

# VAMPYROMORPHA

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## INTRODUCTION

Fifteen specimens of *Vampyroteuthis infernalis* Chun were captured by the Danish Deep-Sea (Galathea) Expedition (Table 1). The collection includes an exceptionally large and moderately well preserved sexually mature female from off Durban, South Africa. This unusual animal is described in detail below. Comparison with previous data (PICKFORD, 1948) shows that it does not differ significantly, except in size, from smaller adults of the same sex. The other specimens, with the exception of two immature adult females, are more or less severely damaged and descriptions have been limited to essential features and points of controversial interest.

In the descriptions which follow the specimens are numbered 105-119, in continuation of the author's list of known representatives of this unique cephalopod. Specimens 1-77 were described previously in the Dana-Reports (PICKFORD, 1946, 1948); speci-

mens 78-95 were collected by the Bermuda Oceanographic Expeditions (PICKFORD, 1950) and specimens 96-104 were collected by the Discovery Expeditions (PICKFORD, 1952). There is an undescribed specimen in the Zoological Museum at Copenhagen, collected by the Atlantide (Stn. 139) and identified by Dr. ANTON F. BRUUN. It is a Stage 2 larva measuring 11 mm. in mantle length and is listed in the author's catalogue as specimen 120.

The author wishes to take this opportunity of expressing her thanks to Dr. ANTON F. BRUUN and the Committee of the Galathea Expedition for the privilege of participating in the work of the expedition during three months, while collections were being made in the Indian Ocean, Gulf of Siam, and South China Sea. Dr. TORBEN WOLFF kindly made notes on the natural color of some specimens that were captured at a later date.

## DESCRIPTION OF THE SPECIMENS

### Specimen 105

This remarkable specimen, taken off Durban, is a sexually mature female that had recently spawned. One egg can be seen in the coelom, and another distorted egg was found in the preserving fluid. The external surface is badly rubbed, the arm tips are damaged, and most of the suckers are lost. The oral face of the web, examined two months after preservation in neutral sea-water formalin, was still black. The right eye is damaged and the lens gone, the left eye is missing.

The standard measurements are given in Table 2, and the corresponding indices are listed in comparison with the range and mean for previously described Stage 5 females. The mantle length is approximately 100 mm. This is about 25 % greater than the estimated mantle length for the largest previously described specimen. The latter (Specimen 1; PICKFORD, 1946, 1948) was taken by the Dana Expedition in the Gulf of Panama and is also a sexually mature female. Its apparent mantle length, 63 mm., was undoubtedly shorter than natural

Table 1. List of specimens of *Vampyroteuthis infernalis* Chun taken by the Danish Deep-Sea Expedition

Spec. No. <sup>1</sup>	Stn	Locality	Latitude	Longitude	Date	Depth m.	EFD m. <sup>2</sup>	Stage and Sex
105	190	Off Durban	29°42'S	33°19'E	3.II.51	2720	—	Mature ♀
106	—	—	—	—	—	—	—	Mature ♂
107	279	Seychelles to Ceylon	1°00'N	76°17'E	8.IV.51	4320	—	Fragments of young adult, ? sex.
108	301	Bay of Bengal	19°30'N	86°32'E	25.IV.51	1110	700-800	Stage 4 larva, ? sex.
109	—	—	—	—	—	—	—	Adult, ? sex.
110	314	—	15°54'N	90°17'E	3.V.51	2600	—	Adult ♂
111	318	—	9°02'N	93°07'E	5.V.51	1440	800-1100	Adult ♂
112	—	—	—	—	—	—	—	Adult, ? sex.
113	471	Sunda Trench	10°26'S	114°15'E	10.IX.51	2990-2810	—	Stage 3 larva, ? sex
114	472	—	10°24'S	114°07'E	10.IX.51	2250-2030	—	Stage 4 larva, ? ♀
115	—	—	—	—	—	—	—	—
116	—	—	—	—	—	—	—	—
117	—	—	—	—	—	—	—	Eye of larva, prob. Stage 4.
118	601	Tasman Sea	45°51'S	164°32'E	14.I.52	4400	—	Immature Stage 5 ♀
119	660	Kermadec Trench	35°35'S	178°51'W	22.II.52	7800-7310	—	Immature Stage 5 ♀

1. Author's list, see text.

2. Estimated Fishing Depth, given only for pelagic hauls.

owing to strong contraction of the mantle, and an estimated true mantle length of ca. 76 mm. was suggested. The mantle-width index of Specimen 105 is at the lowest limit for Stage 5 females. Head width could not be measured accurately on account of the damaged condition of the remaining right eye, but it was estimated by doubling the distance from the center of the head to the outer limit of the lensless right eye. The head-width index, based on this measurement, is at the lowest limit for Stage 5 females.

The anterior fin-length index is normal, but the fin is unusually narrow. This is certainly due, in part, to rubbing of the delicate fin margin. The fin-base index is normal.

The first right arm has a regenerated tip, and the extremities of the fourth right and first, second and fourth left arms are damaged, precluding accurate measurement. Of the remaining arms, the third left is longest, measuring 200 mm., while the second and third right arms measure 190 mm. The total length of the animal is approximately 285 mm. and, on the assumption that the third left arm was actually longest (or subequal to the longest), the arm-length index is 70. This is somewhat greater than the highest hitherto recorded but, on account of the positive growth coefficient for arm length in relation to mantle length, it was predicted that the arms of larger animals would be relatively longer than those of smaller specimens (PICKFORD, 1948). The state of preservation does not permit comparison of the

order of arm length, but the arms are evidently subequal; previous data indicated that the first and second arms tended to be longer than the third and fourth, although the differences are not great and there are many exceptions.

