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Richard K. Johnson

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The mesopelagic animals which are most often detected acoustically are those which contain gas bubbles within their bodies. In the waters off the Oregon coast, the most abundant animals which contain gas bubbles are myctophids. Both the size and the shape of the bubble are important to acoustic measurements. This report summarizes the available information on the acoustically important characteristics of the most abundant myctophids: Stenobrachius leucopsarus, Diaphis theta, Tarletonbeania crenularis, and Protomyctophum

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thompsoni and crockeri.

GAS BUBBLE SIZES FOR SELECTED MYCTOPHIDS*

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Reference 79-6
April 1979

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INTRODUCTION

The mesopelagic animals which are most often detected acoustically are those which contain gas bubbles within their bodies. In the waters off the Oregon coast, the most abundant animals which contain gas bubbles are myctophids. This report summarizes the available information on the acoustically important characteristics of the most abundant myctophids: *Stenobrachius leucopsarus*, *Diaphis theta*, *Tarletonbeania crenularis*, and *Protomyctophum thompsoni* and *crockeri*.

The theory for the scattering of sound by a fish with a gas bubble is given by Clay and Medwin (1977). Both the size and the shape of the bubble are important. These features are usually expressed as the radius of a sphere having the same volume as the bubble and as the eccentricity of the bubble.

METHODS

There is currently no completely satisfactory way to determine the size of myctophid gas bubbles. The methods are either inaccurate or cumbersome or both. On the other hand, it is quite easy to measure the standard length of a fish. Consequently, many investigators have attempted to find a relation between gas bubble size and fish standard length.

A common assumption in the literature is that the bubble volume should be 5% of the fish volume so that the fish will be neutrally buoyant. The argument is apparently based upon a statement by Taylor (1921): "The specific gravity of the fat-free substance of salt-water fish (including backbone but not the head or viscera) can be shown to be 1.076." He does not elaborate.

The general relation for neutral buoyancy is

$$\frac{\rho_{fish} * V_{fish} + \rho_{gas} * V_{gas}}{V_{fish} + V_{gas}} = \rho_{sea}$$

or

$$\frac{V_{gas}}{V_{fish}} = \frac{\rho_{fish} - \rho_{sea}}{\rho_{sea} - \rho_{gas}} .$$

The details of computation involve the effects of temperature and pressure, but a reasonable case would be with ρ_{sea} = 1.026 and ρ_{gas} = 0.002. Consequently, the gas volume should be about 5% of the fish volume if the specific gravity of the fish is 1.076. The predicted volume fractions for other fish specific gravities are shown in Figure 1. Our measurements of fresh specimens (with any gas bubbles removed) indicate that the ranges of specific gravity are 1.015 to 1.025 for <u>S. leucopsarus</u>, 1.025 to 1.045 for <u>D. theta</u>, 1.045 to

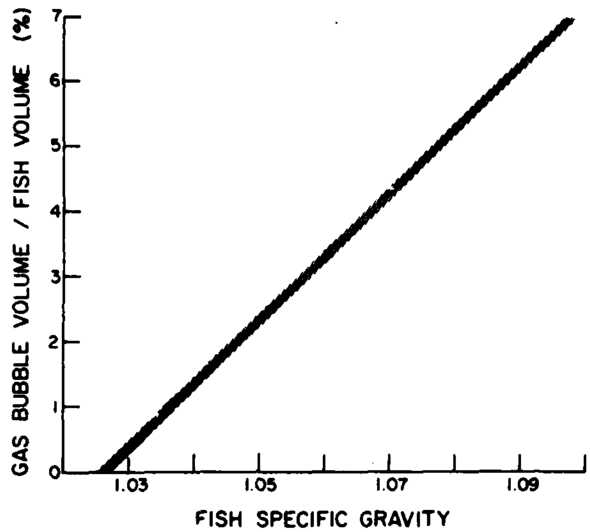

Figure 1. The ratio of gas bubble volume to fish volume that is predicted for neutral buoyancy increases with the density of the fish. The density of the medium is 1.025 to 1.027.

