Exuviation and Variation of Plankton Copepods with special reference to Calanus finmarchicus.

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In the life history of *Calanus finmarchicus* it has been observed that twelve stages intervene between the laying of the egg and the attainment of maturity. The first six of these are the nauplius or larval stages; the others are the copepodite or postlarval stages. Successive stages are separated from one another by an exuviation and, contrary to what occurs among higher crustacea, the copepods undergo no further exuviation after sexual maturity has been reached. All copepod exuviations are, therefore, developmental and not merely the result of continuous growth.

The changes in external form which *Calanus* undergoes in passing from one stage to the next have been described recently by Marie Lebour ("Stages in the Life History of Calanus finmarchicus," Journ. Mar. Biol. Ass. Plymouth, XI, March, 1916), whose paper is not concerned with questions of variation in growth and consequently does not anticipate the results contained in the present report. In his "Notes biologiques sur les Copepodes de la mer Norvégienne" (C.P. I.E.M. Pub. Circ. 22, Copenhagen 1905) D. Damas defined the copepodite stages of *C. finmarchicus* and stated that the five phases of metamorphosis leading up to the adult form probably correspond to as many successive exuviations. The extraordinary variation in length met with in stage IV., together with the character of the coxal teeth or denticulations on the inner margin of the basal joint of the fifth pair of swimming feet, to which neither Marie Lebour nor D. Damas makes any reference, might lead to the supposition that an additional moult would be intercalated within the period occupied by this stage, but this is not so. There remains the possibility which can only be substantiated by experimental rearing, that there is more than one race of *C. finmarchicus* in the material examined. The stages which were studied at the Atlantic Biological Station, St. Andrews, N.B., during the months of June, July and early part of August 1916, were III, IV, V, and VI., the last including the adult male and female. Besides *C. finmarchicus*, observations were made

upon *Eurytemora*, *Tortanus*, *Acartia*, *Pseudocalanus* and *Metridia*, which will be detailed in their turn.

A. Calanus finmarchicus.

Stage III. In this stage there are five free thoracic segments in the forebody, two segments in the urosome, four pairs of swimming feet and the fifth pair (p.5)[1] rudimentary.

Only twenty-three specimens of this stage were examined, all being from "Prince" Sta. No. 3, June 28th, 1916, 10 fathom tow.

Length Variation. The length varied from 1·5 mm. to 1·8 mm. with an average of 1·615 mm. The variation is continuous without any abrupt deviations which might be taken to indicate the existence of two races at this stage.

Exuviation. During the stages intervening between its successive moults, a copepod is continually growing and acquiring the characteristics of the following stage within its cuticle, which becomes stretched to its limit of elasticity. The cuticle of the next stage, owing to its larger surface, is wrinkled and crowded within the old one. When it is ready to exuviate, the copepod first withdraws its eating and swimming appendages and the caudal furca, beginning from the inner lobes of the eating appendages, the inner rami of the swimming feet, and the two rami of the caudal furca; the antennæ are the last which it withdraws. The new setæ loosen themselves from the exuvia by withdrawing within the body of the appendages as if they were being turned inside out from the bases. This turning inside out process is never completed for when the setæ have been pressed in until their tips are on a level with their bases the pressure created stretches the internal cuticle until the exuvia reaches its limit of elasticity and breaks on the top of the head and along the back. As soon as the exuvia is broken the pressure is reversed. The setæ are again stretched out, in so doing pushing the exuvia away from the copepod. The setæ of the eating and swimming appendages are forced out by their contents swelling and exerting pressure at the tips (Fig. 1), whereas those of the caudal furca are pushed out by the contents of the rami swelling and exerting such pressure around the setæ that the bases of the setæ are pushed out as cylinders about their protruding tips (Fig. 2). These cylinders lengthen and as they lengthen the setæ are brought farther out from the body until they are quite stretched out

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[1] List of abbreviations used in the text.

p 5, Fifth swimming foot or feet; *Li I*, First inner lobe; *Re* Outer ramus or branch of an appendage; *Ri*, Inner ramus; *Bi*, First coxal or basal joint; *Se*, Outer marginal setæ; *St*, Terminal setæ.

For explanation of figures see end of report.

and the cylinders disappear (Fig. 3). The pressure is greatest at the tips of the rami as is shown by the different lengths of the cylinders formed by the unfolding setæ; those of the middle termina setæ being longer than the other terminal ones which in their turn are longer than the one of the outer seta (Fig. 2).

During this energy consuming process of exuviation the stored supply of oil within the copepod, which is comparatively large at the beginning of exuviation, gradually diminishes as it is being used for food. The copepod does not dart about in the water, but remains apparently motionless except for an occasional quiver as it frees itself from its appendages.