Measurements of web depth are as follows: sector A, 104 mm.; left sector B, 84 mm.; right sector B, 82 mm.; left sector C, 77 mm.; right sector C not sufficiently well preserved for measurement; left sector D, 62 mm.; right sector D not sufficiently well preserved for measurement; sector E, 96 mm. The order of web depth is therefore A:E:B:C:D. In other specimens, as in this, the A sector is usually the deepest, but the E sector is most frequently the shallowest. However, the measurement varies greatly with the state of contraction and distortion, so that no special significance can be attached to the greater depth of the E sector in Specimen 105. The web-depth index, and the disparity index between shallowest and deepest sectors, are normal.

The diameter of the largest sucker provides a normal sucker-diameter index. No arms bear a complete set of suckers: none are preserved on the left arms, there are three on the first right arm, seven on the second right, and none on the third and fourth right arms. A specimen of this size would be expected, from previous calculations, to have about 35 suckers on a perfect arm.

The cirri are unusually long and attenuated, perhaps as a result of the conditions of capture and preservation; the cirrus-length index of 15 is well

Table 2. Measurements and indices of Specimen 105, compared with previously described Stage 5 females.

Character	Measurement mm.	Index <sup>1</sup>	Range and mean for previously described specimens <sup>2</sup>
Total length	285	—	180 <sup>3</sup>
Mantle length	100	—	55,63 <sup>3</sup>
Mantle width	60	60	60-75-102
Head width	82	82	80-95-109
Anterior fin:			
Length	57	57	33-53-69
Width	20	32.5	44-50-68
Base	18	31.6	26-38-58
Longest arm	200	70	51-61-68
Sucker diameter	3.6	3.6	2.0-3.0-4.8
Cirrus length	15	15	6.9-9.1-10.9
Web depth:			
Deepest	104	52	43-61-72
Shallowest	62	57.5	43-63-92
Eye diameter	29	29	29-39-48
Fin light organ:			
Length	4.0	4.0	3.9-5.2-6.9
Width	3.6	90	66-88-100
Composite light organ:			
Length	4.2	4.2	5.1-6.7-9.1
Width	2.5	60	31-45-65
Number of nodules ca.	30	—	38-54-76
Gill length	25	25	19-23-28
Number of primary gill lamellae per demibranch	11,12	—	10-12-15
Funnel length	31	31	36-41-47
Lower jaw:			
Rostral length	16	16	12-14-17
Rostral notch	5.5	34.5	34-41-46
Gladius:			
Length	96	—	65 and (?) 76.2 <sup>3</sup>
Inner asymptote length <sup>4</sup>	77	80.2	66-75-83
Outer asymptote length <sup>4</sup>	60	78	62-72-81
Pro-ostracal breadth	25	26	18-23-27
Lateral plate breadth	38	39.6	32-38-44
Conus vane:			
Breadth	37	38.5	31-36-45
Depth	19	19.8	14-18-22

1. Definition of indices and previous data from PICKFORD (1948).
2. Indices or numerical value if so indicated.
3. Measurement in mm. for two previously described mature females.
4. Measured from apex of conus, without rostrum.

above the range for Stage 5 females and, with one doubtful exception (Specimen 28; PICKFORD, 1948), no such high values have been recorded for younger stages. The number of primary cirrus pairs could

be counted on some of the arms since, even when the first sucker is missing, its torn stump can be seen. The first arms have 7 pairs, the second right 7 pairs, the third left 6 pairs; the fourth arms also probably had only 6 pairs, although this is not certain. However, the specimen evidently conforms to the pattern for Indo-Pacific *Vampyroteuthis*, discussed in the next section; in these oceans the typical maximum number of primary cirrus pairs is 7, the typical minimum number 5.

The diameter of the damaged right eye is somewhat uncertain on account of its collapsed condition. The estimated diameter gives an eye-diameter index which is at the lowest limit of the range for Stage 5 females. The lens is not preserved, but a rough estimate based on the diameter of the lensless pupil aperture suggests that it may have been about 9 mm. Previous calculations indicate that this would be about right for an eye of this size.

The fin light organs are preserved; the length-width index is normal but the size, in terms of mantle length (fin light organ-length index) is low, at the lowest limit for Stage 5 females. The left composite light organ is better preserved than the right and was therefore selected for study. The shape, reflected in the width-length index, is normal, but the relative size in terms of mantle length is unusually small. The small size of the organ is also apparently reflected in the small number of luminescent nodules; only about 30 could be counted, as compared with normal counts of 38-76 in Stage 5 females (mean 54). It was thought, from previous data (PICKFORD, 1948), that the composite light organs were significantly larger in females than in males, but, in the case of Specimen 105, the length index is at the lowest limit even for Stage 5 males. The hypothesis of a sex difference, which is reviewed in the next section, may have to be abandoned but, at the present time, it seems more probable that Specimen 105 is aberrant.

The gills are well preserved and the relative length, reflected in the gill-length index, is normal. There are 11 primary lamellae in the outer and 12 in the inner demibranch, making a total of 24 if the terminal lamella is included. This is normal for adults of either sex. The hypothesis that no new gill lamellae are added after metamorphosis receives welcome confirmation from so large an animal.

The funnel is rather short, with a funnel-length index of only 31; similar figures have been recorded for males but there are no grounds for suspecting that there is a sexual difference and presumably the

low value in Specimen 105 can be attributed to the state of contraction.