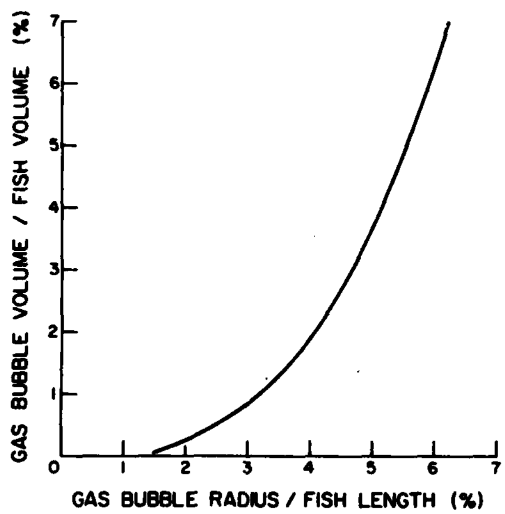

Figure 2. Calculated relationships between bubble volume fraction and bubble radius fraction for the myctophids.

1.065 for P. thompsoni and 1.055 to 1.08 for T. crenularis. (The fishes with specific gravities less than that of water were captured at about 500 m. Presumably they are compressible enough that they are nearly neutrally buoyant when at depth.) From these specific gravities, we would predict bubble volumes from 0 to 6% of the fish volumes. Swimbladder measurements (Brooks, 1976; Capen, 1967; Butler and Pearcy, 1976) have typically indicated volume fractions of 3% or less.

The volume fraction is, of course, not the same number as the ratio of bubble radius to fish length. To determine this ratio it is necessary to have a relation between fish length and fish volume. We have determined empirically that these myctophids are shaped such that the fish volume is equal to the volume of a sphere with radius equal to 15% of the fish length. Using this factor, the bubble radius fraction can be calculated from the bubble volume fraction (Fig. 2).

A popular method to measure gas bubble size is to dissect the fish and measure its bladder with an optical microsope (Capen, 1967; Brooks, 1976). This method does provide a direct, relatively easy measurement of shape as well as size. However, the dimensions of the gasbladder can change when the fish is cut open both from restraint removal and from stretching. Moreover the outside of the bladder is measured and in some species, the outside can be significantly larger than the gas volume.

A similar method which could be more accurate is to determine bladder size from x-ray photographs of the fish (Sand and Hawkins, 1973). The disadvantage of this method is, of course, the amount of equipment involved.

Kanwisher and Ebeling (1957) and Shearer (1970) used pressure chambers to measure gas bubble volumes. This technique is appealing because it does not disturb the bladder, and it offers the potential of determining whether the gas is at greater than ambient pressure. Unfortunately, the compliance of small gas bubbles is typically no larger than the compliance of the pressure chamber. Consequently, accurate measurements of the microliter myctophid gas bubbles are difficult.

We have made measurements using a gas pipette. The bladder is punctured under an inverted funnel which guides the released bubble into a pipette in which the bubble volume is measured. This technique is simple, but there is a potential problem that gas can be gained from or lost to the body cavity.

Table 1. Gas bubble occurrence and size.

Fish	Fraction[1]	Radius[2] mm	Eccentricity[3]
SL	39/138	0.7±0.2	
DT	61/109	1.0±0.2	2.2±0.5
TC	13/25	1.2±0.2	1.9±0.15
PT	44/51	2.0±0.5	

[1]Number of fish releasing gas/number of fish examined in puncture test.

[2]Mean ±1 standard deviation. These values are gas bubble radii for SL, TC and PT; swimbladder radii for DT.

[3]Major axis/minor axis of the outside of the bladder.

RESULTS

The most abundant midwater fishes with gas filled swimbladders in our area are the myctophids: *Stenobrachius leucopsarus*, *Diaphis theta*, *Tarletonbeania crenularis* and, to a lesser extent, *Protomyctophum thompsoni* and *crockeri*. In order to determine the proportion of fishes in these species that have gas in their swimbladders, a number of them were punctured under water and the release of a gas bubble was noted. The results of these tests are listed in Table 1. It is possible that some animals lost their gas before being tested; therefore these fractions may be underestimates.

S. leucopsarus

The most abundant lanternfish in our collection is *S. leucopsarus*. It has a large swimbladder which is frequently fat invested and containing little or no gas. Small *S. leucopsarus* are more likely to contain gas than big ones as shown in Figure 3. The volume of gas present is usually less than 4 μl. There may be a small increase of bubble radius with fish length (Fig. 4).

D. theta

The equivalent radii of 25 *D. theta* swimbladders measured under a microscope are shown in Figure 5. There is a plausible regression of radius on standard length. The bladders frequently contain tissue and/or fluid, so the gas volume would be smaller than is indicated by these radii. Gas collection is difficult because of the rubbery character of the bladder.