After the setæ are quite unfolded the pressure exerted by the tissues is so great that it forces the tips of the rami into the setæ, thus forming an inner cylinder at the base of each seta (Figs. 2-3). These inner cylinders are also of definite lengths, those of the two middle terminal setæ being twice as long as the other two, and four times as long as the outer one. If any seta of the caudal furca, except the inner one, is pulled off, it slips off this inner cylinder formed by the ramus at its base and leaves it exposed (Fig. 2).

If the copepod is in a healthy active condition, initial attempts to regenerate lost setæ of the caudal rami are made and usually an irregularly shaped, sometimes even bifurcated seta protrudes from the rim of the cylinder (Fig. 4). When the setæ do not wholly break away from their bases but are injured or broken, regeneration is also attempted (Fig. 27).

Among all the individuals of *C. finmarchicus* III examined, none was found exuviating to stage IV., but an excellent example of *C. hyperboreus* III. in this condition (Fig. 5) was obtained in a vertical haul from "Prince" Sta. 3 on May 24th. This species differs from *finmarchicus* in certain morphological features, but the two are so closely related that the exuviation of both of them from one stage to another takes place in a similar manner.

Stage IV. In this stage there are five free thoracic segments in the forebody, each with a pair of swimming feet, and three abdominal segments in the urosome. The ramus externus (Re) and ramus internus (Ri) of the fifth feet (p5), each consists of one joint. On the proximal joint (Bi) of the stem of the fifth foot there are coxal teeth like those of the adult but with a different distribution and varying in number.

Length variation. One hundred and forty eight specimens of stage IV., taken in several hauls from "Prince" Sta. 3, were examined. As shown by graph. I, instead of there being a continuous variation in length, as appears to be the case in stage III, about a single mean,

there are two averages, one large and the other small. The occurrence of these two size-classes gave rise to the supposition that there might be an ecdysis intercalated within this stage. Of twenty-seven examples examined from a vertical haul made on May 24th the averages were 2·5 mm. and 3·2 mm.; of 116 examples from a 10 fathom tow on June 28th, the averages were 2·1 mm. and 3·1 mm. Both in the haul and in the tow there were a great many more of the smaller individuals, 23 of the 27 from the vertical haul and 87 of the 116 from the tow, belonging to the small size class. If there were an exuviation during this stage such a large variation in the numbers of the individuals of the two sizes would not be expected, but if there were two races of *C. finmarchicus*, this variation could be easily explained by one race being more numerous than the other.

The coxal teeth of the fifth feet in stage IV, besides varying in number, seem to have no regularity in their distribution. Usually they are more or less scattered, although sometimes, on one or both of the feet, they may be in a distinct transverse or marginal row, or they may be in a row and scattered as well. They are arranged in two principal ways, which correspond to the two leading size classes, as is shown by the similarity of the graphs 1 and 2.

In the one class, containing small individuals, the teeth are generally few in number, from three to ten, and of a certain size, but they may be more numerous and smaller, the numerical and substantive variation in this regard showing no regularity. In the other class containing large individuals, generally there are from eleven to eighteen teeth of a large size. Graph 3 shows the correlation between the lengths and the teeth. As a general rule, the shorter the individual the fewer are the coxal teeth. The few-teeth-small-size-class includes those with lengths from 1·8 mm. to 2·7 mm., and teeth from three to eleven in number. The many-teeth-large-size-class includes those with lengths from 2·7 mm. to 3·2 mm. and teeth from eleven to eighteen in number. Since one class contains many more individuals than the other, one might be led to believe that the supposition that there are two races of *C. finmarchicus* is correct, though not definitely recognizable in later stages.

Although in both these classes there is no regularity in the distribution of the coxal teeth, yet each has a characteristic appearance. A typical example of the teeth of the small size is given in Fig. 6, and of the large size class in Fig. 18. The small size class may have large or small teeth. As a general rule when the teeth are large they are not so numerous as when they are small. Some specimens occurred with comparatively large and few teeth (Figs. 8, 11), while others had small and many teeth (Figs. 9, 10, 12); and there were quite a number

with both large and small teeth together (Figs. 13, 14, 15) suggesting that new teeth may be intercalated. This idea was strengthened by the observation that the nuclei below the small teeth were usually very large and closely appressed to the cuticle, as if indicating active metabolism. One specimen occurred with supernumerary teeth (Fig. 7), five needle-shaped teeth at the proximal end of the left basal joint, while the other teeth on this joint were large and numerous. Another specimen with a normal row of ten teeth on the left B I was abnormal in having but one tooth on the right B I but had a normal internal row of the teeth of stage V. This is not only a proof that the few-teeth-small-size-class exuviates directly to stage V, but that an abnormality occurring in one stage may disappear in the next. The large size class may have large teeth (Figs. 16, 18, 19) or small teeth (Fig. 17). As a rule, in this class, the teeth are large and crowded in an irregular marginal row.

