# ESCAPEMENT BY FISHES FROM MIDWATER TRAWLS: A CASE STUDY USING LANTERNFISHES (PISCES: MYCTOPHIDAE)

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## ABSTRACT

Escapement of fishes through the meshes of a trawl is a recognized but unquantified problem in estimating size of mesopelagic fish populations. This paper provides estimates of net escapement by midwater fishes, using the lanternfishes as an example. Comparison of overall catches for Tucker trawls of 1.6 mm and 4.0 mm mesh show highly significant differences. The small mesh size outcaught the large by a factor of 2.7 for fishes smaller than 30 mm SL, while for larger fishes, the small mesh catches averaged 90% of the larger mesh. Among six ranking abundant species, three patterns of escapement were observed, based on significant differences in cross-sectional fish dimensions and morphological characters: 1) The entire size range of the species was significantly underestimated (*Benthosema suborbitale* and *Notolychnus valdiviae*); 2) only size ranges below those of sexually mature adults were significantly underestimated (*Lampanyctus alatus* and *Lepidophanes guentheri*); 3) only juveniles <30 mm SL were significantly underestimated (*Ceratoscopelus townsendi* and *Diaphus dumerilii*). "Conventional" midwater trawl meshes of 4 to 6 mm diameter mesh provide adequate data for general distributional surveys and also for some quantitative estimations such as overall biomass. Determinations of juvenile biomass, spawning period, trophic impact, and relative species abundances based on conventional mesh collections may be prone to substantial error depending on species size. It is suggested that a net mesh of <2 mm be used in conjunction with larger mesh trawls if quantitative life history data on smaller size classes and species are required.

Requisite to studies of the roles of mesopelagic fishes in deep-sea ecological processes are accurate determinations of species composition and the vertical and horizontal structure of populations. Although these are now well documented for many groups in many regions of the world ocean (see Marshall 1980), accurate abundance estimates, particularly over the entire size range of a species, are often not possible because of sampling biases related to net construction and trawling methods (Stein 1985).

Two factors responsible for much of the difficulty in estimating abundance of midwater fishes are net avoidance by large size classes and escapement through the net meshes during capture by small fishes of slender body shapes (Harrisson 1967). Both result in underestimates of species abundance, which can apply to either particular size classes, or, in the case of diminutive species, an entire population.

While some studies show that net avoidance may be reduced through the use of trawls with large mouth areas, there are a number of attendant difficulties including enhanced escapement due to increased mesh size (Stein 1985). Of the two problems, net avoidance remains the most difficult to quantify. Escapement is more easily calculated, but little quantitative research has been directed towards this problem in studies of midwater fishes (Harrisson 1967; Clarke 1983a).

In this study we quantify escapement through net meshes of midwater trawls using the lanternfishes (family Myctophidae) as an example. The ecological implications of net escapement are discussed.

## MATERIALS AND METHODS

Myctophids were collected during eight cruises aboard the RV *Suncoaster* from an area centered at lat. 27°N, long. 86°W. The cruises covered four seasons over a period of 30 months. Sampling months were September (1984), November (1985), January (1986, 1987), March (1985, 1987), May (1986), and July (1985). Station data are presented in Table 1.

All samples were taken using modified Tucker trawls fished open in an oblique "V" sweep from the surface to 200 m at night. This depth range encompasses the peak nighttime abundance of all

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numerically dominant lanternfish species in the eastern Gulf of Mexico (Gartner et al. 1987). All nets were fished at 1.5 to 2.5 knots with a total fishing duration for each sample of approximately 1 hour. Sampling usually began about 1 hour after sunset and ended 1 hour before sunrise. The bottom trawl bar was weighted to incline the net mouth about 30° from the vertical at these towing speeds (determined from observations using scuba). Two trawl configurations were used: a 5.3 $m^2$ (effective fishing area) net of 4 mm bar mesh in the body and 1 mm mesh in the funnel, and a 2.6 $m^2$ net of 1.6 mm mesh. Both nets had cod ends lined with 505 $\mu$m mesh.

Trawl depths were recorded by mechanical time-depth recorder (TDR) and monitored with an electronic deck readout linked to a transducer mounted on the trawl frame. The volume of water filtered during each net haul was calculated from flow meters mounted on the trawl frame.