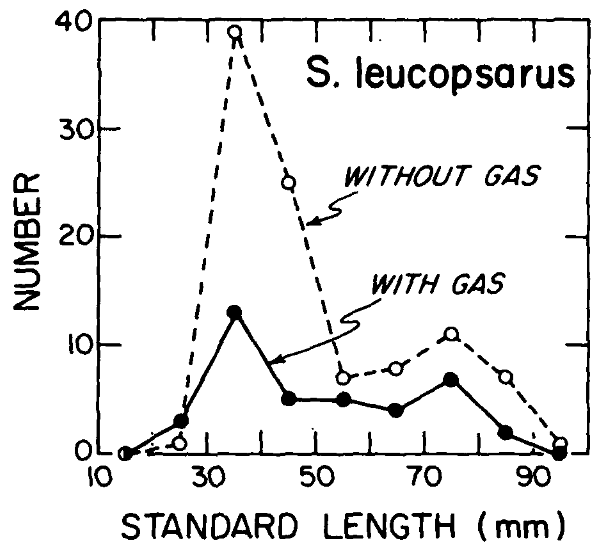

Figure 3. Relative abundances by standard length of S. leucopsarus with (•) and without (o) gas in their swimbladders. Gas is found in about 75% of those with SL < 30 mm and about 30% of those with SL > 30 mm.

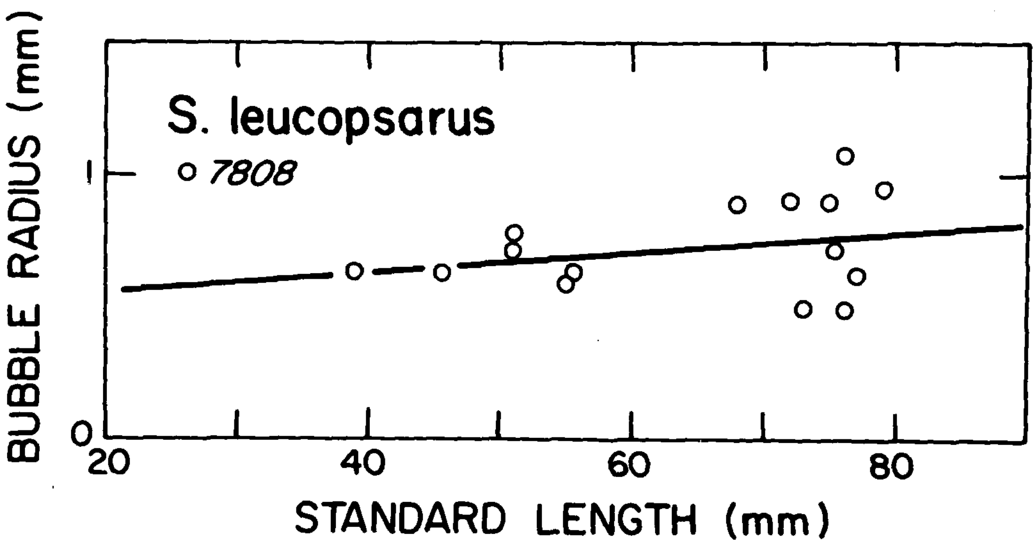

Figure 4. Regression of equivalent bubble radius on standard length for S. leucopsarus. The radii are calculated from gas collected. The values are listed in Table 3. The regression is in Table 2.

Table 2. Regressions of gas bubble radius (SL,TC,PT) or swimbladder radius (DT) on fish standard length together with the number of points and ranges of values used for the regressions.

Fish	Regression	R^2	N	SL mm	R mm
SL	0.48+0.004SL	.10	14	39-79	0.5-1.1
DT	-0.07+0.02SL	.87	25	37-66	0.7-1.7
TC	-0.31+0.04SL	.92	32	25-77	0.6-2.9
PT	0.67+0.03SL	.29	28	29-52	1.3-2.9

Table 3. S. leucopsarus data for fishes containing gas.

Standard Length (mm)	Volume (µl)	Radius (mm)
39	1.0	.62
46	1.0	.62
51	1.5	.71
51	2.0	.78
55	0.8	.58
56	1.0	.62
68	3.0	.89
72	3.0	.89
73	0.5	.49
75	3.0	.89
76	1.5	.71
76	5.5	1.10
77	1.0	.62
79	3.5	.94