These two quite distinct tooth classes seemed to indicate that there is an ecdysis during stage IV. It would be expected, if this were true, that the numbers of individuals belonging to each class would be about equal. This is not the case as mentioned before and illustrated by the graphs.

Exuviation. The most convincing proof of ecdysis during stage IV would be to find a copepod of the few-teeth-small-size class exuviating to the many-teeth-large-size-class. Instead of this, it was found that the copepods of both classes exuviate directly to stage V, as shown in the following table, in which the features peculiar to stage V of each individual were easily recognized through the exuvia *i.e.*, internal teeth, segmentation and number of setæ (Fig. 20, 22).

TABLE I.

COPEPODS OF STAGE IV IN EXUVIATION TO STAGE V.

	Date of Collection	Station	Tow	Class	Length in mm.	Coxal Teeth on Bl of p5 of exuvia		Coxal Teeth on Bl. of p5 of Stage V	
						right	left	right	left
1	June 28	"Prince" 3	10 fathom	small size	2·38	6	6	31	31
2	July 14	Wilson's Beach	surface tow	"	2·4	2	3	x	x
3	May 24	"Prince" 3	vertical haul	"	2·56	1	10	x	x
4	"	"	"	"	2·66	1	4	21	21
5	"	"	"	large	3·2	9	17	x	x
6	August 2	culture flask	"	"	3·2	9	9	36	36

Stage V. At this stage there are five free thoracic segments in the forebody and four segments in the urosome. The antennæ, mandibles, maxillæ, anterior maxilliped and four pairs of swimming feet are like the adult. The posterior maxilliped has not the full number of setæ and the last swimming foot (p5), although it has the full number of setæ, has only two segments in each ramus.

Length variation. Upwards of two hundred specimens were measured and the coxal teeth counted. The total length from the front of the head to the end of the caudal rami varied from 2·5 mm. to 4·68 mm., the average being 3·2 mm. Although there was such a variation in length, yet there were no abrupt changes as in stage IV. There is the one average of 3·2 mm. about which the lengths fluctuate. If there had been two races of *C. finmarchicus*, as our observations of stage IV seemed to indicate, we would have expected to find them represented in stage V.

Coxal teeth. The denticulations on p5 at stage V are arranged like those of the adult in a regular row, usually with a slight sigmoid bend in the middle of the row, along the inner margin of BI. The number of teeth varies from twenty-four to forty-four, the average being thirty-two. The right BI has rarely the same number of teeth as the left, but there is no regularity in this variation. Occasionally a specimen will be found with many more teeth on one side than on the other. When this is the case, the teeth that are more numerous are correspondingly smaller in size. One individual had exceptionally few large teeth: eighteen on the right, ten on the left (Fig. 23). This variation from the average number and size of the teeth is so great, that it may be classed as an abnormality. Very often, in addition to the long regular row of teeth, there are a few supernumerary teeth either at the proximal end of the series or at the distal end. The number of teeth at this stage makes no difference in the number of teeth in the succeeding stage VI, as the teeth of stage VI are formed quite independently of those of stage V. (Figs. 24, 25).

Setæ. In the *Account of the Crustacea of Norway*, (Vol. IV, Calanoida I and II, Plates II and III) G. O. Sars figures the p5 of *C. finmarchicus* female with one external seta on the Ri and that of the male with two external setæ (se) on the inner ramus. Marie Lebour (op. cit.) describes stage V as having "swimming feet like adult except the fifth pair which has the full number of bristles, but only two segments to the endopodite and exopodite." If this were the case it would be expected that the copepods of stage V destined to be females would have one Se on Ri of p. 5, and that those destined to be males would have two Se on Ri. According to the general law of nature we would also be justified in expecting that there would be just as

many prospective males as prospective females and that, although there is but one average length for stage V, the largest specimens would be famales, since in the adult stage the female averages larger than the male.

In the 184 specimens of stage V examined, 140 of them had two Se on Ri, only 38 had one Se on Ri, and 6 had one Se on the Ri of one swimming foot (p5) and two on the other. The occurrence of six, out of 184, with one Se on one foot and two on the other is peculiar in that the percentage is too large for them to be classed as mere abnormalities. *C. finmarchicus V* can evidently be divided into three classes as regards the setæ on the internal ramus of p5, and these classes do not appear to have any relation to the size of the copepods or to the prospective sex of the adult stage.

Exuviation. It is unknown whether in stage V of *C. finmarchicus* there are certain characteristics which indicate what sex it is to be when it exuviates to stage VI. Microscopic examination of the gonads might throw light on this point. Although copepodite exuviation is continually occurring, yet during ecdysis the vitality of the copepods is so low that they sink towards the bottom of the water. Perhaps this is why it is so rare to find a copepod in the actual process, and it is rarer still to find that the exuviation has progressed far enough to distinguish, within the exuvia of Stage V, the sex of stage VI. In a few specimens Numbers 1-9, Table II, the commencement of exuviation was only apparent in the eating and swimming appendages and in the caudal furca, especially in p5 where the coxal teeth of stage VI could be seen through the cuticle. Others, numbers 10-18 Table II, were in ecdysis when examined, and the exuviation had progressed to such a degree that the sex could easily be ascertained. These were obtained from Dr. Willey's copepod cultures.

