SOME ASPECTS OF THE ECOLOGY OF STOMIATOID FISHES IN THE PACIFIC OCEAN NEAR HAWAII

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ABSTRACT

Forty-seven species of eight families of stomiatoid fishes were collected in the upper 1,000 m near Hawaii. Most species appear to undertake diurnal vertical migrations; only two definitely did not. Many of the abundant species showed changes in size composition within both day and night depth ranges, the smaller fish occurring shallower. All sizes of several other species appeared to occur throughout their depth ranges. Seasonal changes in the size composition of several species indicated that they spawn principally in the summer. Several species appear to avoid the Isaacs-Kidd trawl better during the day than at night. Some species appeared to avoid the Isaacs-Kidd more than a larger trawl, but many were sampled as well or better by the former. Absence or rarity of mature individuals of several species indicated that the larger fish avoided both trawls.

Relationships between vertical distribution and morphology of some species are proposed, and potential interactions between species are considered relative to the degree of similarity of depth ranges or size-depth patterns.

Stomiatoids are a dominant and diverse group of mesopelagic fishes. Most previous work on the group has been of a systematic or zoogeographic nature, and only recently have the systematics of some families come into order. With the exception of a few works such as Kawaguchi and Marumo (1967) and Krueger and Bond (1972), ecologically pertinent information such as depth ranges, migration habits, etc., has been appended to other studies and is usually based on so few specimens or inappropriate sampling programs that it is of dubious value. Consequently, even for the frequently collected species, little is known of their ecology—especially in comparison to knowledge of the myctophids, another important group of mesopelagic fishes.

This paper considers data on 47 species of stomiatoids collected by a mid-water trawling survey in the central North Pacific near the Hawaiian Islands. (Specimens of the Sternoptychidae and the gonostomatid genus *Cyclothone* are being investigated by other workers, and the systematics of three genera of the Melanostomiatidae are so confused at present that these genera cannot be considered in detail here.) For many species, sufficient numbers were collected to present reliable estimates of depth ranges, migrations, and seasonal changes in size composition. The habits of this diverse group are compared with those of other mesopelagic fishes.

METHODS

All specimens considered here were collected near the island of Oahu, Hawaii (lat. 22°20-30′N, long. 158°20-30′W). Details of the sampling program are given in Clarke (1973), and will be only summarized here. Four series of samples were collected with a 10 foot Isaacs-Kidd mid-water trawl (IK). These were taken at approximately quarterly intervals (September 1970, December 1970, March 1971, and June 1971) and attempted to cover the upper 1,000 m of the water column both day and night for each season. Useful information was also derived from a series of samples collected with a 6-foot IK in the upper 400 m at night and between 400 and 1,000 m during the day in June 1970, from a series of samples with a 10-foot IK in the upper 190 m at night during periods of new and full moon in September-October 1971, and from preliminary samples taken in September-November 1969. Also included are data from a series of tows made by the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service (NMFS), NOAA in conjunction with the March 1971 IK series; these sampled the

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upper 200 m at night with a modified Cobb pelagic trawl (CT) described by Higgins (1970). I have also examined specimens of some species taken near Hawaii by R. E. Young with a modified Tucker trawl equipped with an opening-closing device.

The IK and CT were fished without opening-closing devices. Winch and ship speed were adjusted to minimize forward motion of the trawl during descent and ascent. Time-depth recorders were attached to the trawls. A few oblique tows were made, but mostly the trawls were towed for 2-3 h at the same depth. Actually, the trawls often sank or rose gradually during the "horizontal" part of the tow, but the range fished was small relative to spacing of different tows. A single, most frequently fished depth was assigned to each tow. The IK was towed at about 1.75 m/s and the CT at about 1.5 m/s. All "night" samples were taken between 2000 and 0500 h, "day" samples between 0800 and 1700 h.

Specimens were identified principally from data given by Grey (1964), Morrow (1964a, b, c), Morrow and Gibbs (1964), Gibbs (1964), Barnett and Gibbs (1968), Goodyear and Gibbs (1969), and Novikova (1967).[2] Standard length of all specimens was measured to the nearest millimeter. With a few exceptions, gonads of only larger specimens were examined to determine size at maturity and any seasonal changes in gonad development in mature females. Size at maturity was taken as that of the smallest female which carried obviously ripened ova. For each species considered, the total number of specimens examined and the length range in millimeters are given in parentheses after the species name.

The lower limits of depth ranges of the species are, of course, open to some question since the trawls were fished without opening–closing devices. The reliability of estimated depth ranges for the more abundant species (50-100 specimens) is probably fairly high. Catches from tows within the depth range were obviously greater than those of deeper tows which passed through the depth range. The latter were comparable with catches of short oblique tows taken during the program and were considered to be contaminants, i.e., caught during ascent or descent, unless data from the opening-closing Tucker trawl indicated otherwise. Any catches below the "normal" depth range that were unexpectedly high or different in size composition, etc., are discussed under the species headings.

Many species considered here were, however, so rarely taken that there is considerable doubt about estimates of depth ranges and vertical migration. The chances of being taken in a tow within the actual range were not much greater than those of being taken during descent or ascent of a deeper tow. Catches with the opening-closing Tucker trawl were helpful in only a few cases since the species where greatest doubt exists were rare to begin with and many were not captured at all or as frequently by the Tucker trawl.

For species which were collected in sufficient numbers (ca. 10/tow or more) in more than one tow during a series, changes in size composition with depth were assessed by comparing the size-frequency curves of individual samples from different depths using the Kolmogorov-Smirnov test (Tate and Clelland, 1957). Size composition was considered significantly different if the probability associated with the difference between curves was 0.05 or less. For rarer species, plots of size vs. depth were made using pooled data for all specimens. Trends in size composition with depth were noted, but no statistical significance can be attached to these.

Only one species, *Vinciguerria nimbaria,* was caught consistently in high enough numbers to permit a quantitative consideration of abundance and size composition throughout the water column (cf. treatment of data on the more abundant myctophids in Clarke, 1973). Thus considerations of day-night or seasonal differences in abundance in the remaining species are subject to some doubt. For these, the data from each series were simply pooled without any attempt to weight the catch of each tow for the relative thickness of the depth stratum it represented. Nevertheless, comparisons between seasonal series are merited since the total trawling times and depth coverages for each of the series were reasonably similar. In comparing data from different seasons, I have assumed that changes were not a result of horizontal advection or migration.

RESULTS

Gonostomatidae

Diplophos taenia **(169; 35-153 mm)**

The day depth range of *D. taenia* was 450-610 m and the night range 15-100 m. The smaller fish

[2]Specimens of all species considered here will be deposited at the U.S. National Museum.

tended to occur shallower during both periods. During the day those over 70 mm long were mostly below 525 m and those over 120 mm were below 575 m. At night none over 90 mm were caught shallower than 50 m and none over 120 mm were above 75 m.

Smaller *D. taenia* (< 70 mm) were more frequently taken in June, July and September, and larger fish appeared most abundant in March. This suggests that spawning is seasonal, but the season cannot be estimated since the age of 35–to 70-mm individuals is not known. Size at maturity was about 140 mm. It was not possible to determine the spawning season from gonad state of females since very few mature females were taken. The data from the March 1971 series indicated that individuals 100-140 mm long avoided the IK better than the CT, but that neither trawl sampled larger individuals adequately.