The jaws were studied *in situ* since it was not desired to damage the specimen by removal of the buccal mass. Only two measurements could be made, the rostral length and rostral notch length of the lower jaw. The rostral-length index is near maximal for Stage 5 females. Previous studies suggested that the jaws of adult females were relatively larger than those of males, and the rostral-length index of Specimen 105 supports this hypothesis. However, two immature Stage 5 females (see below) were low. The rostral notch of Specimen 105 is rather short, but the index is in the range for previously described specimens.

The diameter of the single coelomic egg is 4 mm., in good agreement with previous findings which indicated an average diameter of 3.86 mm for free eggs attributed to this species (PICKFORD, 1949). The diameter of the sucker-like oviducal aperture is 9 mm., which is very large. In the case of the two previously described adult females the diameters were 3.2 mm. and ca. 5.5 mm. respectively. In terms of actual (not corrected) mantle length these figures give indices of 9, 5.8 and 8.7 respectively.

The gladius was removed and studied in detail. The total length of 96 mm. is greater than anticipated from previous data regarding the relationship between gladius length and mantle length. Calculations based on equations for all stages (PICKFORD, 1948) indicated that a specimen of 100 mm. mantle length would have a gladius of about 87 mm. It should be noted that one other very large female (Specimen 2; PICKFORD, 1948) had a gladius length that was also considerably longer than anticipated (mantle length 55 mm., gladius length 65 mm.). These differences may be incidental to the inaccuracies of exact mantle length measurement, but it is possible that a different allometric equation should be applied to mature females. The proportions of the gladius, reflected in a series of indices given in Table 2, are normal for Stage 5 females. The only feature of interest was the presence of a well developed rostrum, an apical projection that is sometimes, but not always, present in the vampyromorph gladius; an example was figured previously (PICKFORD, 1948, Fig. 41).

As a general conclusion, it can be stated that Specimen 105 is an unusually large but otherwise typical female of *Vampyroteuthis infernalis* Chun.

#### Specimen 106

This sexually mature male was taken off Durban, South Africa, in the same haul as the sexually mature female described above. It is badly rubbed and a great deal of mud is entangled in the skin and on the exposed underlying tissues. The color, after five years preservation in neutral sea water formalin, is completely faded. A tangled mass of skin at the apex makes an exact measurement of mantle length uncertain, but an approximate estimate of 46 mm. is probably correct. Calculations from the rostral length of the lower jaw, which measures 5.5 mm., would give an expected mantle length of 43.9 mm. The size is therefore in agreement with the mean of 49.2 mm. based on four previously captured sexually mature males (range 44-55 mm.). This finding tends to confirm the hypothesis that adult males are considerably smaller than adult females, but a mature male described below (Specimen 110) was somewhat larger.

The mantle width, which was ca. 34 mm., could only be measured approximately. The head width, ca. 31 mm., is also uncertain since both eyes are damaged. The corresponding indices for mantle-width and head-width are 74 and 67.5 respectively; the former is in the expected range for adult males, but the latter is unusually narrow.

The fins are in good condition, except for rubbing of the skin. Measurements are the same for right and left sides: length 32.5 mm., maximum breadth 13 mm., width of fin base 10 mm. The fin-length index, 70.7, is higher than previous records for Stage 5 males, but no great significance can be attached to this owing to the uncertainty as to the true mantle length. One Stage 5 female had an index of 69. The fin-width index is unusually narrow, 40.0, probably owing to rubbing of the skin. The fin-base index is also unusually narrow, 30.8, presumably for the same reason.

The arm crown is badly damaged; the longest arm (third left) measures 120 mm. It is complete but badly rubbed and apparently attenuated. The approximate total length of the animal is ca. 160 mm, giving an arm-length index of 75 which is in the normal range, but high. The suckers and cirri are not preserved and the web depth could not be studied.

The eyes are collapsed and distorted, but the eye diameter was probably about 14 mm. This gives an eye-diameter index of 30.5 which is rather low. The diameter of the somewhat damaged left lens is about 6 mm., giving a lens-diameter index of 42.8, which is normal for adults of both sexes.

The light organs are not preserved, and the gills are too badly rubbed for study. The rostral length of the lower jaw is 5.5 mm. giving a rostral-length index of 12, which is normal for adult males, thus tending to confirm the hypothesis that males have smaller jaws than females. The rostral notch measures 2 mm. and the rostral-notch index, 36.4, is rather low for Stage 5 males. The gladius was not studied.

#### Specimen 107

This example, taken between the Seychelles and Ceylon, consists of five fragments of a medium sized specimen, preserved in alcohol. Apparently all parts belonged to the same specimen and the following observations on the fragments may be noted:

1. Part of the arm crown with the posterior salivary glands attached. The oral face of the web was black, two weeks after capture.
2. The rest of the arm crown.
3. The buccal mass. Length of lower jaw 6 mm., rostral length 5 mm., length of rostral notch 1.6 mm. The estimated mantle length, calculated from the rostral length, is 37 mm. The rostral notch index, 32, is rather low.
4. The brain with optic lobes and eyes; the whole length of the oesophagus attached.
5. Parts of the visceral mass with the gills. The gill length is ca. 6.2 mm., and the estimated mantle length, calculated from the gill length, would be about 33 mm. This is in reasonable agreement with the estimate of 37 mm. derived from the lower jaw.