TABLE II.

COPEPODS OF STAGE V IN EXUVIATION TO STAGE VI.

No.	Length in mm.	Coxal teeth on Bl of p5 of Stage V		Coxal teeth on Bl of p5 of Stage VI		Se on Ri of p5		Sex of Stage VI.
		right	left	right	left	right	left	
1	3·16	30	26	x	x	1	1	—
2	3·5	32	32	x	x	2	2	♂
3	4·1	32	32	29	33	2	2	♀
4	4·45	35	35	29	29	2	1	—
5	3·78	39	35	x	x	2	2	—
6	2·75	27	25	x	x	1	1	—
7	3·1	33	38	x	x	1	1	—
8	3·	32	36	22	23	2	2	♀
9	—	35	36	x	x	1	1	—
10	—	32	32	x	x	—	—	♀
11	—	—	—	—	—	1	1	♀
12	—	—	—	—	—	1	1	♀
13	—	—	—	—	—	—	—	♀
14	—	—	—	—	—	—	—	♀
15	—	39	39	35	35	2	2	♀
16	—	—	—	—	—	—	—	♀
17	—	—	—	—	—	2	2	♂
18	4·2	29	29	33	33	—	—	—

The freshly gathered plankton was brought from the outside to the laboratory in quart thermos flasks. The material was then decanted into a glass jar, active copepods picked out with a glass tube and transferred to a litre flask containing filtered sea-water sterilized by heating to 70°C. The most successful experiment was started on July 14th from material conveyed to the laboratory in a thermos flask on the previous day. The air temperature in the laboratory at 9 a.m. was 19°C. The half-filled litre flask was loosely corked and placed in an ice-house near the laboratory, with a fairly constant temperature of 10°C. The Copepods remained active, without addition to diatom food, until August 28th, when the experiment was discontinued. See Table II.

Number 15, table II, proves that those copepods of Stage V with 2 Se on the Ri do not always exuviate to males (Fig. 28). Those that were undoubtedly exuviating to females as shown by the segmentation and the enlagrement of the first segment, of the urosome, (Figs. 1, 2, 25) and the large number of teeth on BI of p5, showed no peculiarities which might distinguish their sex in stage V, nor did those exuviating to males as shown by the segmentation of the uro-

some and large sized but few teeth on BI of p5 (Fig. 29). From the observations of the specimens of Table II it appears that there is no constant external feature which will serve to distinguish the sexes in stage V.

Exceptional Cases. One specimen, number 13, was peculiar in that the withdrawn parts of the setæ in the rami were wrinkled, Fig. 26. This was probably due to the pressure of the crowded tissues, but it is worth mentioning that the wrinkling in the two rami was practically identical. Number 17 was exceptional in that the distal point of the external ramus Re of the left p5 was obpyriform in shape (Fig. 32) while that of the right p5 was like those of the other swimming feet (Fig. 33). Another *Calanus* stage V obtained from "Prince" Sta. 3 on May 24th, showed an abnormality in the external rami of p5. Instead of the usual three Se on the distal joint, there were only two Se. (Fig. 35).

Stage VI. This is the adult stage which terminates the series of ecdyses and, although feeding continues, the main energy of the copepod is used in reproduction.

Length at stage VI. Of twenty-seven females examined, the lengths ranged from 2.92 mm. to 5.1mm., the average length being 3.6 mm. As in stages III and V, only one average length could be distinguished.

Coxal Teeth of female at stage VI. The first basal joint of p5 is denticulate along the inner margin. The teeth are in a long regular row, usually with a sigmoid bend in the middle of the row, extending the whole length of the joint. The average number of teeth is 34; 34·1 for the right p5 and 34·17 for the left. This average is greater than that for stage V.

Setæ. In the typical condition, as figured by G. O. Sars, there is one Se on both Ri of p5 in the female. Out of 59 specimens examined, 43 were typical, 15 had two Se, one had 2 Se on one Ri and one on the other. The two Se when present, are slender, as in stage V.

Length of male. Of 29 specimens examined, the length varied from 3 mm. to 5 mm., the average being 3·5 mm.

Coxal teeth of male. The denticulations on the basal joint of p5 are much larger and fewer in number than those of the female. Usually the distal end of the row is terminated by a large jointed tooth. The average number of teeth is 22; 23·4 for the right and 22·5 for the left.

Setæ of male fifth foot. In the typical condition, figured by Sars, there are two Se on the Ri of p5 in the male. These setæ are much stouter than those of stage V. All those examined conformed to the type except one that had one Se on the right Ri and two on the left.