Cruise 7808, Bruce Mundy, gas collections

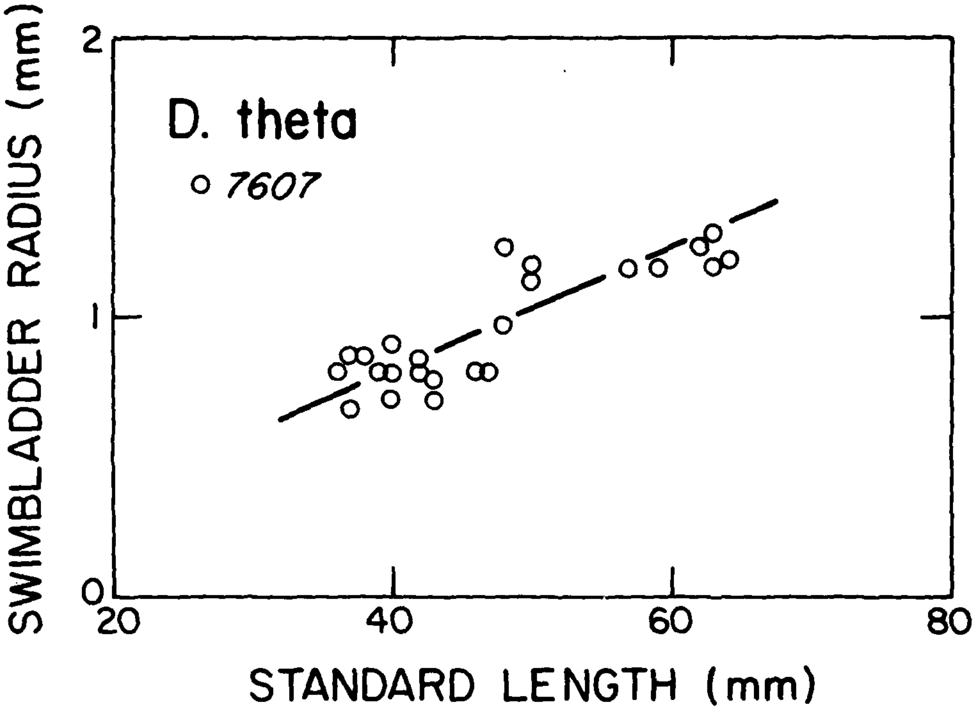

Figure 5. Regression of equivalent swimbladder radius on standard length for D. theta. The radii are calculated from microscopic measurements. The values are listed in Table 4.

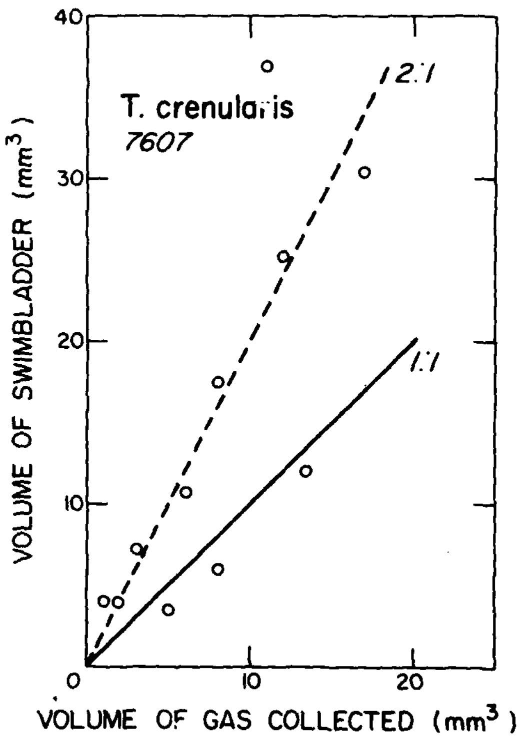

Figure 6. The gas bladder volumes calculated from microscopic measurements of T. crenularis were often twice as large as the volume of gas collected.

Table 4. *D. theta* data for fishes with intact swimbladders.

Standard Length (mm)	Volume (μl)	Radius (mm)
36	2.1	.80
37	1.3	.67
37	2.6	.86
38	2.6	.86
39	3.1	.91
39	2.3	.82
40	1.5	.71
40	2.0	.79
40	2.8	.88
42	2.4	.83
42	2.1	.80
43	1.4	.70
43	1.8	.76
46	2.2	.81
46	2.2	.80
47	3.9	.98
48	8.2	1.25
50	6.6	1.16
50	6.0	1.13
57	6.7	1.17
59	6.7	1.17
62	8.3	1.26
63	6.7	1.17
63	9.2	1.30
64	7.2	1.20

Cruise 7607, Tom Keffer, microscope

T. crenularis

Gas bladder volumes for 11 *T. crenularis* were measured both with a gas pipette and with a microscope. As shown in Figure 6, the microscope measurements typically give twice the volume of the pipette measurements. The microscope measurements could be in error if the bladder is not gas-filled. The pipette measurements could be in error if all of the gas is not collected. The regression of equivalent radius (determined by pipette) on standard length is shown in Figure 7.