The sex could not be determined and the fins are not preserved. However, the estimated mantle length suggests that the specimen was a young individual that had just completed metamorphosis. It is larger than any recorded Stage 4 specimen, and within the minimum for Stage 5.

#### Specimens 108 and 109

The damaged remains of two specimens were taken at Stn 301, in the Bay of Bengal. The better preserved example, Specimen 108, was found entangled in the net and, in consequence, it is severely damaged. The oral face of the web, when freshly caught, was black. The sex is presumably female, since no remains of male organs could be discovered. The mantle length of 22.5 mm. indicates that it was a larva, probably in Stage 4. However, no signs of

the posterior fins could be discovered, which suggests that they may have been in the last stages of resorption and, in view of the poor condition of the specimen, their apparent absence is not significant. The size agrees with the mean for Stage 4 larvae, and is far below that of any metamorphosed Stage 5 specimen. The head width, ca. 24 mm., gives a head-width index of 107, which is in the high range but not unusual. The left anterior fin measures 9 mm., which is larger than would be expected in an animal of this size. The calculated mantle length, derived from the allometric equation for larvae in Stages 2-3, would be 26.7 mm. for an animal with the fin length of this specimen.

Specimen 109 consists of two damaged fragments that apparently belong to the same animal. One piece consists of an arm and web, the other an arm fragment. Both arms have suckers with a maximum diameter of 2.1 mm.; this would correspond to an estimated mantle length of 57 mm., derived from the allometric equation for Stage 5 specimens. The animal may therefore have been an adult male, or an immature Stage 5 female.

#### Specimen 110

This specimen, a male from Stn 314 in the Bay of Bengal, is in poor condition. The mantle skin and fins are torn away from the shell sac and the viscera exposed. The arm crown is badly damaged and the eyes are lost. The oral face of the web, after preservation for five years in formalin, is a deep sepia, almost black but, when freshly captured, it was velvet black. The mantle length is approximately 60 mm. in the preserved specimen, and this will be used for calculation of the indices noted below. However, when freshly captured, it was slightly larger, ca. 63 mm. The gladius length, measured *in situ*, is ca. 55 mm., which gives an estimated mantle length of 59.8 mm., in good agreement with the actual measurement. The gladius length of the largest male hitherto captured (Specimen 13; PICKFORD, 1948) was only 52 mm. and its mantle length only 55 mm. Evidently the newly captured male is larger than any that have been described previously.

Only the muscular axis of the fins remain and the length measurements may therefore be somewhat too short; the left anterior fin measures 22 mm., the right 26 mm. The latter yields a fin-length index of 36.7 which is lower than the hitherto recorded range for Stage 5 males. However, there is no difference between the sexes in respect to relative fin length, and some Stage 5 females have an index as low as

33. The rostral length of the lower jaw is 8 mm., yielding a rostral-length index of 13.4, which is slightly greater than the highest index hitherto recorded for Stage 5 males, but well below the mean for Stage 5 females. The rostral notch measures 3 mm. and the rostral-notch index of 37.5 is normal.

The condition of the specimen does not permit further description. The condition of the male sex organs suggests that it was probably mature, although spermatophores are not preserved.

#### Specimens 111 and 112

Two very damaged specimens were taken at Stn 318 in the Bay of Bengal, both were found entangled in the net. Specimen 111 is in slightly better condition than Specimen 112. The visceral mass is badly damaged, the left eye is gone and the right eye enucleated. When freshly captured, the oral face of the web was black. The mantle length could not be measured directly but was estimated from the funnel length and from the rostral length of the lower jaw. The former measures 18.5 mm. and gives a calculated mantle length of 50 mm.; the latter measures 6 mm. and gives a calculated mantle length of 48 mm. The rostral notch measures 2.5 mm. and gives a normal rostral-notch index of 41.7. The specimen appears to be an adult male.

Specimen 112 consists of the buccal mass with fragments of arms, brain and enucleated right eye. There are remains of viscera and fins. The sex is uncertain, but it may have been a female since no male organs could be discovered. The anterior fin length of 27 mm. yields an estimated mantle length of 50 mm. The rostral length of the lower jaw is 6.5 mm., giving an estimated mantle length of 52 mm. The rostral notch is 3 mm., giving a normal rostral-notch index of 46.2.

#### Specimen 113

One very damaged larva was taken at Stn 471 in the Sunda Trench. The oral face of the web, after five years preservation in formalin, is light brown. The mantle appears to be stretched and the mantle length of 17.5 mm. may be too large. The head width is ca. 10 mm. Both eyes are badly damaged; the eye diameter of ca. 3.0 mm. gives a calculated mantle length of only 12.7 mm. Both anterior and posterior fins are present; they are very damaged on the left side but approximate measurements could be made on the right: right anterior fin length 5 mm., right posterior fin length 4 mm. This larva is obviously in the four-finned Stage 3. The arm crown is in poor

condition, but the number of pairs or primary cirri could be counted on some of the arms: there are 7 pairs on the first left, and first, second and third right arms, but possibly only 6 on the third left. The rostrum of the lower jaw measures 2.1 mm., which gives a calculated mantle length of 17.6 mm.; this tends to support the correctness of the actual measurement and casts doubt on the smaller value derived from the diameter of the damaged eyes. The sex is uncertain.