The position of the one seta was opposite the middle of the distance between the two distal internal setæ, while the two Se were each opposite an internal seta. This suggests that two Se had been replaced by one Se, and we would expect to find the one Se double the normal size, but this was not the case.

B. Calanus hyperboreus

This species was not very abundant in the tows, only twenty individuals being obtained from a vertical haul taken at "Prince" Sta. 3, May 24th, 1916. There is a regular row of large coxal teeth on p5 in Stages V and VI, but unlike *C. finmarchicus*, there are no coxal teeth in stage IV. The teeth are larger and fewer in number than in *C. finmarchicus* and the row does not reach the distal end of the joint. Like *C. finmarchicus* there may be two Se on each Ri of p5, or only one. Of three females examined, two of them had one Se on each Ri; the other had one Se on the right and two on the left. The occurrence of similar variations in the two species is a point of interest.

Final Exuviation of Eurytemora and Tortanus

Eurytemora herdmani, Thompson and Scott, was the most abundant copepod in the tows taken from the wharf of the Biological Station during the latter part of June and first part of July. Unlike *Calanus* which has no exuviation after it has reached the female ♀1 stage, *Eurytemora* exuviates from an immature stage of the female (Fig. 36) to the mature female ♀2 (Fig. 37). In ♀1 the postero-lateral angles of the forebody are produced as soft points, each with a single subapical spinule, and are not expanded into the characteristic winglike structures of ♀2 (Fig. 37). It is further distinguished from ♀2 by the structure of the fifth swimming feet (Figs. 38, 39). In ♀1 the undivided rami of p5 have each a smooth claw-process directed obliquely inwards and distal, not bent so as to lie parallel with the distal part of the ramus which is not articulated in this stage; there is no external seta on the second basal joint, nor is there a cilium proximal to the first external seta of the ramus as in the adult.

One measuring 1·2 mm. in length was kept alive three days in filtered sea water in a Syracuse watchglass covered by another. On the third day (June 14th), although still alive, it had ceased darting about and on close examination was discovered to be in a process of ecdysis to ♀2. Its appendages were moving and heart beating intermittently. At 9 a.m. on June 15th, the heart had stopped beating, but there was still an occasional quiver of the appendages and a slight peristaltic movement of the intestines; the exuvia had partly

separated from the new cuticle. The copepod was transferred to a slide and a coverslip supported by a strip of paper was put over it. This slight pressure caused the exuvia to break away from parts of the body. The new postero-lateral angles of the forebody were freed and showed that they were more expanded and winglike than those of the exuvia. (Fig. 40). The caudal rami, which are 4½ times as long as they are wide, had partly withdrawn. The p5 of ♀ 2 could be clearly distinguished within the old cuticle, especially the spines of the claw process of the proximal joint of the ramus and the articulation of the terminal joint (Fig. 41).

In an oblique haul taken from the wharf on June 12, there were many mature females with their ovisacs attached, darting about in the water. One specimen had not less than fifty eggs in its ovisac, each ·082 mm. in diameter, and on examination it was found that there were many more eggs in the oviduct. It was estimated that there were enough eggs within the copepod to fill three successive ovisacs. In another specimen the eggs within the ovisac were much farther advanced and were nearly ready for hatching. In fact the ovisac had broken and a few of the nauplii had already escaped. In the same haul were a few males easily distinguished by the naked eye from the females and the other copepods by the scarlet tumefied portion of the right antenna. The right ramus of p5 had a roughened ridge at the end of the terminal joint, but no plumose seta (Fig. 42).

Tortanus discaudatus, Thompson and Scott, was usually found in the tows taken from the wharf at the Biological Station in June and July. Although it was not nearly as abundant as *Eurytemora* yet it could be picked out from the other copepods by its slightly bluish tinge. This colour was due to small dark blue spots at the base of the appendages. Towards the end of June and during July females were obtained with spermatophores attached.

As in *Eurytemora* there is an exuviation within the female stage. *Tortanus* ♀ 1 is 1·52 mm. in length. There are three segments in the urosome and the rami of the caudal furca are nearly alike (Fig. 43). The p5 are 3-jointed, with a plumose seta on the distal basal joint and four delicate spines on the ramus (Fig. 44). *Tortanus* ♀ 2 is about 2·25 mm. in length, with unequal caudal rami and a clump of stiff cilia on the right side of the second segment of the urosome. The large right caudal ramus has an area of pubescence on the outer surface, and a row of cilia on the inner surface; and the basal portion of the outer seta is enlarged to form a conspicuous process (Figs. 45 and 46). The p5 differs from that of ♀ 1 by having the ramus smooth and without any spines (Fig. 47). Eggs were seen in the ovaries of ♀ 1 as

well as in ♀ 2, but in ♀ 1 they were in a single row while those of ♀ 2 were in two or three rows. In *Tortanus, Eurytemora* and many others the sexes can be separated by the character of p5 in earlier stages.

