# DETECTION OF KRILL (*EUPHAUSIA SUPERBA*) NEAR THE SEA SURFACE: PRELIMINARY RESULTS USING A TOWED UPWARD-LOOKING ECHO-SOUNDER

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ABSTRACT. Results from using a towed, upward-directed echo-sounder are described. Krill swarms were detected near the sea surface. The problems of detecting and quantifying these right at the surface are discussed.

## INTRODUCTION

The establishment of a krill fishery in the Southern Ocean has focused attention on methods of monitoring the stocks. Acoustic techniques have proved successful in estimating krill abundance below 10 to 20 metres from the surface (BIOMASS, 1985). Krill also occur at the surface, a layer not sampled by downward-directed echo-sounders. It is nonetheless important to detect and quantify krill at the surface, partly to derive estimates of total abundance but also to determine how much is available to surface feeding predators (Everson, 1983).

The present study was set up to investigate the feasibility of detecting and quantifying krill near to the surface. This paper reports our preliminary findings.

## METHODS

A SIMRAD EKS 120 echo-sounder was used with the following instrument settings:

| | |
|---|---|
| Operating frequency | 120 kHz |
| Pulse repetition frequency | 250 per minute |
| Range | 0–50 m |
| Pulse duration | 0.3 ms |
| Mode | White line |
| Bandwidth | 3 kHz |
| Gain | 0 dB |
| TVG | 20 log $R$ |
| Transducer beam angle | 10° |

The echo-sounder transducer was mounted in a hydrodynamically designed towed body. Two mounting arrangements were used:

(1) The transducer directed upwards 45° from the vertical and 45° to the right of the towed body's axis of trajectory. In this configuration the beam was directed ahead and away from the ship (Fig. 1).

(2) The transducer directed vertically upwards from behind the towing point.

The towed body was fitted with sensors for pitch, roll and depth. It was towed from a boom on the ship's starboard side, about a third of the way along from the bow and the available cable allowed it to operate at a depth of between 5 and 10 metres at towing speeds of 2.5–4 knots. Echo-charts were marked at 0.2 nautical-mile intervals to coincide with distance intervals on the downward directed echo-sounder

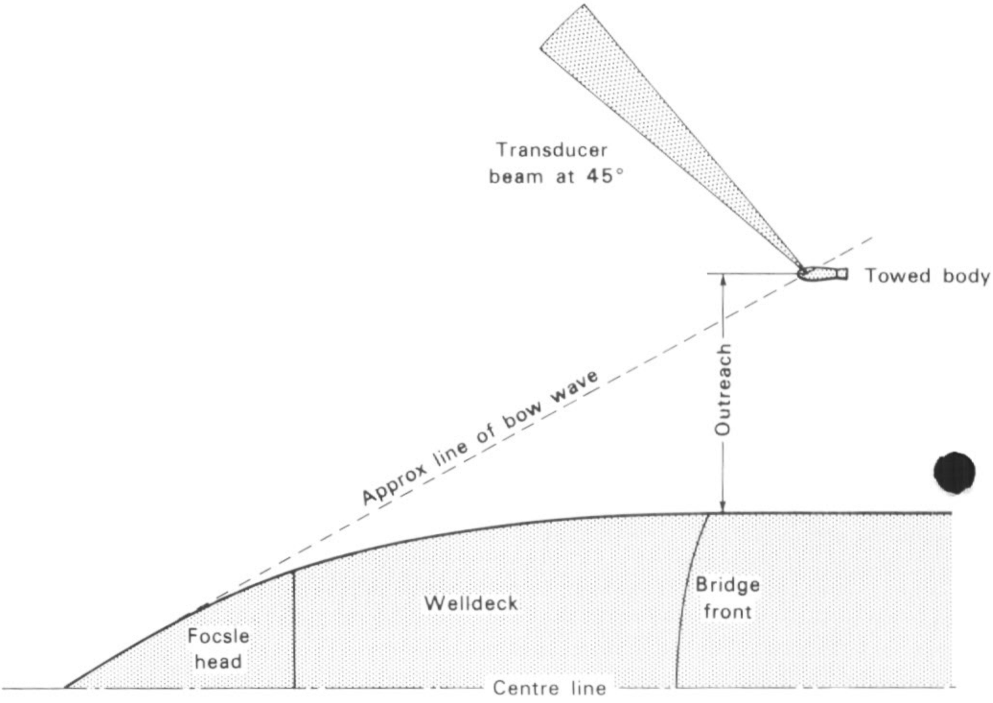

Fig. 1 Diagrammatic representation of the position of the towed body relative to the ship.