***Vinciguerria nimbaria* (2,927; 8-49 mm)**

For most series, the data indicated that *V. nimbaria* occurred at 400-560 m during the day and migrated to 20-125 m at night. In December 1970, two night tows in the day depth range caught substantial numbers of *V. nimbaria*—more than expected on the basis of short oblique tows and other night tows below 150 m. The size composition of these catches was within the range of that of the shallow night catches and close to those of day catches at similar depths. The number of mature fish in the deep night catches was low, but there was no obvious difference in sex ratio or gonad state between these and those of other tows. Thus it appears that a fraction, roughly 60%, of the population did not migrate in December.

The larvae of *Vinciguerria* are restricted to the surface layers and do not apparently undertake substantial migrations until metamorphosis (Ahlstrom and Counts, 1958). Those collected during this study (8-14 mm) were taken mostly at 15-50 m at night. (No day tows were taken above 250 m.)

Consistent and frequently significant differences in size-frequency curves indicated that smaller *V. nimbaria* occurred shallower in the water column both day and night (Figure 1). Few fish over 25 mm were captured shallower than 75 m at night and few less than 20 mm were captured below this depth. In the day, the small fish occurred mostly above 500 m and the large individuals were taken almost exclusively below 500 m.

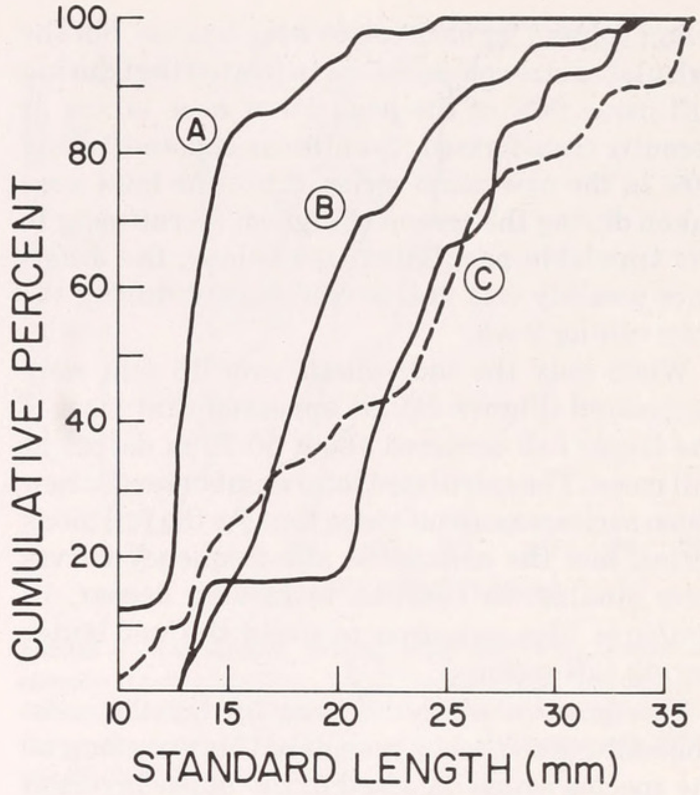

FIGURE 1.—Cumulative size-frequency curves for *Vinciguerria nimbaria* taken at 60 m (A, 35 individuals), 80 m (B, 96), 100 m (C dashed line, 44), and 125 m (C, solid line, 12) at night in September 1971. All pairs were significantly different ($P<0.05$) from each other except 100 m vs. 125 m.

The full-new moon series of night tows in the upper layers during September-October 1971, indicated substantial differences in depth distribution related to phase of the moon (Figure 2A), but the picture was complicated by the presence of many more larvae and recently transformed juveniles during the October (full moon) series. Calculated (see Clarke, 1973) total numbers in the

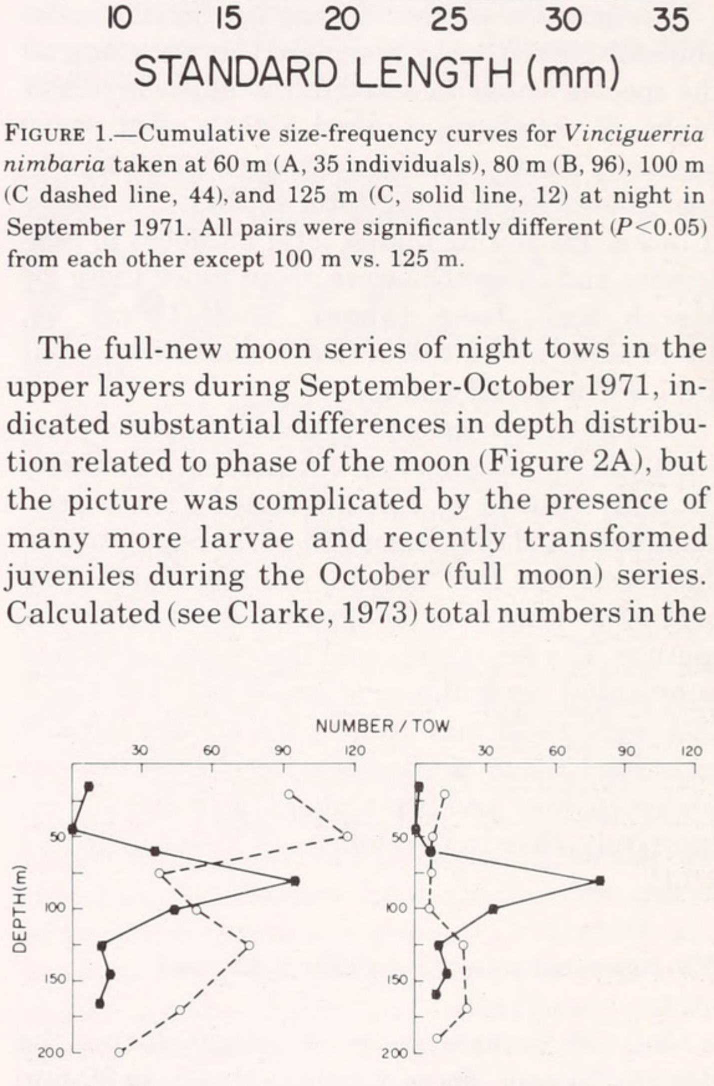

FIGURE 2.—Catches of *Vinciguerria nimbaria* per tow (1½ h each) at several depths at night at new moon (solid circles and lines) and full moon (open circles, dashed lines) during September-October 1971. Left: total catches including larvae and recently transformed juveniles. Right: catches of fish larger than 15 mm.

water column for each series were similar, but the calculated size compositions indicated that during full moon 90% of the population were larvae or recently transformed juveniles as opposed to only 50% in the new moon series. Since the tows were taken during the season of highest recruitment to the trawlable population (see below), the difference possibly was due to recruitment during the intervening 2 wk.

When only the individuals over 15 mm were considered (Figure 2B), it appeared that most of the larger fish occurred about 50-75 m deeper at full moon. The calculated total number for the new moon series was about twice that for the full moon series, and the calculated size-frequency curves were similar. In addition to moving deeper, *V. nimbaria* also appeared to avoid the net better during full moon.