Species of Acartia

During the latter part of July and the first week in August, a species of *Acartia* was very abundant in the tows taken at the mouth of the St. Croix River opposite the Biological Station. On July 21st, a foggy rainy day, a tow of five minutes was taken off Kitty's Cove when the tide was on the ebb. The copepods were numerous and nearly a pure culture of *Acartia* of all stages from the nauplius to the adult. The general appearance and specific characters of the adult resembled more closely than any other the description of *A. clausi* Giesbrecht. The female ranged from 1·08 to 1·13 mm. in length, without any trace of rostral filaments. Some specimens had the lateral lobes of the last segment of the forebody beset with from four to six cilia. These cilia were not present in all the copepods examined. Some had them only on the right lobe while others had no trace of them. On the dorsal surface of the first segment of the urosome were a few cilia, but the posterior edges of the first two segments were not clothed dorsally with a transverse row of denticles as in the Norwegian material described by Sars. The urosome of the females was half as long as the forebody; the first segment measured ·124 mm., the second ·072 mm., the third ·04 mm., and the caudal furca ·072 mm. The anterior antennæ scarcely exceeded the length of the forebody, the fifth articulation having a distinct denticle in front. The length of the apical spine of the outer ramus in the second to fourth pairs of legs scarcely exceeded that of the ramus. The p5 were similar to the figure given by Sars. A specimen was obtained holding a spermatophore with the terminal joints of p5 (Fig. 48).

The male of *A. clausi* ranged in size from ·92 to 1·04 mm. The caudal rami were shorter than those of the female, being about as long as the anal segment. The p5 (Fig. 49) resembled Sars' figure except that the third joint of the left leg had two clumps of cilia on its posterior surface and the terminal joint was more spoon-shaped with the concavity filled with long slender cilia in addition to stout marginal cilia (Fig. 50). The terminal joint of the right p5 had two minute tufts of cilia on its posterior surface (Fig. 51).

In a tow taken at "Prince" Sta. 1 on July 23rd, 1916, three specimens of *Acartia longiremis*, two adult females and one adult male, occurred. This is the first record of this species at St. Andrews. It can be distinguished from *A. clausi* by the lateral lobes of the last

segment of the forebody, which are rounded at the tip, each carrying dorsally a conspicuous spinule. The terminal joint of p5 of the female is much longer and slenderer than that of *A. clausi*, as it equals in length the long plumose seta of the second joint. (Fig. 52).

Rudimentary p5 in Pseudocalanus

Pseudocalanus elongatus was the most abundant copepod taken in the tows during June, July and first part of August. The majority of these were females with no fifth swimming legs, but on June 28th, in a ten fathom haul taken at "Prince" Sta. 3, two females were noted with rudimentary p5 (Fig. 53). This rare anomaly has been signalized by A. Bœck (1864) and A. Mrazek (1902). Mrazek's figures are reproduced by P. J. van Breemen in *Nordishches Plankton*, Bd. LV., 1908, p. 25. These rudimentary p5 are small, three-jointed appendages with the terminal joint blunt, not tipped with a spinule. No females of stage V were found with any trace of p5. All the males in stage V have immature p5 which are four-jointed, tipped with a spinule, and much larger than the rudimentary p5 of the adult female (Fig. 54). The peculiar asymmetry of the p5 of the adult male is not evident in Stage V, except that the left leg is slightly larger and longer than the right.

Immature p5 of Metridia

Two species of *Metridia* occurred occasionally in the tows. *M. lucens* and *M. longa*. Even in the immature copepodite stages, not only the species, but the sex may be determined. From a vertical haul made at "Prince" Sta. 3 on June 28, 1916, a number of *Metridia* at different stages were obtained. There were three specimens of *M. lucens* stage IV; one female and two males. Both female and males were 1·4 mm. in length and had three joints in the p5. The terminal joints of the p5 of the female are about equal in length to each of the other joints and carry at their tips two slender setæ (Fig. 55).

The terminal joints of the male are two and a half times as long as each of the other joints, and each carried three short external setæ, one terminal seta, and two internal setæ (Fig. 56).

There were seven specimens of *M. lucens*, stage V two females and five males. One female was 2·1 mm. in length, the other measured 2 mm. and was exuviating to stage VI. Three of the males were 1·9 mm. in length, the other two being 1·8 mm., and 1·3 mm. respectively. The fifth swimming legs of the female were similar to those of the adult except that one female had an outer seta on each of the

second joints. This seta was not present on the other specimen which was exuviating to stage VI, nor is it figured by Sars.