that was operating concurrently. Net hauls were made at 1–3 metres depth using a one-metre square frame net and a smaller frame net having a cod end pump. The latter net giving a more or less continuous picture of krill distribution. Weather information was taken from the ship's meteorological log.

## RESULTS

The stability of the towed body was good. Roll rarely exceeded more than ± 1° and pitch varied with vessel speed and sea-state but was rarely more than ± 3°. Depth varied with towing speed but remained constant within the limits of the sensor calibration for a constant vessel speed.

Several characteristic patterns were noted on the echo-charts:

(i) Clear surface echoes and white line (Type I) (Fig. 2a).
(ii) 'Spiky' surface echoes (Type II) (Fig. 3a).
(iii) Near surface marks coincident with krill catches (Type III) (Fig. 2b).

The clear surface echoes are always more or less regular and rarely had an amplitude greater than one metre. These Type I marks probably indicated the true 'sea surface' even though the wave amplitude recorded by the meteorological observers was generally much greater. The Type II marks were rarely present at regular intervals and were often of varying amplitude. Observations at the time suggested that these were almost certainly related to the weather, most probably by surface aeration induced as a result of wave action or by the ship or the towing cable (the last only with reference to the transducer when directed vertically). Dalen and Løvik (1981) and Novarini and Bruno (1982) have demonstrated that windspeed does