Vinciguerria nimbaria was by far the most abundant of the fishes considered here. Among all the species which occurred in the upper layers at night, *V. nimbaria* ranked eighth after seven species of myctophids, but because of its small size, contributed little to the total estimated biomass (Clarke, 1973). Calculated total numbers in September and December were about twice those for March and June (about 30-35/10^3m^2 vs. 15-18/10^3m^2). The calculated biomass was about 7-8 g/10^3m^2 at all seasons.

Vinciguerria nimbaria appears to spawn principally in the summer and fall and reach maturity (27 mm) within 1 yr. The calculated size compositions indicated that about 75% of the population in June were less than 15 mm, while in March, 75% of the fish were over 20 mm and about 40% were mature. The September and December series had substantial percentages of small fish, but about 50% were 15-25 mm. Among the mature females examined, the proportion bearing ripened ova was higher in June and September (15/16 and 7/9, respectively) than in December and March (5/10 and 4/11).

Vinciguerria poweriae (365; 9-35 mm)

Only 35 *V. poweriae* were caught during the day by IK tows. These were mostly 25- to 30-mm fish caught around 500 m. A daytime CT tow at 300 m caught seven individuals (15-29 mm), suggesting that this species occurs rather shallow in the water column during the day and avoids the net due to higher light intensities. At night, *V. poweriae* occurred at 100-200 m. Few larger than 20 mm were caught above 150 m and practically none under 15 mm were taken below 150 m.

Seasonal changes in size composition indicated that *V. poweriae* spawns in the spring and summer. All caught in March were over 15 mm and over 50% were larger than the size at maturity (27 mm). Ten of 11 mature females from the March series carried ripe ova. In June, few of any size were caught, but these included both juveniles (< 15 mm) and mature fish. Three of the four mature females caught in June were ripe. In July and September, the bulk of the fish were 9-20 mm and very few mature. The few caught in December were all over 15 mm. Of the five mature females taken in September and December, only one was ripe.

Ichthyococcus ovatus (45; 12-55 mm)

All but nine *I. ovatus* were taken during the day between 400 and 500 m. The night catches consisted of two small fish (15 mm) taken near the day depth, two larger ones taken at 350 m, and five others (26-35 mm) taken at 150 m and 260 m. Since it seems unlikely that this species occurs as shallow as 150-260 m during the day, at least some fraction of the population apparently moves into the upper layers at night. *I. ovatus* matures at about 35 mm.

Gonostoma atlanticum (680; 10-66 mm)

Gonostoma atlanticum was taken principally at 490-560 m during the day and at 150-300 m at night. In several cases, the size-frequency curves from samples at different depths within the same series differed significantly and indicated that the smaller fish occurred at shallower depths. In December, at night all fish from 170 m were less than 30 mm, most from 190 to 200 m were 30-45 mm, and most from 250 to 300 m were 40-60 mm. Catches from day tows in both March and September indicated that few fish less than 50 mm occurred deeper than 500-525 m.

Gonostoma atlanticum apparently spawns over most of the year. Between 90 and 100% of the mature females (over 50 mm) in each series carried well–developed ova, and there were no evident seasonal changes in size composition of the catch.

Gonostoma ebelingi (306; 12-158 mm)

Gonostoma ebelingi occurred at 520-700 m during the day and at 125-300 m at night. The size composition of the catches changed with depth for both day and night series. The largest taken shallower than 150 m at night was 45 mm, and most fish taken below 200 m exceeded 60 mm. During the day, few fish over 100 mm were caught above 600 m, and none less than 75 mm were caught deeper.

Female *G. ebelingi* matured at about 120 mm, but males, as far as could be told without histological studies, appeared to mature at about 100 mm. There was, however, no evidence to suggest that this species is a protandrous hermaphrodite as observed in *G. gracile* by Kawaguchi and Marumo (1967). There were no obvious seasonal differences in the percentages of ripe females among mature females, but differences in size composition of the catches of different series suggested some seasonality in spawning.

All *G. ebelingi* caught in December were over 70 mm. In March, all fish were either less than 50 mm or over 70 mm. In June, 40% of the catch was 20-60 mm and the rest about evenly distributed between 61 and 150 mm. In September, the catch was again bimodal with all fish either smaller than 70 mm or over 100 mm. Recently transformed juveniles were taken only in March and September and were most abundant in March. More data would, of course, be helpful, but it seems that *G. ebelingi* spawns principally in early spring and early fall.

Gonostoma elongatum (1,346; 10-218 mm)

In all series but December 1970, *G. elongatum* occurred at 560-725 m during the day and moved to 60-265 m at night. In December, no individuals over 115 mm long were caught in the upper layers at night, but larger fish were taken in two night tows within the day depth range (of 22 fish, 9 were 117-200 mm, Figure 3). These deep night catches were not large relative to those expected from contamination, and consequently may have resulted from encountering patches in the shallow layers. However, the difference in size suggests that the large individuals did not migrate.

Size-frequency curves from night samples at different depths during the same series were frequently significantly different and consistently indicated that small fish occurred shallower (Figure 3). Those caught above 100-125 m were less than 35-40 mm, most caught between 175 and 200 m were 60-80 mm, and larger fish were taken mostly in tows below 200 m. It was not clear whether a similar pattern existed at depth during the day.

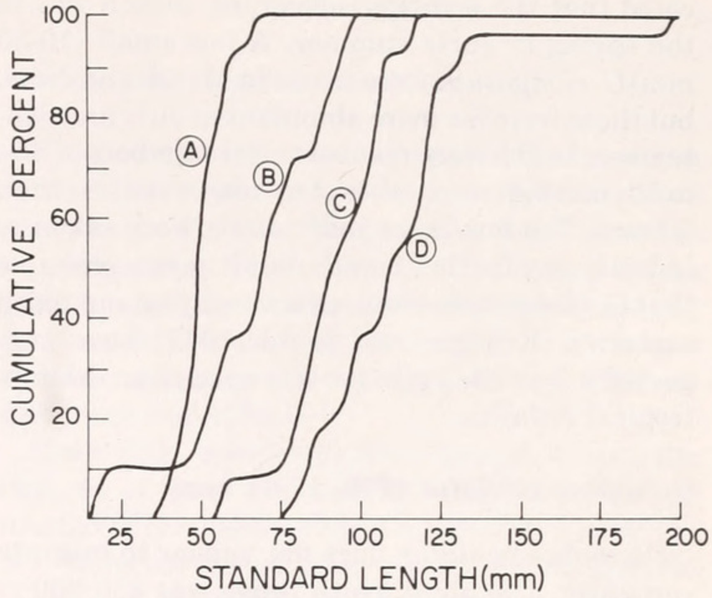

FIGURE 3.—Cumulative size-frequency curves for *Gonostoma elongatum* taken at 170 m (A, 25 individuals), 190-200 m (B, two tows, 11), 265 m (C, 13), and 750 m (D, two tows, 22) at night during December 1970. The curves were all significantly different ($P<0.05$) from each other.