Three specimens of *M. longa* stage V occurred; two females and one male, 3·5, 3, and 3 mm. The p5 of both sexes were much larger than those of *M. lucens*, and four jointed, the first three joints similar in appearance and size. The third joint of the female carried distally a short slender outer seta; the terminal joint was about equal in length to the third and carried three long slender setæ (Fig. 57). The third joint of the male carried distally a very small outer seta; the terminal joint was nearly 4½ times as long as the third joint, with two small outer setæ, two terminal setæ and four small inner setæ (Fig. 58).

In conclusion I wish to acknowledge the kindness and assistance which I received from my professor, Dr. Willey.

Explanation of the Figures

Fig. 1. *C. finmarchicus* V exuviating to VI. Part of outer ramus of fifth foot, showing terminal and external setæ withdrawn into seta sacs.

Fig. 2. Same. Caudal ramus with inner cylinders of terminal setæ of exuvia exposed, cylinders and seta sacs formed by everting setæ.

Fig. 2.[1] Same. Seta of exuvia slipping off inner cylinder.
Fig. 3. Same. Terminal setæ of caudal ramus unfolding.
Fig. 3.[1] Same. The new third terminal seta of the right caudal ramus with inner cylinder formed at base.
Fig. 4. *C. finmarchicus* V. Urosome showing regeneration of lost setæ.
Fig. 5. *C. hyperboreus* III–IV.
Fig. 5.[1] Mandible; inner lobe (molar process) withdrawing.
Fig. 5.[2] Maxilla; first inner lobe (Li I) withdrawing.
Figs. 6 to 19. *C. finmarchicus* IV. Variations of coxal teeth on the fifth feet. The lengths in millimetres were (6) 2·017; (7) 2·00; (8) 2·00; (9) 2·10; (10) 2·06; (11) 2·13; (12) 2·12; (13) 2·18; (14) 2·26; (15) 2·60; (16) 2·80; (17) 3·06; (18) 3·08; (19) 2·84.
Fig. 20. *C. finmarchicus* IV–V. Fifth foot showing internal coxal teeth of stage IV; also internal segmentation of Re and Ri.
Fig. 21. *C. finmarchicus* IV–V. Coxal teeth of p5, external and internal.
Fig. 22. *C. finmarchicus* IV–V. A caudal ramus.
Fig. 23. *C. finmarchicus* V. Bl of p5, aberrant.
Fig. 24. *C. finmarchicus* V–VI. Bl of p5 showing external and internal coxal teeth.
Fig. 25. *C. finmarchicus* V–VI. Bl of p5 showing external and internal coxal teeth.
Fig. 26. *C. finmarchicus* V–VI. Caudal ramus showing wrinkled bases of seta sacs.
Fig. 27 A. *C. finmarchicus* V–VI. Urosome.
Fig. 27 B. *C. finmarchicus*. Outer aspect of new caudal ramus.
Fig. 28. *C. finmarchicus* V–VI. External and internal coxal teeth.
Fig. 29. *C. finmarchicus* V–VI. External and internal coxal teeth.
Fig. 30. *C. finmarchicus* V–VI. Exuviation of urosome.

Fig. 31. *C. finmarchicus* V–VI. Exuviation of urosome.
Fig. 32. Same. Distal joint of Re of left p5, showing the internal obpyriform joint of stage VI.
Fig. 33. Same. Distal joint of Re of right p5.
Fig. 35. *C. finmarchicus* V. Distal joint of Re of p5 showing only two Se.
Fig. 36. *Eurytemora herdmani.* First (immature) form of female showing one of the postero-lateral angles of the forebody and the urosome.
Fig. 37. *Eurytemora herdmani.* Second (mature) form of female.
Fig. 38. *Eurytemora herdmani.* 1. Fifth feet.
Fig. 39. *Eurytemora herdmani.* 2. Fifth feet.
Fig. 40. *Eurytemora herdmani.* I–II. Exuviation of the right postero-lateral angle of forebody.
Fig. 41. *Eurytemora herdmani* I–II. Exuviation of p5. The serrated claw of 2 is seen within the smooth claw of 1.
Fig. 42. *Eurytemora herdmani.* Terminal joint of right of p5, showing a distal ridge instead of a plumose seta.
Fig. 43. *Tortanus discaudatus* I. Posterior part of forebody and urosome from above.
Fig. 44. Same. Fifth foot showing spinules on the ramus.
Fig. 45. *Tortanus discaudatus.* 2. Urosome in side view showing clump of cilia on the right side of the second segment and an area of pubescence on the right caudal ramus.
Fig. 46. *Tortanus discaudatus.* 2. Urosome showing row of cilia at inner margin of right caudal ramus.
Fig. 47. *Tortanus discaudatus.* 2. Fifth foot showing absence of spinules on the ramus.
Fig. 48. *Acartia clausi.* Genital segment, showing spermatophore held by p5.
Fig. 49. *Acartia clausi.* Fifth feet.
Fig. 50. Same. Part of left p5, showing slender and stout cilia on terminal spoon-shaped point; two clumps of cilia on third joint.
Fig. 51. Same. Distal joint of right p5, showing two distal clumps of setæ.
Fig. 52. *Acartia longiremis.* Fifth feet and postero-lateral spines.
Fig. 53. *Pseudocalanis elongatus.* Rudimentary p5.
Fig. 54. *Pseudocalanus elongatus* V. Immature p5.
Fig. 55. *Metridia lucens* IV. Immature p5.
Fig. 56. *Metridia lucens* IV. Immature p5.
Fig. 57. *Metridia longa* V. Immature p5. Distal setæ omitted from right leg in the figure.
Fig. 58. *Metridia longa.* V. Immature p5.