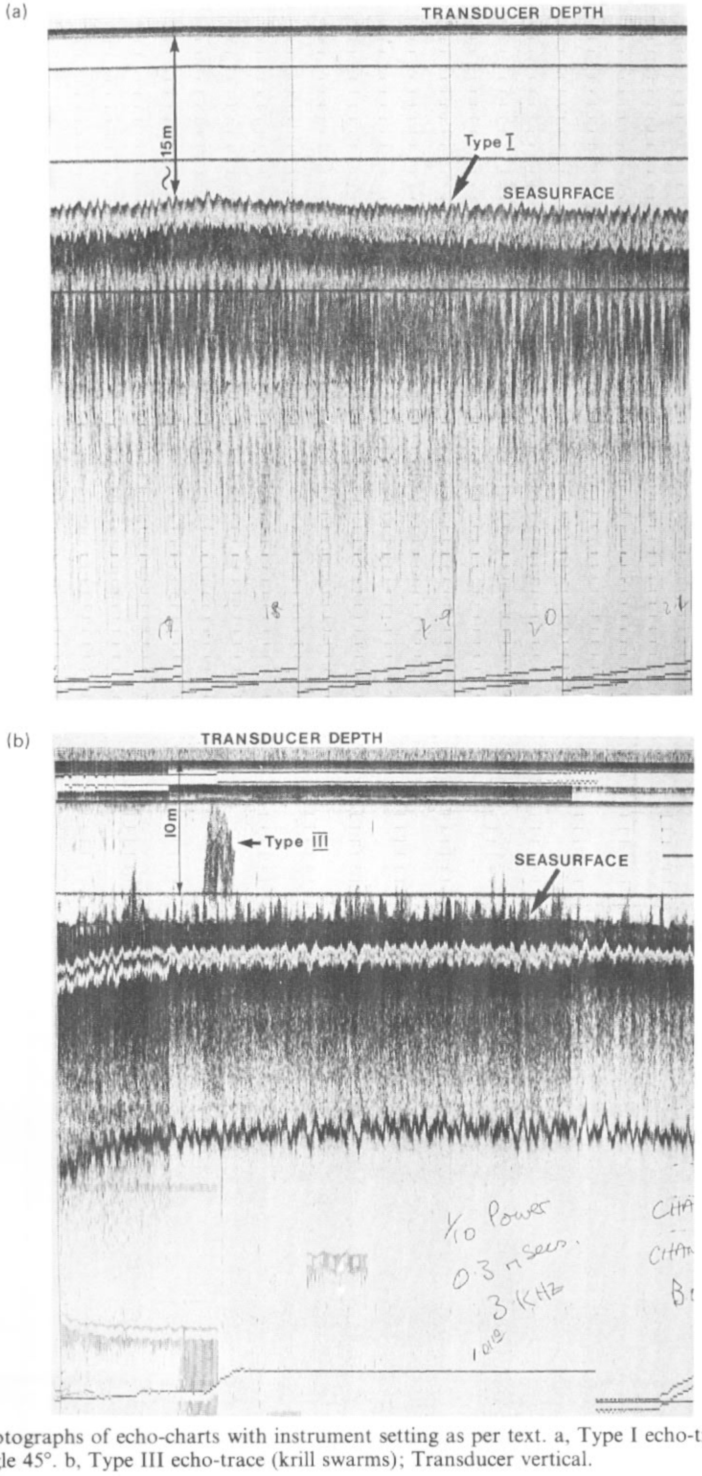

Fig. 2. Photographs of echo-charts with instrument setting as per text. a, Type I echo-trace; Transducer angle 45°. b, Type III echo-trace (krill swarms); Transducer vertical.