There was considerable sexual difference in size at maturity. Males appeared to reach maturity at about 120 mm; the largest male was 161 mm. The smallest mature female was 193 mm. Some small, clearly immature females (120-140 mm) were found, but unfortunately, no fish between 161 and 193 mm was collected. Although histological studies of specimens of all sizes are obviously necessary, the above data suggest that some *G. elongatum* mature directly as females, while others are protandrous hermaphrodites. Kawaguchi and Marumo (1967) have shown that a congener, *G. gracile* is a protandrous hermaphrodite. Butler (1964) has shown that in some species of pandalid shrimps, a group within which protandrous hermaphroditism frequently occurs, the degree of hermaphroditism varies throughout the species' ranges. Butler suggests that this is a result of varying ecological factors. Varying degrees of protandry may similarly occur among the *Gonostoma* spp.

Too few mature females were collected to assess any seasonal trends in gonad ripeness, but the pooled size composition data for each series indicated that the principal spawning season was in the spring or early summer. A few small (10-30 mm) *G. elongatum* were taken in March and June, but these were far more abundant in July and September. In December, substantial numbers of 35– to 50–mm fish were taken, but none were less than 30 mm. Too few large individuals were taken to indicate any further trends, but it seems probable that *G. elongatum* requires several years to reach maturity. Krueger and Bond (1972) have suggested a 3-yr life cycle for this species in the subtropical Atlantic.

Danaphos oculatus (229; 19-41 mm)

Danaphos oculatus does not appear to migrate vertically. The night depth range was 430-600 m and the day range 480-650 m. The day-night difference is an artifact due to depth spacing of the samples. There were no trends in size composition with depth. *Danaphos oculatus* matures at about 30 mm. There were no seasonal trends in size composition or reproductive condition.

Valenciennellus tripunctulatus (600; 10-32 mm)

During the day, *V. tripunctulatus* was taken principally between 400 and 550 m. The size-frequency curves for tows at 500 and 525 m taken in September 1970 were significantly different; 70% in the shallower tow were 20-25 mm, and 75% in the deeper were over 25 mm. The day depth range and evidence of changes in size composition with depth agree with results reported by Krueger (1972) for *V. tripunctulatus* in the central North Atlantic.

Krueger's data show that *V. tripunctulatus* remains at the same depths during the night, but near Hawaii this species undertakes a limited, but definite upward migration. The night depth range was 200-330 m. The catches per effort within this range were roughly equivalent to those during the day at 400-500 m. Catches below 330 m at night were lower and probably due to contamination. All sizes were taken within the night depth range. Changes in size composition with depth were evident, but numbers sufficient to make statistical comparisons were taken at more than one depth only in December 1970. In that case, the curve from the 200–m depth sample differed significantly from those from samples at 270 and 320 m. About 90% of the fish in the shallower sample were 10-16 mm and over 90% in the deeper were over 20 mm. Thus the upward extension of the depth range at night was not due solely to shallow catches of postlarvae or juveniles as Krueger (1972) has suggested may be the case for Badcock's (1970) earlier observation of limited diurnal vertical migration by *V. tripunctulatus in the eastern Atlantic.*

Valenciennellus tripunctulatus matures at about 25 mm. Large proportions of the mature females (90-100%) carried well-developed ova at all seasons. There were no obvious seasonal trends in size composition.

Other Gonostomatidae

Two *Woodsia nonsuchae* (39 and 106 mm) were taken at 530 and 620 m at night, respectively. A damaged specimen (22 mm) that was probably *W. nonsuchae* was taken in a day tow to 875 m.

Margrethia obtusirostra (18; 8-44 mm) was taken mostly at night between 180 and 200 m. The two day catches were in tows at 350 and 540 m. The two largest specimens, 44 mm, were mature females and the next largest, 34 mm, was a female with ova beginning to develop.

Chauliodontidae

Chauliodus sloani (147; 21-250 mm)

Chauliodus sloani appeared to migrate from a day depth range of 450-825 m to 45-225 m at night. No individual over 65 mm was taken above 100 m at night nor above 500 m during the day. All fish over 120 mm were taken below 175 m at night or below 600 m during the day.

The pooled data from each series showed significant differences in size composition (Figure 4A) which indicated that *C. sloani* spawns principally in the spring or early summer and reaches lengths of 70-100 mm by the following March. Individuals less than 40 mm were present only in June, July, and September and were most abundant in the June and July series. These were likely represented by the large numbers of 40– to 70–mm fish present in September and December and 70– to 100–mm fish which dominated the March samples. Too few large fish were collected to assess any further trends in size composition. *Chauliodus sloani* almost certainly takes several years to reach maturity. Only the two largest specimens (females, 225 and 250 mm) were mature. The next largest was only 185 mm.

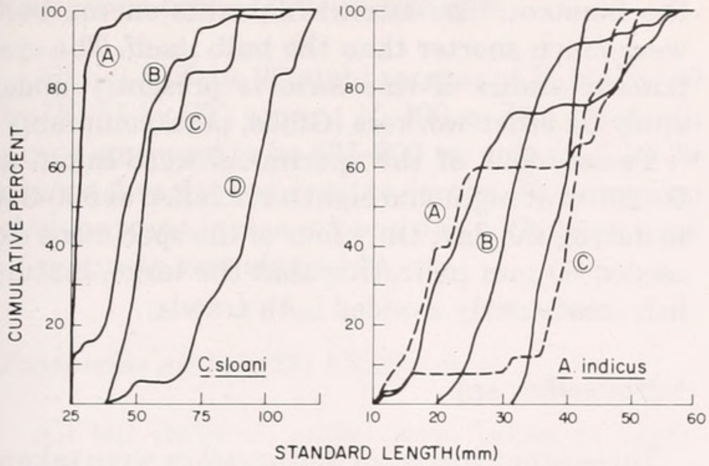

FIGURE 4.—Left: Cumulative size-frequency curves for the pooled catches of *Chauliodus sloani* (exclusive of individuals over 120 mm) in June 1971 (A, 21 individuals), September 1970 (B, 42), December 1970 (C, 13), and March 1971 (D, 19). The curve for the catch in July 1970 (not shown) did not differ significantly from and was almost identical with that for June 1971. All other curves differed significantly from each other ($P<0.05$). Right: Cumulative size-frequency curves for the pooled catches of *Astronesthes indicus* (exclusive of individuals over 60 mm) in September 1970 (A, dashed line, 20 individuals), December 1970 (A, solid line, 41), March 1971 (B, 128), June 1971 (C, solid line, 18), and July 1970 (C, dashed line, 27). All pairs except June-July and September-December differed significantly ($P<0.05$).

Stomiatidae

Four *Stomias danae* (55-75 mm) were taken at night. Two were from tows at 100 m and two from a tow at 250 m that extended well past dawn. A larger (154 mm), damaged *Stomias* sp. was taken in a night tow at 225 m.