Myctophids were fixed in 10% (v:v) formalin and preserved in 50% isopropanol. During all cruises except January and March 1987, a large number of postlarval specimens from the dominant species were removed from the catches for use in life history studies. These were blotted to remove excess moisture and measured to the nearest millimeter standard length (mm SL). The remaining myctophids were measured in the lab after preservation. Because of shrinkage of preserved specimens, the lengths of freshly measured individuals were decreased by 12% (shrinkage factor determined from Gartner, unpub. data; K. J. Sulak pers. commun.[3]). All myctophids were identified to the lowest possible taxon, with species identifications made using Nafpaktitis et al. (1977).

The effect of using nets of differing mouth areas was minimized by calculating the abundance of individuals per $10^4$ $m^3$ for each net over the entire size range, which was then divided into 5 mm SL size classes. Kolmogorov-Smirnov (K-S) two-sample tests (Siegel 1956) were used for overall internet comparisons of capture over the size range by size classes and by net mesh for size groups smaller than 30 mm SL and larger than 30 mm SL. The K-S tests were applied to similar comparisons for each of the ranking myctophid species. Except where noted, the significance level for all tests was $P < 0.01$. Ranking species for all cruises were defined as the most abundant species which combined comprised 75% or more of the total number of specimens captured (Gartner et al. 1987).

To evaluate if escapement was related to body morphology as well as size, measurements of the greatest cross-sectional dimensions were made on a series of preserved specimens of each of the ranking species. Measurements were made to the nearest 0.01 mm using dial calipers on a series of randomly selected individuals which encompassed the postlarval size range of each species. Assuming that myctophids are elliptical in cross section, areas were calculated for each specimen using the formula $\pi ab$, where $a$ and $b$ are the radii of the short and long axes of the ellipse. Cross-sectional areas were regressed against the square of length and tested for significance ($P < 0.01$) among species using a Student's $t$-test (Sokal and Rohlf 1981).

## RESULTS

### Collection Data

The 4 mm mesh net was used at 78 stations, from which 7,861 myctophids were collected with a total volume filtered of $1.65 \times 10^6$ $m^3$ (Table 1). The 1.6 mm mesh net was also used at 78 stations, with totals of 7,494 individuals captured and $8.97 \times 10^5$ $m^3$ filtered (Table 1). The mean ratio of volume filtered for the larger to smaller nets was 1.84:1 (range for all cruises was 1.72:1 to 2.07:1).

TABLE 1.—Collection data.

| Cruise | Number of samples (Volume filtered $10^4$ $m^3$) | | | |
|---|---|---|---|---|
| | 3.2 $m^2$ | 1.6 mm | 6.5 $m^2$ | 4 mm |
| September 1984 | 3 | (3.84) | 3 | (6.42) |
| March 1985 | 14 | (16.94) | 11 | (24.31) |
| July 1985 | 9 | (10.28) | 8 | (17.56) |
| November 1985 | 4 | (4.21) | 17 | (30.92) |
| January 1986 | 10 | (11.85) | 11 | (26.13) |
| May 1986 | 13 | (13.91) | 10 | (20.19) |
| January 1987 | 16 | (18.89) | 7 | (16.32) |
| March 1987 | 9 | (9.82) | 11 | (22.74) |
| Totals | 78 | (89.74) | 78 | (164.59) |

### Abundances by Size Class

The numbers of individuals collected per $10^4$ $m^3$ for both nets are shown in Figure 1. Data for fishes larger than 80 mm SL were not included because only 16 specimens were collected. Catch differences were highly significant between the two mesh sizes ($P < 0.001$). In both nets, the 16 to 20 mm SL size class was most abundant, but the 1.6 mm mesh net

[3]K. J. Sulak, Atlantic Reference Centre, Huntsman Marine Laboratory, St. Andrews, New Brunswick, Canada E0G 2X0, pers. commun. May 1988.