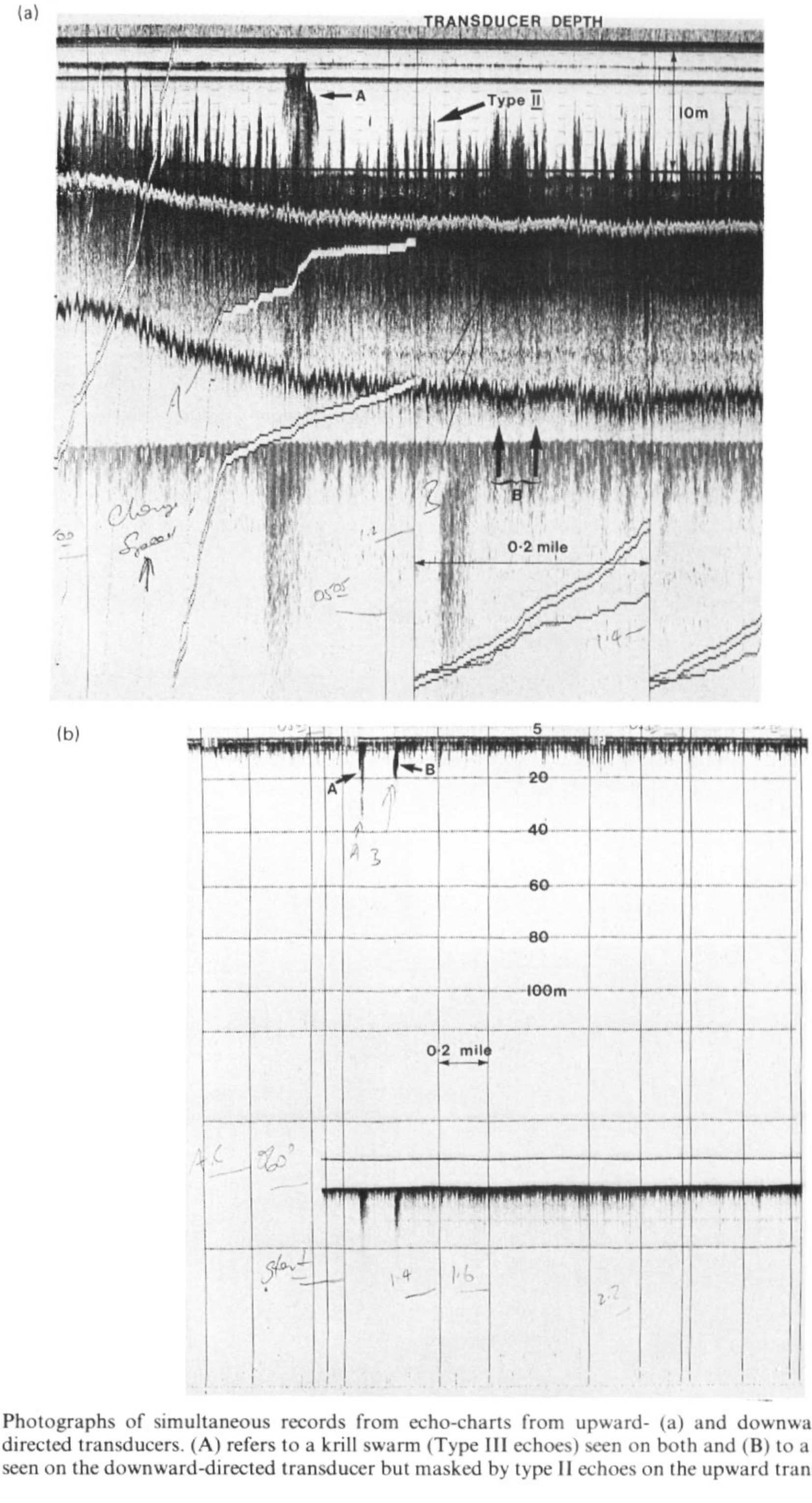

Fig. 3. Photographs of simultaneous records from echo-charts from upward- (a) and downward- (b) directed transducers. (A) refers to a krill swarm (Type III echoes) seen on both and (B) to a swarm seen on the downward-directed transducer but masked by type II echoes on the upward transducer.

Table I. Height of Type II echoes relative to wind speed and observed wave height. Values are mean ± one standard deviation.

| *Transducer configuration* | *Number of acoustic runs* | *Number of 0.2-mile intervals* | *Type II height (m) (range)* | *Wind speed (knots)* | *Observed wave height (m)* |
|---|---|---|---|---|---|
| 45° | 37 | 390 | 1.89 ± 2.60<br>(0–9.28) | 18.5 ± 7.67 | 2.05 ± 0.95 |
| Vertical | 20 | 222 | 4.54 ± 2.16<br>(1.48 – 8.67) | 18.8 ± 7.52 | 1.85 ± 0.88 |
| All | 57 | 612 | 2.82 ± 2.75 | 18.6 ± 7.55 | 1.98 ± 0.92 |

affect the sub-surface bubble layer and cause significant attenuation of signals from downward directed transducers. The same effect is likely to cause confusing signals [illegible] upward directed transducers and is probably the cause of the Type II echoes. It is clear from comparison of echo-charts with net catches that Type II echoes are not caused by krill. They do however mask echo-traces from krill swarms and the conditions under which they occur have therefore been examined.

For each 0.2-miles interval, the extent of the greatest Type II echo-trace has been measured and a mean value of all estimates during a particular 'acoustic run' made. Summary statistics, after grouping the mean values into the categories based on the transducer configuration, are set out in Table I. Even though there was no significant difference in the wind and sea-state, there is a highly significant difference in the mean size of Type II echoes ($t = 3.95$ $P < 0.001$). This difference must therefore have been due to the transducer configuration. The transducer when directed away from the ship and upwards at 45° is less likely to receive echoes resulting either from the ship's bow wave or the towing cable and this may explain the difference. All the data were collected during net hauls with the vessel proceeding at constant speed into the wind. While this would generally mean that the ship would also be heading into the waves this would not always necessarily apply. Unfortunately, wave direction relative to ship's heading was not monitored sufficiently to be able to draw any conclusions. With the transducer directed at 45° the frequency distribution of the size of Type II echoes is bimodal. Thirty-three of the mean values are less than 4.1 while the remaining four are all greater than 8. The magnitude of the high values is similar to those when the transducer was vertical. This may indicate that the high values were a result of the [illegible]-state causing the bow wave to effect the Type II echoes. If these four high values are excluded then there is a reasonably good relationship between Type II marks and windspeed and wave height (Fig. 4).