Three specimens (99-290 mm) of the genus *Macrostomias* were taken, but depth information on the samples was questionable for all three. Fedorov and Melchikova (1971) described a new species of *Macrostomias, M. pacificus,* which they distinguish from *M. longibarbatus* mostly on the basis of anal fin ray and photophore counts. Two of the specimens I collected had 14 anal rays, and one had 15. Complete photophore counts were possible on only one specimen with 14 anal rays: PV = 81, OV = 82, VAV and VAL = 64. The other specimen with 14 anal rays had PV = 82, OV = 80. The estimated PV + VAV for the remaining specimen was 148. Thus the photophore counts definitely indicate *M. longibarbatus,* while the anal ray counts fall between those given for the two forms by Fedorov and Melchikova (1971). I suspect that additional specimens will indicate there is only one valid species, *M. longibarbatus.*

Astronesthidae

Astronesthes cyaneus (45; 16-66 mm)

Astronesthes cyaneus is used here pending further study of the systematics of this species group in the Pacific. The specimens were closest to *A. cyaneus* as defined by Goodyear and Gibbs (1969), but all had rudimentary barbels. Also, the luminous tissue on the operculum of the few larger specimens was not exactly as described by Goodyear and Gibbs.

Only eight specimens were caught during the day, six of these between 600 and 700 m. Three-fourths of the night catches were at 80-100 m; the few collected deeper were scattered throughout the water column and were probably contaminants. None of the specimens were near maturity; only eight were over 25 mm. Larger fish undoubtedly avoid the trawl and may occur deeper than the small individuals. It appears that even the small ones avoid the trawl during the day.

Astronesthes indicus (307; 11-117 mm)

Astronesthes indicus was taken principally at 500-800 m during the day and at 30-200 m at night except in the December 1970 series. In that series, no *A. indicus* were taken in the upper layers at night, but 21 were taken in three night tows at 625-750 m, within the day depth range. The numbers collected in these tows were larger than expected if they had been due to contamination and were comparable to catches of day tows at this time. At night, no individual over 50 mm was taken shallower than 125 m, but smaller individuals were taken with roughly equal frequency throughout the night depth range. The small fish also appeared to occur throughout the day depth range, but large fish were taken mostly in tows near the deep end.

The size composition of the catch varied considerably with season and suggested that spawning occurred principally in the summer and fall and that about 2 yr were required to reach 50-60 mm. A few small individuals (< 20 mm) were taken in July 1970, many in September and December, and none in March or June of 1971 (Figure 4B). The small individuals of the September and December samples appear to be represented by a 21- to 35-mm group in March and a 34- to 45-mm group in June. A similar sized group, 37-49 mm, was present in the July 1970 samples and appeared to be represented by a 42–to 51–mm group in September and a 46– to 57–mm group in December. The CT series in March collected 99 specimens, 56 of which were 24-36 mm or roughly equivalent to the majority of the IK specimens. Of the remaining CT specimens, 26 were 50-76 mm-perhaps representative of the 46– to 57–mm group in the December IK series.

The catch per effort and size composition of IK catches were roughly equal for day and night indicating no differential avoidance. However, 22 of the 35 specimens over 60 mm were taken by the CT. The largest taken by the CT was 89 mm and only four larger individuals were taken by scattered IK tows. Thus it appears that individuals over 60 mm regularly avoid the IK and that larger ones avoid both trawls. The largest individual (117 mm) was a female that appeared to be nearing maturity. Judged from the above data, it is likely that this species takes at least 3 or 4 yr to mature.

Astronesthes splendidus (82; 22-110 mm)

About 75% of the *A. splendidus* collected were taken at 25-130 m at night. There was no obvious trend in size composition with depth. Only 16 specimens were taken during the day, all but 2 of these between 600 and 800 m. Nearly transformed larvae with photophores (< 25 mm) and small juveniles were present only in June, July, and September suggesting summer or early spring spawning. These young may have been represented by 40– to 60—mm fish which made up 85% of the March catch, but so few fish were caught in December that the connection between the two size groups is tenuous. Only 15 of the 82 specimens were over 60 mm and none were mature. The size composition of IK and CT catches in March was similar. Thus both trawls were avoided by most larger juveniles and consistently by adults.

Astronesthes sp. (near *similis*) (37; 21-133 mm)

The specimens of this species of *Astronesthes* agreed with the description of *A. similis* by Gibbs (1964) except for the barbel tip. Instead of being unornamented, the barbel tip of the Hawaiian specimens had a dark terminal filament about as long as the bulb and often a pale tip at the end of the filament. The lateral filaments on the bulb were much shorter than the bulb itself. The systematic status of this form is presently under study by other workers (Gibbs, pers. commun.).

Twenty-four of the specimens were taken at 50-200 m at night and eight were taken at 500-640 m during the day. Only four of the specimens exceeded 60 mm indicating that the large, mature fish consistently avoided both trawls.

Astronesthes spp.

Three other species of *Astronesthes* were taken. *A. gemmifer* (6; 91-138 mm) was taken once at night at 245 m, four times at 580-690 m during the day, and once by a day tow to 1,150 m. *Astronesthes lucifer* (10; 26-49 mm) was taken five times at night at 25-195 m, and by day at 250, 550 (3), and 640 m. *Astronesthes luetkeni* (6; 26-74 mm) was taken in only three tows for which depth information was valid: 125 and 200 m at night and 600 m during the day.

Heterophotus ophistoma (28; 32-245 mm)

Of 17 *H. ophistoma* taken at night, 15 were taken between 50 and 200 m. The other two were nearly transformed larvae taken in a closing net tow at about 630 m. Ten of the 11 day specimens were taken at 625-775 m; one was taken at 1,000 m. Eighteen were larvae or recently transformed juveniles (32-64 mm), and all but two of these were taken in July or September. The two largest specimens, 235 and 245 mm, were males and appeared to be mature or nearly so.

Neonesthes microcephalus (2; 135-147 mm)

One *N. microcephalus* was taken at 640 m at night and the other in oblique tow to 1,600 m.

Melanostomiatidae

Eustomias bibulbosus (20; 80-145 mm)

Fourteen *E. bibulbosus* were taken at 75-300 m at night; however, only two large (131 and 145 mm) individuals were taken below 125 m. During the day, six were taken between 600 and 960 m. Sixteen of the specimens were small (80-102 mm), and none of the large ones were mature.

***Eustomias bifilis* (128; 41-170 mm)**

All but 5 of the 92 night catches of *E. bifilis* (40 by IK, 51 by CT) were at 15-200 m. The day depth range appeared to be 635-800 m; only 5 of the 29 day catches were at greater depths. There was no obvious trend in size composition with depth. Size at maturity was about 140 mm.

***Eustomias gibbsi* (28; 55-131 mm)**

All but three *E. gibbsi* were taken at night. The night depth range was about 50-200 m, and the three day catches were at 680-800 m. There was no obvious trend in size composition with depth among the night catches. None of the specimens were mature.

***Eustomias* spp.**

Of the remaining specimens of *Eustomias*, about 130 were too badly damaged to be identified with certainty. The great majority of these had pectoral ray and photophore counts within the range of the three species considered above (most were probably *E. bifilis*). Some 150 other specimens include about 20 different forms, most of which cannot be reliably identified due to present uncertainties in the systematics of the genus. These along with other specimens from the Central Pacific will be considered in a later, more systematically oriented report.