#### Specimens 114-117

Three metamorphosing larvae, and the eye of a fourth specimen, were taken at Stn. 472 in the Sunda Trench. Some color notes were made on these specimens by Dr. TORBEN WOLFF, at the time of capture. "Specimens A and B (apparently 114 and 115): mouth area sooty black. Ring around the mouth opening and beak has the color given as No. 688 in SÉGUY (*i.e.* dull violet). Soft parts inside beak the same color. Eyes No. 103 (*i.e.* red), intestine proper (a sketch made at the time suggests that the stomach was intended, G.E.P.) No. 56 (*i.e.* deep red). Specimen C, the one with the arms folded (apparently Specimen 116): mouth area No. 110 (*i.e.* pinkish brown)."

Specimen 114 is very damaged and the right eye is lost, although the optic ganglion remains. The mantle has been pulled away from the exposed visceral mass. The oral face of the web was originally black, as shown by notes on the living specimen cited above, but after five years preservation in formalin it has faded to a light brown. The sex is uncertain, probably female since no penis rudiment could be found. The mantle length, measured from the mid point of the head to the exposed end of the hepatopancreas, is 21 mm., but this is undoubtedly too short and estimates of correct values are given below. The head width, obtained by doubling the distance from the mid point to the outer edge of the left eye lens, is 22 mm. The right anterior fin is contracted and the surface rubbed, it measures only 5 mm., but the left anterior fin, which is apparently attenuated, measures 10.5 mm. The right posterior fin is not preserved but on the left side there is a small rudiment that is badly rubbed. This indicates that the specimen is in Stage 4. The remaining left eye is distorted, but appears to have been about 2.8 mm. in diameter. The arms and web are poorly preserved and no suckers remain. The funnel is well preserved and measures 9 mm.; this gives a calculated true mantle length of 25.1 mm. The rostrum

of the lower jaw measures 2.9 mm. and gives a calculated mantle length of 23.9 mm., in good agreement with that derived from funnel length. A mantle length of 24-25 mm. is in the expected range for Stage 4 larvae.

Specimen 115 is a badly rubbed, damaged and distorted larva. Both eyes are present, extruded. As in the previous specimen, the oral face of the web was originally black but has faded to red brown after long preservation. The apparent mantle length of 28.5 mm. may be too long as the specimen is stretched. The head width is 12 mm. Both anterior and posterior fins are present; the left anterior measures at least 6 mm., the right about 5 mm., but the surface is in poor condition. The left posterior fin, which is evidently in the last stages of resorption, measures 1.5 mm. Clearly this is a Stage 4 larva. The arm crown is severely damaged and could not be studied. The left eye measures 6 mm. in diameter, the right 5 mm.; both lenses are damaged. The funnel is 5.5 mm. in length. The rostrum of the lower jaw measures 2.9 mm. The true mantle length may be estimated from each of three measurements and all support the hypothesis that the apparent mantle length is too great: the eye diameter gives a calculated mantle length of 20.6 mm., the anterior fin length ca. 20 mm. and the rostrum 23.9 mm. The sex is uncertain, presumably female.

Specimen 116 was preserved with an everted mantle which protected the fins from undue rubbing. Both eyes remain but the lenses are gone. The arm crown is badly damaged and, as in the two previous specimens, the oral face of the web has faded to a red brown color after long preservation. The mantle length is 17 mm., but this is probably too short. The right eye is 6.2 mm. in diameter and this gives a calculated mantle length of 21 mm. Similarly, the rostrum of the lower jaw measures 2.9 mm and corresponds to a mantle length of 23.9 mm. The left anterior fin is moderately well preserved and measures 9 mm. in length; the left posterior fin is 3.8 mm. The fins of the right side are badly rubbed. It would appear from the relative lengths of the anterior and posterior fins that the specimen had already passed beyond Stage 3 and was entering Stage 4. The fin light organs and the left composite light organ are preserved. There are six pairs of primary cirri on the left and right fourth arms, and the fourth right arm has a complete set of 7 suckers. This would correspond to a mantle length of about 20 mm. The sex is uncertain, presumably female.

Specimen 117 is represented by an eye with the optic ganglion attached. It cannot be the missing right eye of Specimen 114, taken in the same haul, because the optic ganglion of the latter remains in the head. The eye diameter is 8 mm. and corresponds to a mantle length of 25 mm.; the lens diameter is 3.2 mm. Presumably this specimen was a Stage 4 larva.

#### Specimen 118

This specimen, from the Tasman Sea, is exceptionally interesting since it represents the southernmost record for the species. It is a moderately well preserved Stage 5 immature female. The skin is badly rubbed on the external surface of the mantle. The oral face of the web is red brown after five years preservation in formalin. The entire web is rotated dorsally over the back of the head, as in JOUBIN's supposed genus "*Retroteuthis*", but this is undoubtedly an accident of preservation. The measurement of mantle length is difficult on account of the abnormal position of the arm crown which conceals the dorsal surface of the head. However, an approximate measurement made from the ventral aspect indicates a length of 31.5 mm. The mantle width is 25 mm., yielding a normal mantle-width index of 79.5. The head width measures 31 mm., giving a normal head-width index of 98.5. Both fins are moderately well preserved but unequally contracted; the left anterior fin measures 13.5 mm. in length, the right 17.0 mm. The fin-length index, based on the longer right fin, is 56.8, which is normal. The fin light organs are preserved in a fold of skin and measure ca. 1.8 mm.; this gives an index of 5.8, in agreement with the expected value.