P. thompsoni

The equivalent radii determined by pipette are shown in Figure 8. There is little evidence for a correlation of radius with standard length. It may be seen by comparing Figure 8 with Figures 4, 5 and 7, that *P. thompsoni* has the largest swimbladder for a given standard length.

Our bubble results are summarized in Tables 1 and 2. With the exception *P. thompsoni*, the order of species by bubble radius is the same as their order by specific gravity.

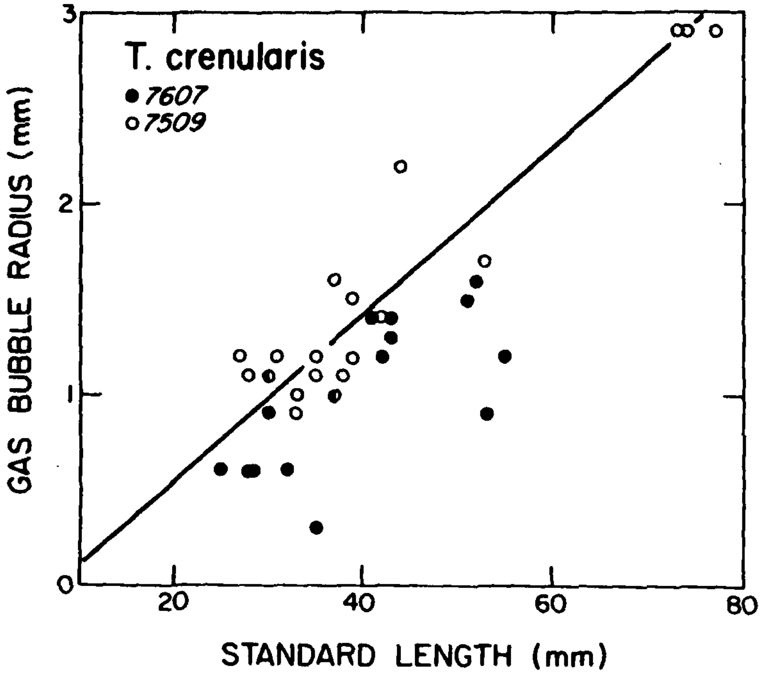

Figure 7. Regression of equivalent gasbubble radius on standard length for T. crenularis. The radii are calculated from gas collected. The values are listed in Table 5.

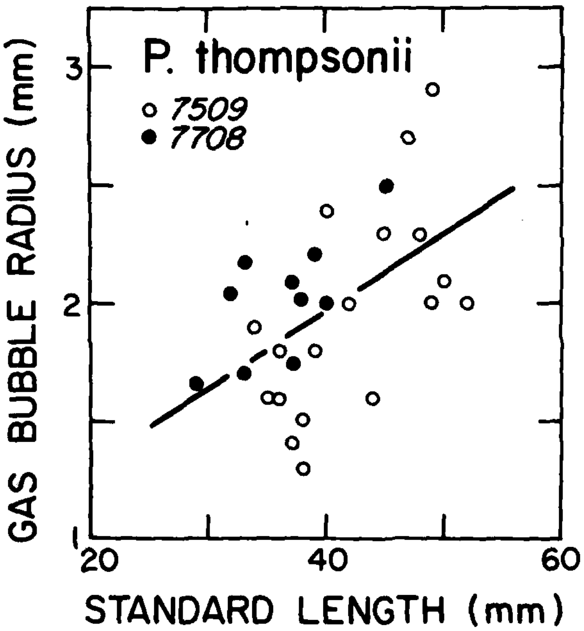

Figure 8. Regression of equivalent gasbubble radius on standard length for P. thompsoni. The radii are calculated from gas collected. The values are listed in Table 6.

Table 5. T. crenularis data for fishes containing gas.