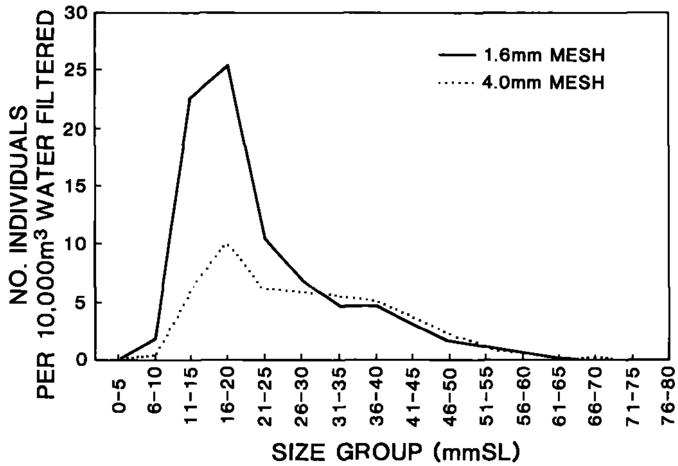


FIGURE 1.—Overall numbers of myctophids collected per $10^4 m^3$ water filtered for the 1.6 mm mesh and 4.0 mm mesh nets.

collected over twice as many specimens as the 4 mm mesh net. Overall, the 1.6 mm mesh net was significantly more effective in collecting individuals of smaller than 30 mm SL with a mean calculated abundance ratio for the 6 to 30 mm size groups of 2.7:1 between the 1.6 mm and 4 mm meshes. The abundance ratios for the small to large mesh sizes is highest for the smallest size group considered (4.4:1 for the 6 to 10 mm SL group).

Although the 4 mm mesh captured more fishes at sizes >30 mm SL, the differences, while significant, were not pronounced and never approached the ratios noted for the smaller size groups. The mean ratio for the 1.6 mm to 4 mm meshes for size groups 31 to 65 mm SL was 0.9:1 (range 0.8:1 to 1.0:1). At sizes larger than 65 mm SL, the ratios were variable owing to small sample sizes.

## Abundances, Cross-Sectional Dimensions and Morphologies of Ranking Species

The same five species made up the ranking myctophids from both nets, although the order of abundance differed (Table 2). A sixth species, *Ceratoscopelus townsendi* (formerly *C. warmingii*, see Badcock and Araújo 1988), was also a dominant myctophid in the 4 mm net catches. Comparisons of internet abundances of ranking species for each size group revealed three basic patterns: 1) Virtually the entire size range was underestimated by the 4 mm mesh net (*Benthosema suborbitale* and *Notolychnus valdiviae*, Fig. 2a, b); 2) only size groups up to sexually mature adults (ca. 40 mm SL) were underestimated by the 4 mm mesh net (*Lampanyctus alatus* and *Lepidophanes guentheri* Fig. 2c, d); and 3) only juveniles smaller than 26 to 30 mm were underestimated by the 4 mm mesh net (*Ceratoscopelus townsendi* and *Diaphus dumerilii* Fig. 2e, f). Of the ranking species, only these last two species were collected in greater numbers by the 4 mm mesh net at sizes larger than 30 mm SL.

The patterns of net capture vs. size ranges were directly related to the general body dimensions and morphologies of the ranking species. Maximum cross-sectional depths and widths were measured on the body at the pectoral fin base in *Benthosema suborbitale*, *Lampanyctus alatus*, *Lepidophanes guentheri*, and *Notolychnus valdiviae*, while for *Ceratoscopelus townsendi* and *Diaphus dumerilii*, the maxima were on the head anterior to the opercular openings. Head profiles also differed among species, with the first four species having pointed or wedge shaped outlines, while the latter two had blunt, rounded heads. Both *N. valdiviae* and *B. suborbitale* (Pattern 1) are diminutive species not exceeding 22 mm and 33 mm, respectively, in the eastern Gulf, while the other four species grow much larger (Gartner et al. 1987; Gartner, unpub. data). Mean cross-sectional measurements (Table 3) show that in relation to body length, *B. suborbitale* is deep bodied, while *N. valdiviae*, *Lepidophanes guentheri*, and *Lampanyctus alatus* (Pattern 2) are all slender. When compared with the previous species at equivalent lengths, *C. townsendi* and *D. dumerilii* (Pattern 3) have generally thick cross-sections.