During the cruise, very few krill were caught at the surface. Catches of krill were accompanied by the occurrence of coincident Type III echoes. The catches from the frame net could not be precisely allocated to Type III echoes because the tow only provides a mean value of krill density within which a swarm had been sampled. The pumped sampler, providing continuous samples, gave a much more precise estimate of swarm location and these matched the timing of Type III echoes observed on the echo-chart.

Type III echoes characteristically were of greater horizontal extent than Type II echoes and often had a greater density near to the transducer. In some cases the same swarm was seen by both the downwardly directed hull-mounted transducer and upwardly directed towed transducer (Fig. 3). This was not always the case because

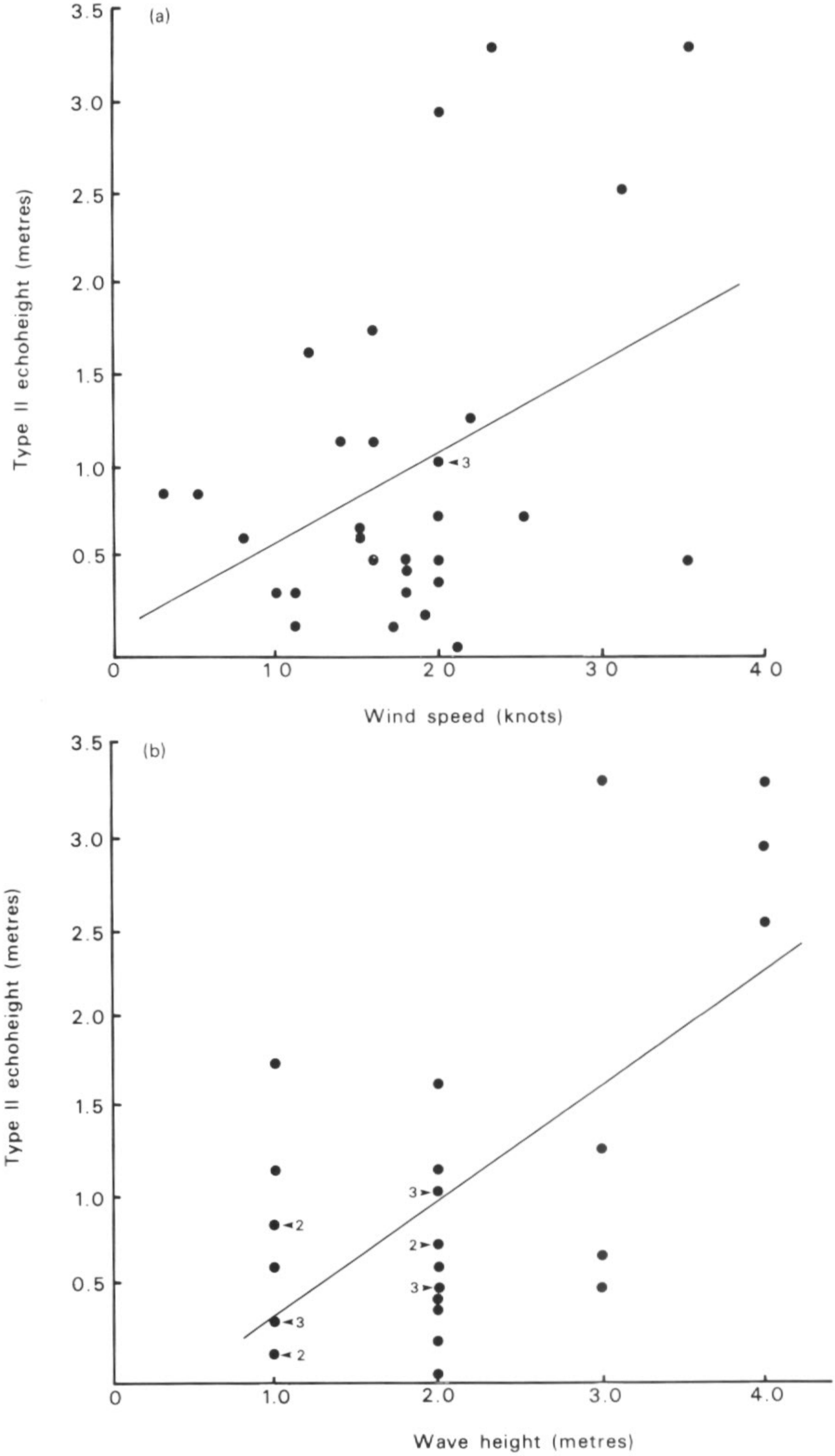

Fig. 4. Graphs of Type II echo-trace height with respect to wind speed (a) and wave height (b). Regression lines, fitted by the method of least squares are. Type II height = 0.071 + 0.050 wind speed; $t = 2.42$, $n = 32$, $r^2 = 0.135$. Type II height = 0.327 + 0.648 wave height; $t = 4.86$, $n = 32$, $r^2 = 0.422$.

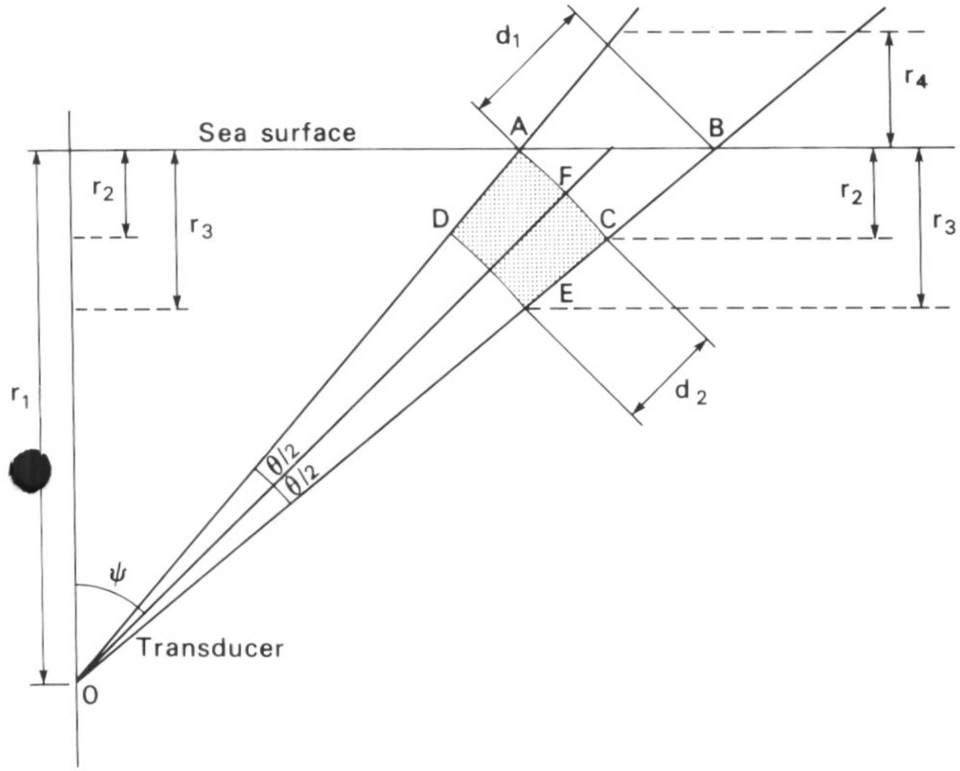

Fig. 5. Theoretical configuration for an angled upwardly directed transducer.

of the differing depths sampled by the two transducers and also because the lines sampled, although parallel, are separated by about 8 metres (half the beam of the ship plus the length of the towing boom). What is more serious is that some near-surface swarms are masked by the Type II echoes (Fig. 3a).

## Discussion

Subject to the limitation caused by the presence of Type II echoes, the upwardly directed transducer can be used to detect krill swarms near to the surface. The precise cause of the Type II echoes is not known but it seems most likely to be due to the sea-state and to be exaggerated by the bow wave. Ideally, the towed body should be towed from as far forward as possible so that it is ahead of the bow wave. But, the further forward the towing point, the greater the vertical movement due to the ship pitching. This would be offset to some extent because the further forward the less the outreach necessary to clear the bow wave and this would reduce the extent of vertical movement of the towed body due to the ship rolling. During these trials the vessel was proceeding slowly into the wind so pitching was the dominant component. A towing point just forward of the centre of buoyancy was therefore selected. From this position the transducer must be directed up and away from the ship in order to sample water unaffected by the bow wave. Setting the transducer at an angle has important implications in its effectiveness for sampling very close to the surface.

