords of the circle at a considerably long distance.

Regarding floats, the reflection will be considered for the array of floats, where rope portions of the float line are excluded. Since the reflection directivity angle ($\kappa$) for the float is quite sharp, the TS at a short distance is determined by the number of the floats included in a circle with a $r \tan \kappa$ radius and so is the TS at long distance by the number of the floats included in a circle with a $P_1Q_1$ radius.
Let a space between the floats be $L$, where $2P_1Q_1$ ranges from $(N-1)L$ to $NL$, $N$ pieces of the floats out of those included in a supersonic beam emitted by the dolphin will contribute to the composition of the reflection wave.

Regarding the lead line, as the length contributing to the reflection changes from $y$ to $y'$, the TS will vary by $10\log y'/y$. On the other hand, as the area of the net which contributes to the reflection changes from $S$ to $S'$, the TS will vary by $10\log S'/S$.

Let $TH$ mean the auditory threshold of the dolphin, the detectable range can be obtained as the distance at which the $EL$ equals $TH$. Since past measurements on the auditory threshold were made with continuous waves and pulses with large width, it is required to correct the values obtained for pulses with small width.

2.2 Results of the calculation of detectable range and discussion

Based on the data reported by Au et al. (1974)$^1$, etc., the waveform characteristic was assumed as follows: pulse width ($\tau$): 50 $\mu$s; frequency: 120 kHz; beam angle ($\alpha$): 10°. The source level was also assumed to be 160 to 180 dB ($0$ dB = $1\mu$Pa) because the space for this experiment was small and shallow. The reflection directivity angles were assumed as follows: $\beta = 10°$, $\gamma = 6°$, and $\kappa = 3°$ based on the data reported by Pence (1986)$^2$, etc.

Let $y_{10}$, $y_6$, and $y_3$ be the radii determined by the distance between the dolphin and gillnet ($r$) and reflection directivity angles ($\alpha = \beta, \gamma$, and $\kappa$), respectively, these radii are shown in Figs. 12 and 13. Where $\tau$ equals 50 $\mu$s, $C\tau/2$ amounts to 3.8 cm and the relation between the distance and $P_1Q_1(y)$ is as shown in Figs. 12 and 13.

The value of radius with which the number of the floats relates to the reflection is maximized is determined by $y_3$ within a 115 m distance and by $y$ at a distance exceeding 115 m.

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Regarding the leadline, the value of radius with which the length relates to the reflection is maximized is determined by $y_{10}$ within a 10 m distance and $y$ at a distance exceeding 10 m. For the net, the maximum area related to the reflection is determined by $y_6$ within a 55 m distance and by the depth of the net at a distance more than 55 m.

The relations among the number of floats, $y_3$ and distance are shown in Table 4.

Assuming the TSs at a 1 m distance for the float, leadline and net to be -25, -33, and -55 dB, respectively, based on previous results of measurements, the corrected values of these TSs are obtained as shown in Fig. 14 by taking into account the distance-related variations for the maximum values of the number of the floats, length of the leadline and area of the net. Let DD be a double distance, the TS for the leadline increases by 3 dB/DD up to 10 m and by 1.5 dB at a distance exceeding 10 m. The TS for the net increases by 6 dB/DD up to 30 m but the rate of increase gradually decreases within a range of 30 to 55 m and there is a constant increase in TS by 3 dB/DD beyond 55 m distance.

The absorption loss coefficient was assumed to be 0.03 dB/m for horizontal propagation of supersonic waves of 120 kHz frequency.

The ELs were calculated by substituting the parameters into formula (1) and are shown in Fig. 15. Although Johnson (1966) reported that the auditory threshold of bottlenose dolphin regarding the continuous waves of 120 kHz frequency was approximately 60 dB, it is necessary to take the correction value (30 dB) for the pulse with a 50 μs width and those regarding the time-related expansion of the reflected waves from the net.

The center of the beam reaches the net first and there is a delay before the outer portion of the beam reaches the net to be reflected.
and this delay becomes larger for the more outer portion. Therefore, time-related expansion is produced to the reflected wave and increases according to distance. For example, in Fig. 12, the supersonic beam emitted by the dolphin forms a circle with a radius of AC at a 100 m distance. Let B, D, and E be the points of intersection between AC, and y, half the net depth and y, respectively. Where the outside circle of the ring relating to the reflection exists between B and D, the area of the ring shows no significant difference and the value of the TS is almost constant although the area becomes larger as the outside circle approaches D. Where the outside circle of the ring exists within a range of D to E, the value of the TS decreases due to the restriction of the area of portion relating to the reflection by the depth of the net. There is a drastic decrease in the value of the TS where the outer circle of the ring exists within a range of E to A because the reflected wave further decreases due to the reflection directivity of the net.

The time-related variations for the length and area which contribute to the composition of the reflected waves were examined for distances of 10, 30, and 100 m and the relations between the delay time and TSs are shown in Fig. 16. For example, the TS for the net and leadline at a 100 m distance are shown as N (100) and L (100), respectively.

The positions of A, B, and D are indicated on the graph of L (100) and so is that of E on the graph of N (100). The positions at which the reflected waves commence decreasing because of the reflection directivity of the objects are indicated with the enlarged marks. There are marks at 0, 5, and 125 μs on the graphs of TSs for the net at distances of 10, 30, and 100 m, respectively. For the graphs of TSs for the leadline, the delay times are less than 10 μs at a 10 m distance and 100 and 450 μs at distances of 30 and 100 m, respectively.

The correction values for the auditory threshold related to the energy integration mechanism were assumed to be 0, 0, and -4 dB for the
distances of 10, 30, and 100 m, respectively for the net, and 0, -3, and -5 dB for 10, 30, and 100 m, respectively for the leadline. Since the reflection directivity of the float is so sharp that the time-related expansion of the reflected wave cannot be expected at a distance of approximately 100 m, the correction value was assumed to be 0 dB. The auditory thresholds to detect the float, leadline, and net are abbreviated as TH (F), TH (L), and TH (N), respectively, and drawn in Fig. 15. The detectable ranges for these objects were obtained for the source levels of 160 and 180 dB and shown in Table 5.

Where the source level is 180 dB, it is indicated that the detectable range is 34 m or more and the dolphin fully detect the gillnet at such distance. However, as the source level becomes 160 dB, there is a sharp decrease in a detectable range and a danger for the dolphins to get entangled in the net at a large swimming speed.

Where a dolphin approaches the gillnet at a diagonal angle, the TS decreases while the time-related expansion of the reflected wave increases. Since the former phenomenon makes it more difficult for a dolphin to detect the gillnet and the latter does the reverse, it is required to determine which influence is dominant. Although the detectable range was calculated based on simplified models of the reflection directivity for the leadline and net, the actual situation is much more complicated and there remains a need for further study. In addition, the gillnets actually set in the sea complicatedly change their configurations three-dimension-wise. Therefore, further studies are required on the reflection of supersonic waves on the gillnet and the dolphin's ability to detect the gillnet.

REFERENCES, TABLES 1 TO 5, AND FIGS. 1 TO 16
ARE IN ENGLISH IN THE JAPANESE DOCUMENT

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