TABLE 2.—Ranking species of myctophids collected, by net.

| Species | 1.6 mm mesh Rank | No. captured | % of total captured | No./$10^4$ $m^3$ | 4.0 mm mesh Rank | No. captured | % of total captured | No./$10^4$ $m^3$ |
|---|---|---|---|---|---|---|---|---|
| *Notolychnus valdiviae* | 1 | 1,752 | 23.40 | 19.52 | 2 | 1,285 | 16.30 | 7.81 |
| *Diaphus dumerilii* | 2 | 1,317 | 17.60 | 14.68 | 1 | 1,572 | 20.00 | 9.55 |
| *Lampanyctus alatus* | 3 | 895 | 11.90 | 9.98 | 4 | 783 | 10.00 | 4.76 |
| *Lepidophanes guentheri* | 4 | 877 | 11.70 | 9.78 | 3 | 1,039 | 13.20 | 6.31 |
| *Benthosema suborbitale* | 5 | 778 | 10.40 | 8.67 | 6 | 597 | 7.60 | 3.63 |
| *Ceratoscopelus townsendi* | | | | | 5 | 645 | 8.20 | 3.92 |

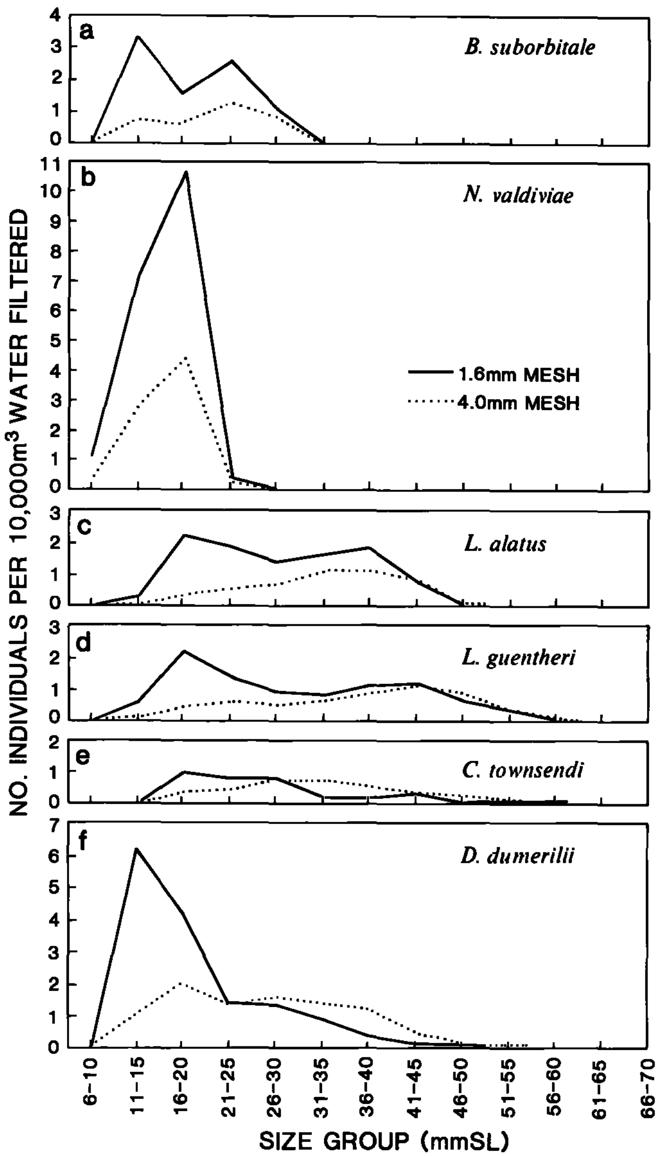


FIGURE 2.a–f.—Numbers of ranking species of myctophids collected per $10^4$ $m^3$ water filtered for the 1.6 mm mesh and 4.0 mm mesh nets.

TABLE 3.—Mean cross-sectional dimensions (mm) and body morphologies for ranking myctophid species by size group. Underline indicates dimensions where number of individuals per $10^4$ $m^3$ filtered are approximately equal between two net meshes (crossover point on Figure 2a–f). D = body depth (mm); W = body width (mm).