*Theoretical implications*

The geometry of an upward-directed transducer is shown in Fig. 5. For an echo-sounder transducer at point 'O' oriented with its beam axis $\psi^\circ$ from the vertical the extent of the dead zones is as follows:

$r_1$ = depth of transducer from the surface
$r_2$ = 'dead zone' due to deviation ($\psi^\circ$) of transducer beam axis from vertical
$r_3$ = 'dead zone' due to pulse length
$r_4$ = 'dead zone' due to waves
$d_1$ = 'dead zone' of beam due to transducer grazing angle
$d_2$ = half pulse length = $c\tau/2$
$c$ = speed of acoustic wave propagation
$\tau$ = duration of pulse
$\theta$ = transducer beam angle

From simple trigonometry

$$r_2 = r_1 - (\cos(\psi + \theta/2) \times \mathrm{OC}),$$

and since

$$\mathrm{OC} = \mathrm{OA} = \sec(\psi - \theta/2) \times r_1,$$

then

$$r_2 = r_1 - (\cos(\psi + \theta/2)) \sec(\psi - \theta/2)\, r_1). \qquad (1)$$

Also

$$\mathrm{AD} = \mathrm{CE} = c\tau/2 = d_2,$$

$$r_3 = r_1 - (\cos(\psi + \theta/2))\, \mathrm{OE},$$

and since

$$\mathrm{OE} = \mathrm{OD} = \mathrm{OA} - d_2,$$

then

$$r_3 = r_1 - (\cos(\psi + \theta/2))((\sec(\psi - \theta/2)\, r_1 - (c\tau/2)).$$

Except when $\theta/2 > \psi$.

The equation $r_3 = r_1(1 - \cos\theta/2) + (c\tau/2)$ (Johanneson and Mitson, 1983) then applies. Since $r_2$ is representative of an infinitely short pulse it will always be shorter than $r_3$.

Some examples of the extent of the dead zone are given in Fig. 6. Grazing angle $(90 - \psi)^\circ$ and pulse duration are both clearly important. The smallest values being with the steepest grazing angle and shortest pulse duration. Of the grazing angles used in this study, 45° was found most effective, presumably due to the bow wave as mentioned above. Reducing the pulse duration, unless accompanied by an increase in receiver bandwidth, reduces the detection threshold of the system. For a 0.1 ms pulse duration the bandwidth would need to be at least 10 kHz (Urick, 1975).

The calculated values of the dead zone in Fig. 6 are all for a constant transdu[illegible] beam angle of 10°. For a transducer at 10 metres and with a grazing angle of 45°, $r_2$ varies from 0.8 m with a beam angle of 5° to 3 m with a beam angle of 20° (Equation 1). Minimizing $r_2$ can therefore only be achieved by minimizing pulse duration and beam angle.

The value of $r_4$ will depend on the wave height and also on the form of the waves. Long swell waves whose wavelength is appreciably longer than the ship length are likely to have little affect. Waves of short length are likely to affect surface echoes by at least their amplitude. The degree of surface reflection will depend on the angle of the wave front relative to the transducer beam axis; since surface waves are generally complex it is impossible to predict what effect they will have. It seems certain however that the dead zone due to surface waves ($r_4$ in Fig. 5) must equal the wave height. The dead zone will therefore equal $r_4 + r_3$. In practice this means that the length of the surface echo will increase and become more diffuse as the sea-state becomes rougher.