***Thysanactis dentex* (340; 39-177 mm)**

Thysanactis dentex, the most frequently collected melanostomiatid, occurred principally at 75-200 m at night. A few individuals were taken as shallow as 40 m, and there were scattered night catches throughout the water column. The principal day depth range was 600-800 m with a few caught between 400 and 600 m or scattered deeper than 800 m. Within both ranges, the larger fish tended to occur deeper and the smaller shallower. At night few over 100 mm occurred above 150 m, and catches of those smaller than 80 mm below 125 m were low and probably due to contamination. During the day those over 100 mm were caught mostly below 700 m and those less than 100 mm mostly between 600 and 700 m. Size at maturity was about 160 mm.

***Bathophilus* spp.**

Seven species of *Bathophilus* were taken. Although data are incomplete for most, it seems that all occur at about 500-700 m during the day and migrate to the upper 250 m at night. *Bathophilus kingi* (23; 24-95 mm) was taken most frequently. At night, 18 specimens were taken between 50 and 225 m. Three specimens were taken at 590-725 m during the day and one each at 1,000 and 1,100 m. *Bathophilus brevis* (3; 12-43 mm) was taken only at night between 200 and 225 m. *Bathophilus digitatus* (9; 23-91 mm) was taken seven times at night at 125-175 m and twice during the day at 520 and 550 m. *Bathophilus longipinnis* (10; 25-97 mm) was taken seven times at night scattered throughout the water column (100-1,175 m) and three times between 520 and 590 m during the day. *Bathophilus pawneei* (7; 30-90 mm) was taken at night between 40 and 195 m and once at 690 m during the day. *Bathophilus* cf. *altipinnis* ? (3; 26-59 mm; pectoral rays 26-28, pelvic rays 15-18) was taken at 170 and 265 m at night and at 640 m during the day. A single *B. schizochirus* (76 mm) was taken at 265 m at night.

Other Melanostomiatidae

Pachystomias microdon (33 mm) was taken once in a day tow at 660 m. Two small (55-56 mm) *Flagellostomias boureei* were taken at 500 m (day) and 750 m (night). Five juvenile *Echiostoma barbatum* (29-89 mm) were taken, four at 30-185 m at night and one in an oblique day tow to 800 m. Four species of *Photonectes* which were collected could be identified with reasonable certainty. *Photonectes achirus* (9; 43-146 mm) was taken at 125-225 m at night and at 400, 550, 620, and 1,400 m during the day. A single *Photonectes caerulescens* (127 mm), which is likely to be proven indistinct from *Photonectes achirus,* was taken in a day tow at 800 m. *Photonectes albipennis* (8; 22-87 mm) was taken once at 620 m during the day and between 60 and 165 m at night. *Photonectes fimbria* (34 mm) was taken once at 620 m during the day. The above specimens of *Photonectes* fit the descriptions given in Morrow and Gibbs (1964) reasonably well. In addition, two specimens (208 and 255 mm), taken at 650 m at night and 490 m during the day, were close to, but not identical with, *Photonectes margarita*.

Leptostomias spp. (15; 68-134 mm) were taken predominantly at night between 100 and 250 m;

four were taken during the day at 500-625 m. *Melanostomias* spp. (23; 48-238) were mostly taken at 50-250 m at night or 520-800 m during the day. Due to either damage to the barbels (mostly *Leptostomias)* or lack of data on the variability of characters used to separate nominal species in these genera, definite identifications cannot be given.

Idiacanthidae

***Idiacanthus fasciola* (341; 13-375 mm)**

Larval *I. fasciola* (13-50 mm) were taken mostly at night in the upper 200 m; deeper catches both day and night were scattered and probably contaminants. Males (30-50 mm) were taken principally between 550 and 800 m during the day. Fourteen of the 20 night captures were also in the day depth range, but 6 were taken at 200-300 m.

At night, females (47-375 mm) were taken principally between 30 and 300 m. All taken below 200 m were over 145 mm, but larger ones did occur shallower. In the December 1970 series seven females were taken, but only one was taken at night in the upper 300 m, the remainder were taken within the day depth range. During the day, females were taken mostly between 600 and 800 m, but one was caught at 250 m and several at 400-600 m. Too few were taken to make detailed comparisons of day and night catch per effort, but the data indicated no gross differences in abundance or size frequency.

Female *I. fasciola* mature at about 250 mm, but too few large individuals were taken to assess any seasonal trends in gonad ripeness. There were no clear seasonal trends in size composition of the catches. Larvae and males were taken most frequently in December. Few were taken in March, with catches for June, July, and September intermediate. In July, September, and December, 84-91% of the females were shorter than 150 mm, while the percentages for March (59%) and June (30%) indicated relatively fewer smaller females. There were, however, no definite size groups which could be traced from season to season.

Malacosteidae

***Photostomias guernei* (159; 24-158 mm)**

Photostomias guernei was taken principally at 15-300 m at night and at 350-800 m during the day. A few specimens were taken in deep night tows with the opening-closing trawl indicating that the entire population does not regularly migrate. Small fish were caught throughout these ranges, but only two fish over 100 mm were caught above 185 m at night and none over 80 mm were taken above 750 m during the day.

Mature female *P. guernei* showed a rather curious size distribution. Of 41 females examined (46-158 mm), 11 bore ripened ova. Nine were 64-85 mm and two were considerably larger—147 and 158 mm. Of the specimens with undeveloped ova, seven were less than 63 mm, and the remainder 93-149 mm. Some of the large individuals could possibly have spawned already, but the individuals between 93 and 125 mm were clearly immature. The bimodal size distribution suggests that two populations were present in the samples, but there was considerable overlap or agreement in photophore and fin ray counts of both large and small females. Also there was no indication that one type of female had a different depth distribution or seasonal pattern than the other.

Photostomias guernei probably spawns over most of the year. Individuals under 40 mm were most frequently taken in June, but were present in all series. There was no obvious seasonal trend in size composition of the larger fish.

***Aristostomias* spp.**

Aristostomias lunifer (12; 30-151 mm) was taken only between 120 and 260 m at night. The largest specimen, a 151 mm female, was mature or nearly so. *Aristostomias grimaldii* (5; 33-117 mm) was taken at 100 and 500 m at night and at 690 and 750 m during the day. The largest specimen, a male, appeared immature. *Aristostomias polydactylus* (10; 33-140 mm) was taken at 100, 175, 320, and 590 m at night and at 625, 850, 875, and 1,100 m during the day. The largest individual was an immature female. Two specimens similar to *A. tittmanni* (68 and 75 mm) were taken at 15 and 250 m at night.

***Malacosteus niger* (133; 26-186 mm)**

Malacosteus niger occurred between 520 and 900 m during the day and 500-850 m at night; the day-night differences were due to sample spacing. Most were taken between 600 and 700 m. The depth-size plot indicated a trend for greater size with increasing depth, but since 106 of the 133 specimens were 75-125 mm any trends for smaller or larger fish are of dubious significance. The only mature females collected were the four largest specimens (172-186 mm). There was no seasonal trend in size composition of the the catches.

DISCUSSION

In spite of the fact that the stomiatoids in the study area were quite diverse and that there have been no really comprehensive studies based on extensive sampling programs in the Pacific, only a few species are either undescribed or of uncertain status (with the exception of the *Eustomias* spp.). To paraphrase Gibbs (1960), it is indeed a relief that most specimens fit descriptions based primarily on Atlantic material.