| | Species | | | | | |
|---|---|---|---|---|---|---|
| | *Benthosema suborbitale* | *Ceratoscopelus townsendi* | *Diaphus dumerilii* | *Lampanyctus alatus* | *Lepidophanes guentheri* | *Notolychnus valdiviae* |
| Head profile: | Pointed | Blunt | Blunt | Pointed | Pointed | Pointed |
| Body morphology: | Deep | Thick | Thick | Slender | Slender | Slender |
| Size class | D W | D W | D W | D W | D W | D W |
| 8–10 | | | | | | 1.72 × 1.14 |
| 11–15 | 3.05 × 1.43 | | 2.69 × 1.49 | | | 2.06 × 1.42 |
| 16–20 | 4.52 × 2.30 | 3.51 × 1.87 | 3.58 × 1.83 | 3.09 × 1.56 | 2.76 × 1.44 | 2.80 × 1.74 |
| 21–25 | 5.70 × 3.02 | 4.75 × 2.60 | 5.03 × 2.54 | 3.90 × 2.14 | 3.85 × 1.77 | 3.26 × 2.10 |
| 26–30 | 6.41 × 3.34 | 5.74 × 3.34 | 5.95 × 3.03 | 4.85 × 2.45 | 4.76 × 2.36 | |
| 31–35 | 7.40 × 4.02 | 6.43 × 3.82 | 6.78 × 3.66 | 5.89 × 3.01 | 5.88 × 3.08 | |
| 36–40 | | 7.56 × 4.41 | 7.61 × 4.24 | 6.77 × 3.43 | 6.87 × 3.64 | |
| 41–45 | | 8.31 × 5.12 | 8.59 × 4.92 | 7.82 × 4.00 | 7.97 × 4.30 | |
| 46–50 | | 9.21 × 6.14 | 9.59 × 5.71 | 8.35 × 4.18 | 8.27 × 4.43 | |
| 51–55 | | 11.33 × 6.35 | 11.42 × 7.00 | | 9.38 × 5.07 | |
| 56–60 | | 11.75 × 7.46 | 12.57 × 7.88 | | 10.24 × 5.21 | |
| 61–65 | | | | | 10.97 × 5.77 | |

The smallest size at which the 4 mm mesh net showed comparable catches to the 1.6 mm mesh for any ranking species was 23 mm SL (Fig. 2). Regression of cross-sectional areas vs. length for sizes larger than 23 mm clearly grouped the ranking species according to the catch patterns (Fig. 3). Differences between groups were highly significant ($P < 0.001$).

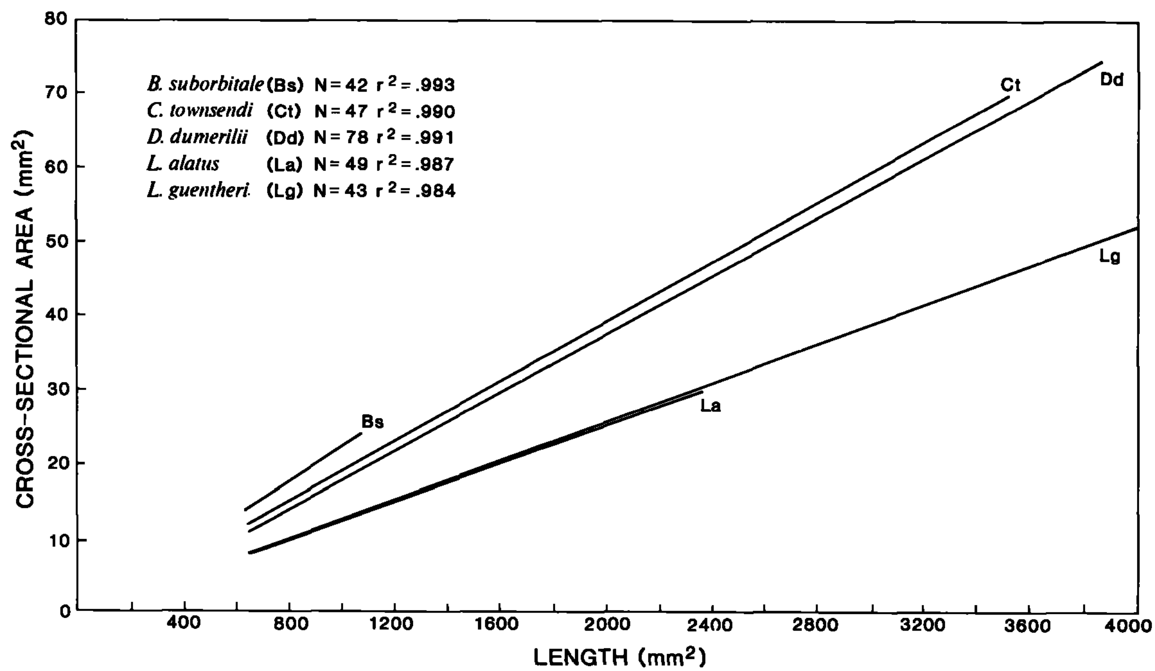


FIGURE 3.—Regressions of body cross-sectional area ($mm^2$) on the square of length for ranking species of myctophids (*Notolychnus valdiviae* excluded).