Standard Length (mm)	Volume (μl)	Radius (mm)	Cruise
25	.8	0.6	6
27	6.4	1.2	5
28	1.0	0.6	6
28	1.0	6.6	6
28	5.0	1.1	6
30	3.0	0.9	6
30	6.0	1.1	6
30	6.0	1.1	5
31	7.0	1.2	5
32	0.7	0.6	6
33	3.0	0.9	5
33	4.0	1.0	5
35	5.8	1.1	5
35	7.0	1.2	5
37	4.0	1.0	6
37	4.1	1.0	5
37	17.0	1.6	5
38	6.0	1.1	5
39	7.0	1.2	5
39	14.0	1.5	5
41	12.0	1.4	6
42	12.0	1.4	5
42	12.0	1.4	6
43	10.0	1.3	6
43	11.0	1.4	6
51	13.0	1.5	6
52	17.0	1.6	6
53	21.0	1.7	5
55	8.0	1.2	6
73	100.0	2.9	5
74	100.0	2.9	5
77	100.0	2.9	5

5 7509, Richard Johnson, gas collections

6 7607, Tom Keffer, gas collections

Table 6. P. thompsoni data for fishes containing gas.

Standard Length (mm)	Volume (µl)	Radius (mm)	Cruise
29	19.0	1.7	7
32	36.0	2.0	7
33	21.0	1.7	7
33	43.0	2.2	7
34	27.0	1.9	5
35	18.0	1.6	5
36	17.5	1.6	5
36	25.5	1.8	5
37	11.0	1.4	5
37	22.0	1.7	7
38	9.0	1.3	5
38	15.5	1.5	5
38	35.0	2.0	7
39	23.5	1.8	5
40	33.3	2.0	7
42	32.0	2.0	5
44	18.0	1.6	5
45	52.0	2.3	5
45	65.0	2.5	7
49	34.0	2.0	5

5 7509, Richard Johnson, gas collections

7 7708, Richard Johnson, gas collections

SIZE DISTRIBUTIONS

The size distributions of the most abundant myctophids caught in our 65 m^2 midwater trawl during July, 1976 and 1977 are presented in Fig. 9. Most of the individuals for all these species have lengths between 20 and 80 mm. We do not know whether fishes of these species with lengths outside of the range are not present or just not captured by our net. It is possible that the peaks are indications of age classes.

Since the fraction of individuals containing gas bubbles varies with species, the relative abundance of fishes (Fig. 9) is not the same as the relative abundance of gas bubbles. Using the fish length distributions (Fig. 9) together with the bubble radius - fish length regressions and the fractional occurrences (Tables 1 and 2), it is possible to construct an approximate graph of the relative abundances of the bubble radii by species (Fig. 10). On this basis, the S. leucopsarus, D. theta and the Protomyctophum species can be sorted out by bubble radius, which means that they can be sorted by resonant frequency.

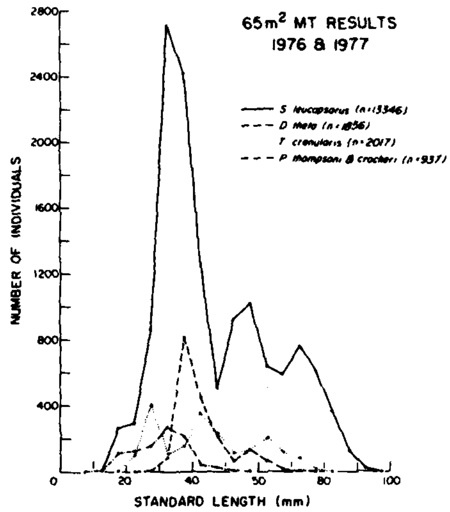

Figure 9. Relative abundance by standard length of the common myctophids are based on 65 m^2 midwater trawl samples. The species shown are S. leucopsarus (-), D. theta (--), T. crenularis (...) and P. thompsoni and crockeri (-.-). The sampled volume was about $10^7 m^3$.

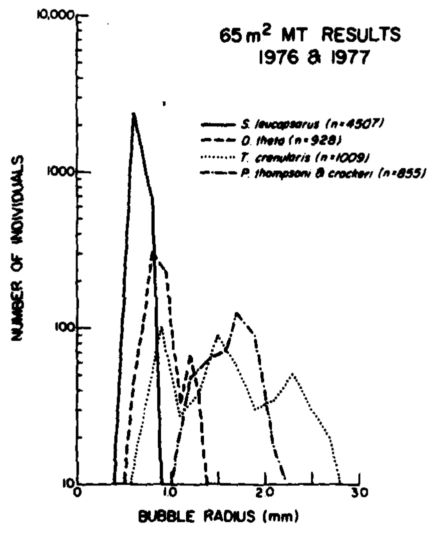

Figure 10. Relative abundance by gas bubble radius S. leucopsarus (-), D. theta (--), T. crenularis (...), and P. species (-.-).

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