Eight species were previously unrecorded in the Pacific: *Astronesthes gemmifer, Neonesthes microcephalus, Aristostomias grimaldii, A. lunifer, A. polydactylus, Eustomias bibulbosus, Photonectes achirus,* and *Bathophilus altipinnis.* Three of the more commonly collected species were previously known only from a few specimens. *Gonostoma ebelingi* (Grey, 1960) and *Eustomias bifilis* (Gibbs, 1960) were described on the basis of two and one specimens, respectively, and no other specimens have been reported since. *Thysanactis dentex,* which was taken regularly by the present study and by King and Iversen (1962), is listed by Morrow and Gibbs (1964) as known from only five captures in the North Atlantic. Further studies of material from other tropical areas will be necessary to determine if these species are for some reason present in high numbers only in the Central Pacific.

Inadequate information from other areas of the Pacific does not permit detailed consideration of zoogeographic patterns of these species. Negative records of several studies and reports cannot necessarily be considered conclusive. It is likely that the majority of the species recorded here occur throughout the warm water masses. However, preliminary examination of samples from the central equatorial Pacific indicates that at least *Vinciguerria nimbaria* and *Gonostoma ebelingi* do not occur continuously across the equatorial region and also confirm Gibbs' (1969) statement that *Stomias danae* is replaced by *S. affinis* in equatorial waters. Two species, *Vinciguerria lucetia* and *Idiacanthus antrostomus,* which appear to occur in eastern and equatorial waters, were not taken during this study. *Vinciguerria lucetia* has been recorded near Hawaii (King and Iversen, 1962; Ahlstrom and Counts, 1958) and *Idiacanthus antrostomus* may also be expected to occur here occasionally, but their absence from the material collected during the study indicates that some warmwater species do not normally occur in the central water mass.

It is clear from the absence or extreme rarity of mature fish, that neither of the trawls used were adequately sampling the larger sizes of many species—particularly the *Astronesthes* spp. Although differences in day-night catches have not been rigorously demonstrated, it also appears that many large species and individuals avoid the IK better during the day than at night.

For most species, the numbers caught by the paired series of IK and CT tows in March 1971, were not sufficient for detailed analyses, but rough comparison of the catches and size ranges (Table 1) indicates some differential avoidance. The total volume sampled by the CT tows was about 10 times that of the IK tows in the same depth range. In 10 species, the ratio of CT/IK catches was considerably lower than 10 (1.3-6.0) suggesting that the IK's greater towing speed was more of an advantage than the greater size of the CT. In these cases, the CT/IK ratio was little affected by considering only the fish larger than the smallest caught by the CT; i.e., the passage of smaller fish through the coarser CT meshes did not seem to be an important factor.

Three species, *Diplophos taenia, Gonostoma*

TABLE 1.—Total numbers and size ranges of 15 species of fish taken in nine tows with the IK and eight tows with the CT in the upper 200 m at night during February-March 1971. The tows with each net were roughly equally distributed between 25 and 200 m. The total volume sampled by the CT tows was about 10× that of the IK tows.

Species	Total catch		Size range (mm)	
	IK	CT	IK	CT
Diplophos taenia	5	62	66-83	61-153
Vinciguerria poweriae	29	122	16-34	15-33
Gonostoma atlanticum	10	40	15-45	20-64
Gonostoma ebelingi	11	100	12-37	16-162
Gonostoma elongatum	97	236	10-139	30-165
Chauliodus sloani	4	13	81-162	68-123
Astronesthes cyaneus	4	13	18-19	17-44
Astronesthes indicus	18	83	21-89	24-89
Astronesthes splendidus	10	13	29-58	30-65
Eustomias bibulbosus	0	10	—	81-141
Eustomias bifilis	2	49	93-115	52-158
Eustomias gibbsi	1	10	77	70-131
Thysanactis dentex	17	102	58-173	44-165
Idiacanthus fasciola	17	81	58-297	54-301
Photostomias guernei	9	26	30-113	40-133

ebelingi, and *Eustomias gibbsi,* were taken in roughly the predicted ratios, and the other two species of *Eustomias* treated here were clearly sampled better by the CT. Size ranges, of course, were greatly influenced by just one large individual, but in general the CT caught considerably larger individuals of the five species which it appeared to sample relatively better in terms of numbers. Although not shown by the figures in Table 1, large *Astronesthes indicus* were also apparently sampled better by the CT (see above).

Of the 47 species considered here, only *Danaphos oculatus* and *Malacosteus niger* clearly did not migrate to shallower levels at night. All the other abundant species migrated to the upper layers at night and, in spite of the fact that no opening-closing device was used, even the data on many of the rarer species are consistent with migrations of several hundred meters. It is, of course, possible that, as in the case of *Photostomias guernei,* a small percentage of some species may not migrate at any given time. Diurnal vertical migration has been shown to occur in a few of the species considered here (e.g., Badcock, 1970; Krueger and Bond, 1972), but due to limited data it had been only "suspected" for many others. Possibly because of the deeper mixed layer and thermocline and greater transparency of the water, migrations in the tropics are greater in extent and thus more easily detected than elsewhere.

As with several species of myctophids (Clarke, 1973), there was evidence that some of the stomiatoids did not regularly migrate during the winter. For *Vinciguerria nimbaria, Gonostoma elongatum, Astronesthes indicus,* and *Idiacanthus fasciola,* night catches within the day depth range during December 1970 were higher than expected if due to contamination and indicated that a fraction of the population remained at depth. Too few of the latter two species were taken to permit consideration of any differences between the migrating and nonmigrating fractions. The evidence for nonmigration was weak for *G. elongatum* but suggested that the large fish did not migrate. There were no obvious differences in the two fractions of the population of *V. nimbaria.* Thus as with the myctophids, there is no explanation for the apparent change in behavior.

Many of the species showed trends for increased size with depth both day and night. Similar trends were noted for many species of myctophids (Clarke, 1973), and qualitative reports (e.g., Badcock, 1970) indicate that this trend is shown by a variety of mesopelagic species. The trend was clearest for the abundant vertically-migrating gonostomatids, *Diplophos taenia, Vinciguerria* spp., *Gonostoma* spp., and *Valenciennellus tripunctulatus,* but was also evident for *Chauliodus sloani, Astronesthes indicus* and *Thysanactis dentex.*

The size-depth patterns at night of 10 species are shown in Figure 5 by straight lines connecting the coordinates for the smallest size, upper limit of depth range with those for the largest size, lower limit of depth range (extremes of size and depth have been ignored). These are only rough approximations of the size-depth patterns; in reality the patterns are rather complex polygons. The straight lines serve mainly as a basis for considering the possible interactions of the various species.