# DISCUSSION

## Net Escapement: Considerations

In the present study, the extent of bias due to net avoidance is unknown, but our trawling program was designed to minimize the problem as much as possible. All of our samples were taken at night when net avoidance is supposedly mitigated (e.g., Pearcy and Laurs 1966). Observations from submersibles suggest that small fishes (<60 to 70 mm) are not as successful in avoiding nets as are larger ones (B. H. Robison pers. commun.[4]). The myctophid faunas in low latitude ecosystems (upwelling regions excepted) tend towards the small end of the size range (Clarke 1973; Gartner et al. 1987). Also, the detection of nets by mechanical stimuli and the effective mouth area of a net have been suggested to enhance avoidance by midwater fishes (Harrisson 1967; Clarke 1973; Pearcy 1980; Stein 1985). Based on these factors, a smaller catch per unit volume would have been predicted for the 1.6 mm mesh net, which was white and had one-half the effective fishing area of the dark green 4 mm net. However, at size ranges smaller than 30 mm SL, it outcaught the larger mesh net by a factor of 2.7, whereas among larger fishes, it collected 80% to 97% ($\bar{x}$ = 90%) of the number of specimens of the large mesh.

Since the introduction of the Isaacs-Kidd midwater trawl (Isaacs and Kidd 1953), most midwater fish surveys have used gear with a net mesh size of 4 to 6 mm bar length (e.g., Badcock 1970; Hulley 1972; Clarke 1973; Gartner et al. 1987; Karnella 1987). While such gear is necessary for general surveys, our data suggest that they may be inadequate for obtaining certain quantitative estimates for small micronekton because of net escapement. It is clear that underestimates of myctophid abundance are marked in the 4 mm mesh (Figs. 1, 2). These underestimates may apply only to certain size ranges of the population, as in *D. dumerilii* or *L. guentheri*, or may include the entire size spectrum of a species, as in *N. valdiviae*. Similar trends of escapement have been noted among dominant species of sergestid shrimps examined from the same collections used in the present study (M. E. Flock pers. commun.[5]).

Many myctophid species, especially strong vertical migrators, are generally muscular and slender and possess very small teeth. They present a relatively small cross section that does not appear to be effectively retained by the large net meshes until some critical threshold of body thickness is reached. Among species with relatively pointed heads, i.e., those whose maximum body dimensions lie *behind* the head, the ability of large mesh nets to hold individuals is as much a function of the lateral thickness as it is of the dorsoventral dimension of the body. Even though dorsoventral thickness may greatly exceed mesh size, lateral measurements must be close to or exceed the mesh bar length in order for the 4 mm mesh net to sample these species as efficiently as the 1.6 mm mesh net (Table 3, Fig. 3). It appears that until both body axes are equal or greater in size than the mesh diameter, if a "pointed head" fish succeeds in getting its head through the mesh, it can readily escape. In contrast, species with maximum body dimensions *on* the head (blunt heads) show reduced escapement from the large mesh when the dorsoventral aspect alone reaches a critical threshold, i.e., they are not able to push their head through the mesh.

## Implications of Escapement for Ecological Data

Collections of mesopelagic fishes from many regions are now extensive enough to provide a good representation of species composition and distribution, especially with respect to the families Myctophidae and Gonostomatidae (Gjösaeter and Kawaguchi 1980; Hulley 1981; Gartner et al. 1987, Karnella 1987). There has been increasing emphasis on quantitative assessment of various aspects of myctophid ecology, such as population dynamics (J. Gjösaeter 1973a, 1981; Clarke 1983b, 1984; Linkowski 1985; H. Gjösaeter 1987), trophodynamics (Clarke 1978, 1980; Baird and Hopkins 1981a, b; Hopkins and Baird 1981, 1985) and fishery potentials for midwater fish species (Gjösaeter and Kawaguchi 1980). In virtually all of these studies, data from mesh sizes of 4 mm or greater were used.

Our findings indicate that escapement among size classes and species smaller than 30 mm SL is pronounced and that midwater trawls with mesh of <2 mm diameter should be used in order to obtain accurate estimates of fishes in this size range. It is not enough to assume that catch efficiencies are proportional over all size ranges and that some factor can be applied to catches with larger mesh nets to account for escapement. It is clear that some species do appear to have proportional catch rates between

[4]B. H. Robison, Monterey Bay Aquarium Research Institute, 160 Central Avenue, Pacific Grove, CA 93940, pers. commun. June 1988.