The arms are somewhat rubbed and damaged, but the number of suckers and primary cirrus pairs could be counted, as follows:

Arm	Number of pairs of primary cirri	Number of suckers
L 1	7	4 + ?
L 2	6 (?)	4 + ?
L 3	5 (?)	6 + ?
L 4	5	9
R 1	7	5
R 2	6	6
R 3	5	3 + ?
R 4	6	9

The maximum and minimum number of primary cirrus pairs is low, in agreement with other speci-

Table 3. Minimum and maximum numbers of pairs of primary cirri on the arms of each specimen of *Vampyroteuthis infernalis* that is sufficiently well preserved to permit study.<sup>1</sup>

Group	Number of specimens with:									
	Maximum number					Minimum number				
	6	7	8	9	10	4	5	6	7	8
Atlantic (previous records)	-	15	20	9	2	1	13	31	7	1
Indo-Pacific:										
Previous records	1	15	10	-	-	4	18	6	1	-
Galathea	-	3	1	-	-	-	1	4	-	-
Total	1	18	11	-	-	4	19	10	1	-

1. The maximum number is usually on the first or second arms, the minimum number of the third or fourth. Previous data from PICKFORD (1948, 1952).

mens from the Indo-Pacific (Table 3). The maximum number of suckers, 9, corresponds to a mantle length of only 25.5 mm., which is considerably less than the actual measurement. However, previous data showed wide variations which may be attributed, in part, to the fact that new suckers are added intermittently. The smallest number of suckers, 5, is in correct relation to the largest number. The diameter of the largest sucker is 0.9 mm., giving a normal sucker-diameter index of 2.85.

The funnel is stretched and unusually long, measuring 15 mm. which gives a funnel-length index of 47.6, at the upper limit of the range. The eyes are damaged and distorted, the diameter of the left eye is ca. 10 mm., giving an eye-diameter index of 31.8, which is within the normal range but low. The gills are badly rubbed and could not be studied. The rostrum of the lower jaw measures 4.1 mm., giving a rostral-length index of 13 which is slightly below the mean for Stage 5 females and at the upper limit of the range for Stage 5 males. The rostral notch measures 1.9 mm. with an index of 46.3 which is at the upper limit for Stage 5 females.

The foregoing description suffices to show that this specimen is in no way different from other members of its sex and age group, and that it is a fairly typical member of the Indo-Pacific vampyromorph population.

#### Specimen 119

This is a rather well preserved immature Stage 5 female from the Kermadec Trench. The following color notes were made by Dr. Torben Wolff at the

time of capture: "Fin light organ turquoise opalescent with yellowish-green tinge. Gills pale orange. Rectum with white end, otherwise pigmented black. Liver on each side of rectum SÉGUY No. 127 (*i.e.* red brown). Web velvet black. Mouth area as in specimens A and B from Stn 472."

The epidermis is largely rubbed away from the external surface, except on the oral face of the web which is red brown after five years in neutral formalin. Dr. WOLFF injected the vascular system with a carmine suspension, but unfortunately the carmine has dissolved in the preserving fluid (presumably owing to its alkalinity) and the entire specimen is now stained deep purple. The eyes are sunk in the gelatinous tissues of the head. The dorsal sectors of the web are rotated backwards in the manner of JOUBIN's supposed vampyromorph genus "*Retroteuthis*", but this is undoubtedly the result of abnormal contraction of the dorsal musculature. The mantle measures 41 mm. in length; the mantle width is 29 mm. giving a mantle-width index of 70.7 which is normal for Stage 5 females. The head width is 30 mm., which gives a head-width index of only 73, this is unusually low for Stage 5 specimens of either sex. The left anterior fin measures 18.5 mm. in length, the right only 16 mm.; the fin-length index, based on the longer left fin, is 45.1, which is in the normal range for Stage 5 specimens of either sex. Fin light organs are present, rubbed up in folds of skin. The right composite light organ is also preserved; it has a length of 2.3 mm. giving an index of 5.6, which is normal. The number of luminescent nodules is ca. 70, which is in the high range but not unusual.

The arms are moderately well preserved and the number of suckers and primary cirrus pairs could be counted in most instances, as follows:

Arm	Number of pairs primary cirri	Number of suckers
L 1	7	10
L 2	8	9 or 10
L 3	7	9 + ?
L 4	7	13
R 1	-	-
R 2	7	10 or 11
R 3	8	12
R 4	6	13

The maximum number of cirrus pairs, 8, is at the upper limit for the Indo-Pacific (Table 3). The maximum number of suckers, 13, occurs, as expected, on

the ventral arms and corresponds to that calculated for a specimen measuring 37 mm. in mantle length. This is in reasonable agreement with the actual measurement. The minimum number of 9 or 10 is also in agreement with the predicted value.

The rostrum of the lower jaw measures 5.0 mm. and the rostrallength index of 12.2 is at the lowest limit for Stage 5 females. The rostral notch measures 2.0 mm. and gives an index of 40, which is typical.

## DISCUSSION

### A. Morphological Characters

In the preceding descriptions of the specimens constant reference has been made to expected indices, and other calculated standards of reference, derived from a previous study of the Dana collections (PICKFORD, 1948). Measurements and indices were compared with their expected numerical values and, when appreciable differences were noted, attention has been called to this circumstance. However, in no instance, were the deviations of sufficient magnitude to warrant a change in the basic assumption that there is but a single species of *Vampyroteuthis*, widely distributed in the middle depths of all tropical and subtropical oceans.

Special attention has been directed towards the following three problems: the natural color of the species, the problem of differences of size and bodily proportions between adult (Stage 5) males and females, and the possibility of racial differences between the Indo-Pacific and Atlantic Oceans.