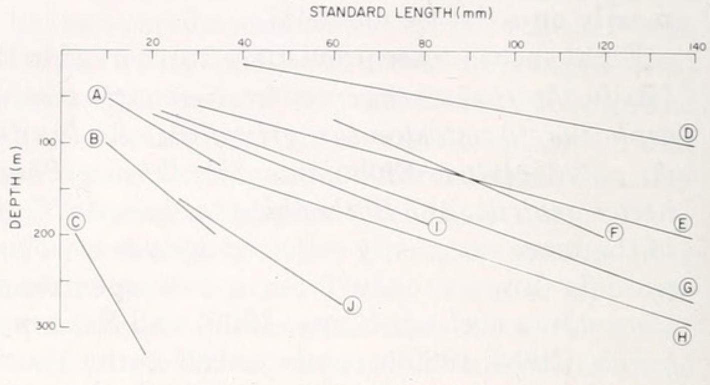

FIGURE 5.—Depth-size profiles (see text) for 10 species in the upper 300 m at night: *Vinciguerria nimbaria* (A), *Vi. poweriae* (B), *Valenciennellus tripunctulatus* (C), *Diplophos taenia* (D), *Chauliodus sloani* (E), *Thysanactis dentex* (F), *Gonostoma elongatum* (G), *G. ebelingi* (H), *Astronesthes indicus* (I), and *G. atlanticum* (J).

Two very similar species, *Vinciguerria nimbaria* and *V. poweriae,* showed distinctly different size-depth patterns. As with many similar species of myctophids, individuals of similar sizes were well separated in the water column. Where the depth ranges overlapped, at 100-125 m, the larger *V. nimbaria* co-occurred with the smaller *V. poweriae. Vinciguerria nimbaria* generally co-occurred with similar-sized or slightly larger individuals of several abundant species of myctophids in the upper 100 m, while *V. poweriae* co-occurred with the deeper living myctophids (Clarke, 1973).

Although their size-depth patterns were slightly different, similar-sized individuals of *Gonostoma elongatum* and *G. ebelingi,* two very similar species, co-occurred over much of their depth ranges. *G. atlanticum,* in addition to being rather different from its congeners in size range, color, and several morphological aspects, also had a quite different size-depth pattern and tended to co-occur with much larger individuals of its congeners. The former two species co-occurred throughout much of their depth range with similar-sized individuals of three species of the myctophid genus *Lampanyctus*. Thus in the 100-250 m layer at night similar species of at least two genera of two families co-occur. This is in contrast to the upper 100 m where only rather different or distantly related species co-occur.

Other gonostomatids exhibited nighttime patterns quite different from any of the other species considered. *Danaphos oculatus* remained at the day depth and showed no trend in size composition with depth. *Valenciennellus tripunctulatus* occurred much deeper than similar-sized individuals of any other species. *Diplophos taenia* occurred much shallower, with respect to size, than any of the species thus far investigated. It is possible that some of the shallow-living myctophids, e.g., *Myctophum* spp., which were not adequately sampled by the trawl also have patterns similar to that of *D. taenia*.

The larger stomiatoids with fanglike teeth, dorsal or mental "lures," or various adaptions for swallowing large items, are generally thought to be predators on small nekton. Near Hawaii, the dominant "predatory" species exhibited a variety of patterns at night. *Astronesthes indicus, Chauliodus sloani,* and *Thysanactis dentex* showed trends for increased size with depth. In the upper 100 m, these species co-occurred with roughly similar-sized or slightly smaller individuals of the more abundant myctophids and *Vinciguerria nimbaria*. Although there are, scattered throughout the literature, several records of larger stomiatoids ingesting rather large prey, it seems unlikely that these three species are important predators on the abundant fishes in the upper 100 m or that the latter are important items in the former's diet. All sizes of *Idiacanthus fasciola, Eustomias bifilis,* and *Astronesthes splendidus* appeared to occur throughout their night depth ranges. Thus it would seem that, if indeed any of the larger stomiatoids are important predators on the small fishes in the upper 100 m, species such as these are more likely candidates.

Malacosteus niger did not migrate, and its depth range was somewhat deeper than the day ranges of most of the vertically migrating species considered here. *Malacosteus niger* has very poorly developed serial, ventral–lateral photophores in comparison with most other stomiatoids. The only nonmigrating species of myctophid, *Taaningichthys bathyphilus,* occurs in the same depth range and has greatly reduced serial photophores in comparison with the other myctophid species. If, as Clarke (1963) has suggested, ventral-lateral photophores are a counter-shading device, their absence or reduction in these deep-living, nonmigrating species is likely related to lower light levels and more nearly spherical radiance distribution at such depths even during the day in comparison to the regime which most of the migrating species experience day or night.

Three of the species which occurred together at 400-600 m during the day, *Danaphos oculatus, Valenciennellus tripunctulatus,* and *Ichthyococcus ovatus,* all have dorsally directed eyes and markedly ventrally directed serial photophores. These characteristics are shared by the sternoptychids of the genus *Argyropelecus* which also occur in the same depth range (S. S. Amesbury, pers. commun.). The argentinoid, *Opisthoproctus soleatus,* which shares the same day depth range, also has dorsally directed eyes and a ventrally directed luminescent apparatus. At night, none of these species appear to undertake extensive migrations. *Danaphos oculatus* remains at the same depths, *V. tripunctulatus* undertakes a limited upward migration, and *I. ovatus* either migrates or disperses upward. The *Argyropelecus* spp. either move upward slightly or remain at the same depths (S. S. Amesbury, pers. commun.). *Opisthoproctus soleatus* was for some reason nearly absent from the night samples; out of the 114 specimens only 4 were taken at night.

Several investigators (see review by McAllister, 1967) have suggested that the dorsally directed eyes are an adaptation for better detection of prey or predators above the fish and that the ventrally directed light organs serve to disrupt the silhouette of the fish to predators below. These adaptive values would be realized only under a situation where light levels were low but still sufficient for vision and where the radiance distribution was dominated by the downwelling component. Such conditions probably obtain only during the day for the above species. This would suggest that they feed primarily during the day and that they are exposed to heavier predation then also. At least the former seems likely. These species probably feed on zooplankton, and preliminary analyses of zooplankton in the study area indicates that these species encounter higher concentrations during the day owing to vertical migrations of the zooplankton. The situation is just the opposite for most of the other fishes which share the same day depth range and have neither upwardly directed eyes nor as pronounced a ventral orientation of their light organs. The latter fishes undertake more extensive vertical migrations at night and encounter higher concentrations of zooplankton and probably predators then rather than during the day.

The species which showed seasonal trends in size composition or gonad ripeness all appeared to spawn primarily in the spring and summer or summer and fall. These were *Vinciguerria* spp., *Chauliodus sloani, Astronesthes indicus,* and probably *A. spendidus* and *Heterophotus ophistoma.* Their seasons of peak reproduction were thus similar to those of the abundant myctophids (Clarke, 1973). The data on *Gonostoma elongatum* and *Idiacanthus fasciola* suggested rather inconclusively that these species spawn primarily in the summer and winter, respectively. Several fairly abundant species, *Gonostoma atlanticum, Danaphos oculatus, Valenciennellus tripunctulatus, Eustomias bifilis, Thysanactis dentex, Photostomias guernei,* and *Malacosteus niger,* showed no indication of seasonality in reproduction. Possibly the larvae of those species which exhibit no seasonality either hatch at a larger size or live at greater depths than those of the seasonal species and thus the former's spawning is not timed to any seasonal fluctuations in food concentration or size distribution in the upper layers.

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