[5]M. E. Flock, Department of Marine Science, University of South Florida, 140 Seventh Avenue S.E., St. Petersburg, FL 33701, pers. commun. June 1988.

the two mesh sizes, e.g., *Notolychnus valdiviae*, while others, e.g., *Lampanyctus alatus*, show very different catch rates depending on size group and mesh size (Fig. 2).

Overall biomass values for myctophids from the two mesh sizes are very similar, 19.61 g/$10^4$ $m^3$ (1.6 mm mesh) and 19.22 g/$10^4$ $m^3$ (4.0 mm mesh). This suggests that the larger mesh sizes provide a fairly accurate estimate of overall standing stock of myctophids and allow for interregional data comparisons (Maynard et al. 1975; Hopkins and Lancraft 1984). However, estimates of standing stock for certain size classes would be erroneous, especially for juveniles smaller than 30 mm SL (Fig. 4).

Net escapement by small size classes can also bias quantitative determinations of relative species abundance, spawning period, juvenile recruitment, and trophodynamic impact. *Benthosema suborbitale*, *Ceratoscopelus townsendi* and *Notolychnus valdiviae* are pan-oceanic in tropical-subtropical latitudes and are among the most abundant species throughout their zoogeographic range (Gartner et al. 1987). Based on our calculations, it is likely that *B. suborbitale* and *N. valdiviae* are of much greater numerical importance than previous data sets have suggested (e.g., Clarke 1973; Backus et al. 1977; Hulley 1981; Gartner et al. 1987).

Net escapement can also affect assessment of spawning period. Abundance comparisons for the two nets by cruise for *D. dumerilii* show that if one were to attempt to determine periods of larval recruitment for this species using length frequencies from the 4.0 mm mesh net, there are only suggestions of a spring-early summer spawning period (May 1986, July 1985), whereas the 1.6 mm net catches clearly indicate an early spring through fall influx of newly metamorphosed juveniles (Fig. 5). Using the small mesh net, the birthdays of juveniles for age and growth studies can more readily be fixed.

In trophodynamic studies that have considered the impact of midwater fishes on zooplankton prey, considerable predation pressure has been shown on certain size classes and taxa of zooplankters (Gjösaeter 1973b; Merrett and Roe 1974; Clarke 1978, 1980; Hopkins and Baird 1981, 1985; T. M. Lancraft pers. commun[6]; Hopkins and Gartner unpub. data). It is well documented that ontogenetic changes in prey taxa and size selection occur among myctophids. Our data suggest that predation pressure would be much higher from small size classes or species of myctophids <30 mm SL than could be calculated from studies using larger mesh collection gear.

## CONCLUSIONS

As Harrisson (1967) remarked, no single midwater net will adequately sample all species or size ranges. At high latitudes and in the lower mesopelagic zone where many midwater fish species may attain sizes >100 mm SL, it has been observed that myctophids readily avoid even large midwater trawls (Pearcy

[6]T. M. Lancraft, Department of Marine Science, University of South Florida, 140 Seventh Avenue S.E., St. Petersburg, FL 33701, pers. commun. June 1988.

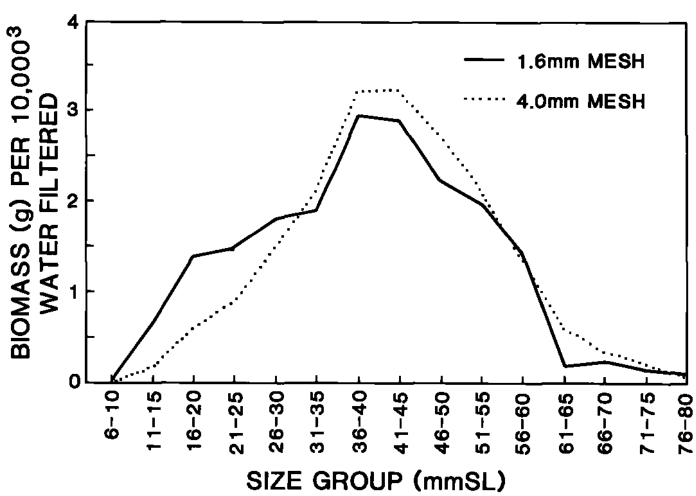


FIGURE 4.—Overall biomass of myctophids per $10^4$ $m^3$ water filtered for the 1.6 mm mesh and 4.0 mm mesh nets.