It was observed by the zoologists of the Discovery Expeditions (PICKFORD, 1952) that freshly captured specimens were deep purple in color, not black as formerly supposed. Moreover, the oral face of the web was black, not red brown as previously described. Some of the specimens captured by the Galathea in the Bay of Bengal were studied by the present author at the time of capture. Unfortunately they were all extremely damaged and most of the skin was rubbed away from the outer surface of the body. Presumably owing to this circumstance, none of these specimens showed the purple color described by the Discovery Expedition, but in all instances the oral face of the web was black. The oral face of the web was also black in the large female from Stn. 190 (Specimen 105), examined two months after preservation in neutral sea water formalin, and in the damaged specimen from Stn 279 (Specimen 107) which was preserved in alcohol and examined two weeks after capture. All the remaining

specimens, examined five years after preservation in formalin, have a more or less faded, sepia or red brown web. But color notes on some of these specimens, made by Dr. TORBEN WOLFF at the time of capture, indicate that here also the oral face of the web was originally a sooty black.

Apart from primary and secondary sexual characters, the following suspected differences between adult males and females were noted previously: males are smaller at sexual maturity, the mantle width is narrower, the shortest arms may be relatively shorter, the composite light organ is apparently smaller, the lower jaw is significantly smaller and the length of the rostral notch slightly greater; it is also possible that the gladius length is slightly shorter in relation to mantle length. As far as the data permit, attention has been paid to each of these characters, as follows:

1. The range for absolute mantle length in sexually mature specimens is extended upwards for both sexes by the Galathea material, but the sex difference remains. Female Specimen 105 measures 100 mm., as compared with 65 mm. and an estimated 76 mm. for the two previously described females. The male from the same station (Specimen 106) measures 46 mm. and is in the range covered by four previously described mature males (44-55 mm.), but a male from the Bay of Bengal (Specimen 110), which was presumably mature, measures 60 mm.

2. In respect to mantle width, the new data for Stage 5 specimens (3 females and one male) has no significant effect on the mean mantle-width index, although the largest female is unusually narrow, perhaps because it had recently spawned. The revised mean mantle-width index for 14 Stage 5 females is now 74, instead of 75; the revised mean for 11 males is 65, instead of 64.

3. The arm crown was not sufficiently well preserved in any of the specimens to permit study of relative arm length.

4. The composite light organ is preserved in only two Stage 5 specimens (Specimens 105 and 119). Specimen 105 has an unusually small composite light organ for a female, but the other is normal. The revised range and mean for the composite light organ-length index of Stage 5 females (11 specimens) is 4.2-6.4-9.1, as compared with a previous range and mean of 5.1-6.7-9.1. The revised mean is still well above the mean for Stage 5 males, and the ranges do not quite overlap, 4.0-4.7-6.4. It still seems probable that the composite light-organ

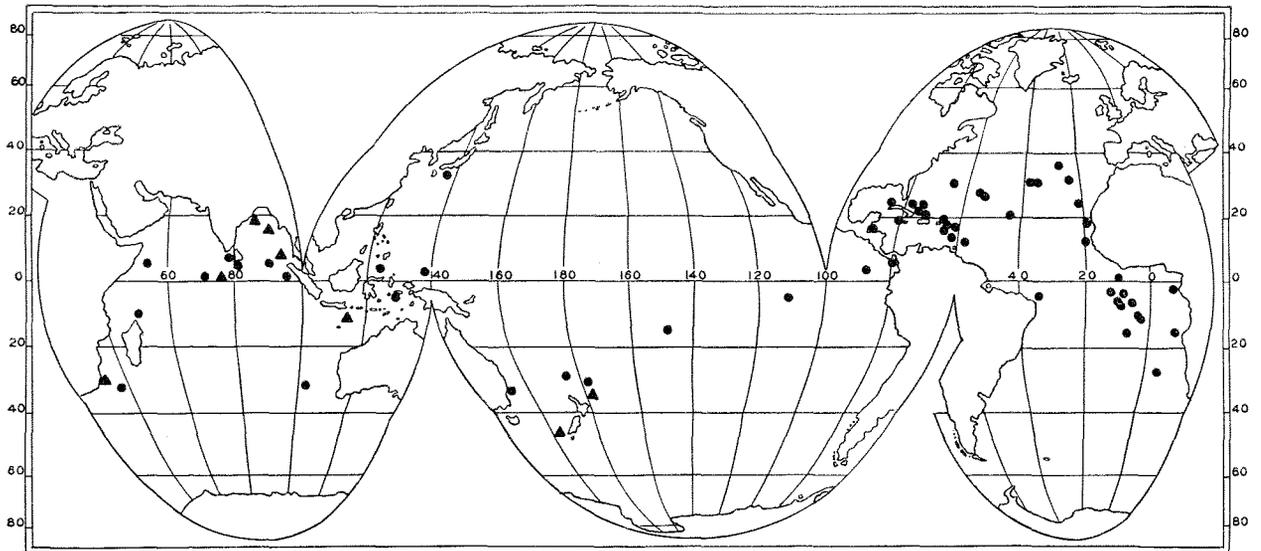


Figure 1. *Vampyroteuthis infernalis* Chun. Distribution. ● Previous records. ▲ New records by the Galathea Expedition.

may be relatively larger in adult females, despite the new low recorded for Specimen 105.

5. The new data (3 females and 2 males) tends to confirm the hypothesis that females have relatively larger jaws, although one female (Specimen 119) had an unusually small rostral-length index for specimens of this sex. The revised mean rostral-length index for 15 females is essentially the same as before, 14.4; the revised mean for 11 males is unchanged, 11.9. There seems to be little doubt that there is a sex difference in respect to this character.