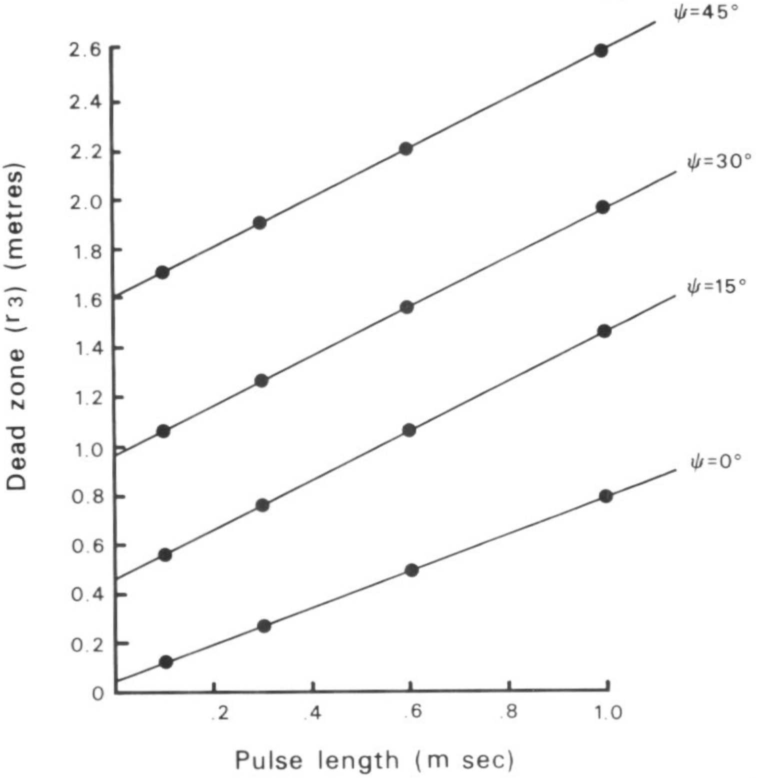

Fig. 6. Graph showing the theoretical dead zone for an upwardly directed transducer mounted at different angles ψ from the vertical.

*Practical considerations*

The theoretical appraisal along with the field results demonstrate that krill swarms can be detected close to the sea surface. However, many surface-feeding birds such as Albatross are unable to catch krill deeper than one metre from the surface (J. P. Croxhall, pers. comm.). The only way that krill swarms can be detected so close to the surface is by minimizing the pulse duration and transducer beam angle. The pulse duration can be reduced and providing the question is one of krill detection and not quantification this would be acceptable. Reducing the transducer beam angle is also possible but requires that the towed body is very stable at the towing speed. The tilt sensors in the towed body indicated that it was sufficiently stable to allow transducers of much narrower angle 10° to function well. This is being considered for future studies. While the presence of swarms at a depth of a few metres may indicate that krill are also right at the surface (Fig. 4) this is not necessarily the case. We have observed surface discolouration due to krill swarms but surface feeding birds such as Cape Pigeon (*Daption capensis*) and Antarctic Tern (*Sterna vittata*) were not observed feeding until the swarm had been disrupted by the ship's propeller, thus, initially, the krill could not have been right at the surface.

Quantification of krill near to the surface presents additional problems. Forward scattering from the sea surface of signals from the angled transducer and multi-directional scattering generally from the sea surface mean that clearly defined surface echoes are rarely obtained. As a result, the echo-sounder bottom pulse reference generator is not triggered in a consistent manner. This means that it is not practical to set echo-integrator intervals close to the surface, which, in turn, means that, although swarms may be detected close to the surface, they may not necessarily be quantified.

A further practical problem arises in that for quantitative estimates the ventral or ventro-lateral aspect target strength (TS) must be used. These are likely to differ from the dorsal aspect TS but it is not known by how much. In fish the difference can be significant (Foote, 1980) and the same has been suggested for krill (Everson, 1982).

For transducers directed vertically upwards, the same factors associated with tilt angle will apply so that, from a knowledge of krill behaviour, a mean TS may be computed. For transducers directed towards the surface at an angle the situation is more complicated. TS will then depend not only on the krill orientation relative to the vertical but also on their orientation horizontally relative to the direction of traverse of the transducer beam. This is adding a virtually unquantifiable additional variable to those necessary for determining TS. Quantitative estimates of krill abundance using angled upward transducers must therefore for the time being be considered of low precision and accuracy.

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