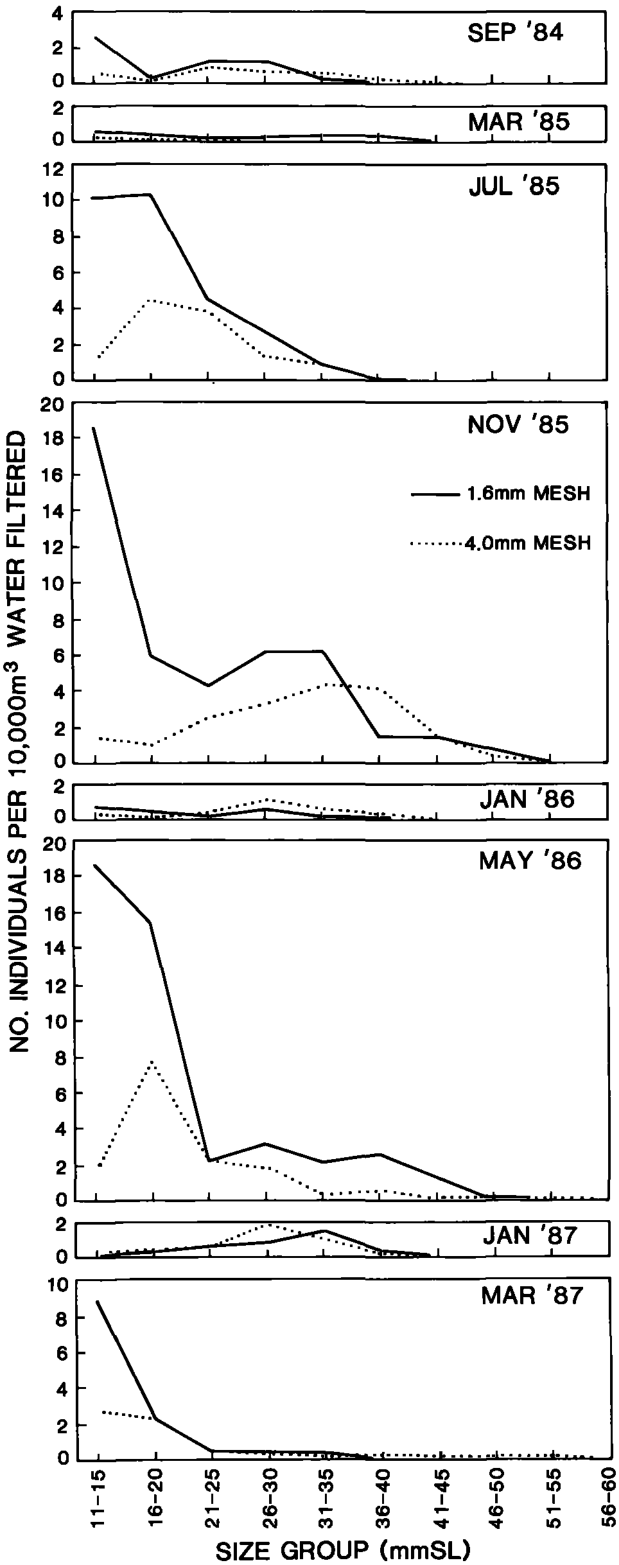


FIGURE 5.—Size frequencies of *Diaphus dumerilii* among collection periods.

and Laurs 1966; B. H. Robison, unpub. data from submersible observations). Our data and those of Clarke (1973) from conventional midwater trawls suggest that avoidance is not a primary concern in lower latitudes which are dominated by small (<70 mm SL) species. In all regions, however, escapement of small size groups and species through meshes is a real problem which until now has not been well quantified.

Future quantitative ecological research on postlarval midwater fishes should use a midwater trawl of mesh size <2 mm in conjunction with larger mesh in order to correct for the effects of net escapement. This ancillary net should ideally be mounted on an identical frame design (although not necessarily identical mouth area) as the large mesh and fished in a similar manner in order to readily facilitate internet comparisons. Should logistic considerations restrict gear use to a single type, our data indicate that the small mesh gear would be more efficient overall for collection of size groups from 10 to approximately 70 mm SL.

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