6. On the other hand, data for the length of the rostral notch (3 females and 3 males) fails to clarify the supposed sexual difference. The mean for 12 females is reduced from 41 to 40, and the mean for 12 males is reduced from 45 to 44. The change is insignificant.

7. The relatively long gladius of the sexually mature female (Specimen 105) tends to confirm the possibility that this structure may have a somewhat greater relative length in females.

The only real difference between Atlantic and Indo-Pacific specimens concerns one character, the number of pairs of primary cirri on the arms. A study of the fine series in the Dana collections indicated that Atlantic specimens tended to have one more pair of primary cirri than those from the Indo-Pacific. This hypothesis was supported by an examination of the Discovery specimens (PICKFORD, 1952). Not many of the Galathea specimens have an arm crown that is sufficiently well preserved to determine this character, but as far as the evidence goes (Table 3) the results appear to confirm the

previous findings. There are no exceptions to the rule that Indo-Pacific specimens never have more than a maximum of 8 pairs (usually on the first or second arms) and more than a minimum of 7 pairs (usually on the third or fourth arms). The typical maximum number for the Indo-Pacific is 7, the typical minimum number 5, whereas in the Atlantic the typical maximum number is 8 and the typical minimum number 6.

#### B. Distribution and Biology

Some of the new records add valuable information regarding the geographical distribution of the species (Fig. 1). The two specimens from off Durban (Specimens 105 and 106) are of special interest because there has been only one previous record, taken by the Discovery Expedition, from this region. The newly established records from the Bay of Bengal and the Sunda Trench confirm the wide occurrence of *Vampyroteuthis* in the Indian Ocean. There are still no records from the South China Sea, although one of the pelagic hauls was made in this area at a depth of 3400-3800 m. in the express hopes of catching *Vampyroteuthis* (Stn. 407). The depth may have been too great, however. Two of the Dana specimens were taken in the East Australian Basin, but the new record from the Tasman Sea (Specimen 118) is considerably further south. It is, in fact, the southernmost record for the species. The Dana Expedition collected specimens from north of New Zealand and the new record from the Kermadec Trench (Specimen 119) establishes the widespread occurrence of *Vampyroteuthis* in this general area.

Two hypotheses advanced previously (PICKFORD, 1946) appear to receive partial support from our enlarged knowledge of the distribution of *Vampyroteuthis*, viz. 1. that the species can pass from the Atlantic to the Indian Ocean by way of South Africa, and 2. that it can pass from the Indian to the Pacific Ocean not only by way of the East Indies but also south of Australia. However, no specimens have yet been taken either from the region directly south of Cape Agulhas or from the waters south of Australia, so that final proof is still lacking.

Most of the Galathea specimens were caught in bottom hauls from deep water but, since open nets were employed, there is no evidence that they could not have entered the nets during lowering or raising. The data on depth distribution therefore provides no decisive evidence that would extend our knowledge of the vertical distribution of the species to greater depths than those hitherto recorded. In a few instances, where hauls were made in middle depths, the range is in agreement with previous records which indicate that this bathypelagic species occurs most abundantly between 1500 and 2500 m. and that none have been taken in depths of less than 300 m.

Two sexually mature specimens, a male and a female, were taken together in the same haul, off Durban in February, 1951 (Specimens 105 and 106). A very large adult male (Specimen 110) was taken in the Bay of Bengal in April, 1951; it was probably sexually mature although the poor state of preservation did not permit observations regarding the presence of ripe spermatophores in the ducts. An attempt was made previously (PICKFORD, 1946) to determine whether there was a seasonal difference in the frequencies of capture of young larvae or sexually mature adults that would throw light on the possible occurrence of a breeding cycle. The results were indecisive on account of the geographical scattering of the stations, the small numbers taken at the same time in any one locality, and the fact that no one area has been collected at all seasons of the year. However, larvae appear to occur at all times of year and the evidence regarding sexual maturity was fragmentary. The best data was for the Indo-Australian Basin in which there were indications that sexually mature individuals were absent from the catches in September and October

and appeared in November and December. Even if this could be established, which is doubtful, the breeding period must be different in other regions. A single mature female was taken by the Princess Alice in the Monaco Deep in August, and a mature male and female were captured by the Dana Expedition in January and September respectively, in the Gulf of Panama. The new records tend support the view that sexually mature individuals may be found at all seasons of the year, but if the breeding season in the Indian Ocean begins in November the capture of a spawned out female in February (Specimen 105) would be expected.

## SUMMARY

Fifteen specimens of *Vampyroteuthis infernalis* Chun were captured by the Danish Deep-Sea Expedition in the Indian Ocean and Western Pacific, making a total of 120 known specimens. Measurements and indices confirm the hypothesis that there is only a single species, but the number of pairs of primary cirri is less in the Indo-Pacific than in the Atlantic Ocean confirming the hypothesis that there may be a racial difference between these regions. The oral face of the web is black in freshly captured specimens, confirming the observations of the Discovery Expedition, but the color fades to brown after long preservation in formalin. A sexually mature male and female were taken off Durban, South Africa; the female, which had recently spawned, is 25 % larger than any hitherto captured but does not differ significantly in its proportions. An adult male from the Bay of Bengal is somewhat larger than any hitherto recorded for this sex. New data confirms the hypothesis that adult females are larger than adult males, and that there are minor sex differences in the bodily proportions of Stage 5 males and females.

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