Legends for Graphs

Graph I. *C. finmarchicus IV.*

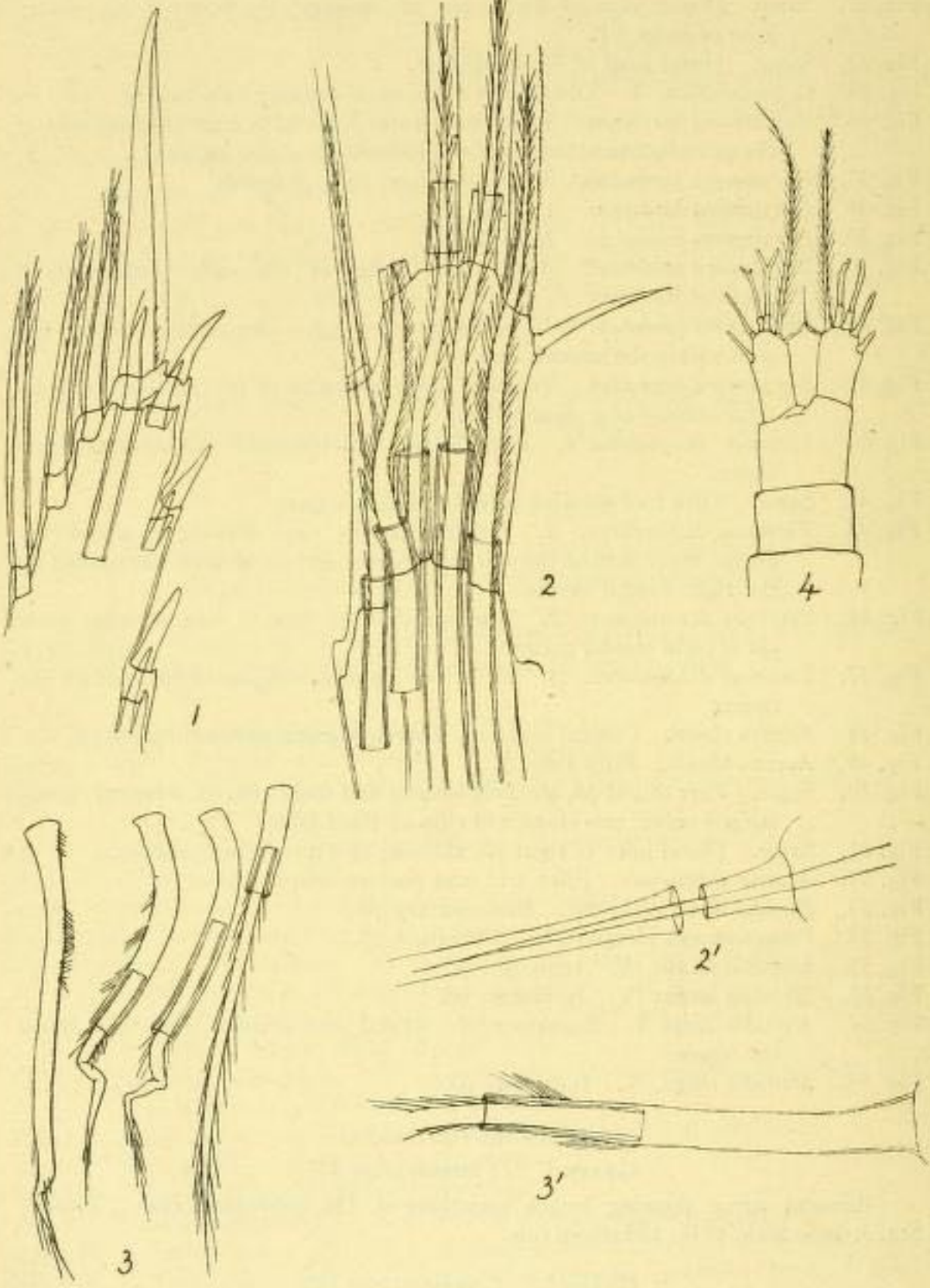
Bimodal curve showing length variations of 116 individuals from "Prince" Sta. 3, June 28th, 1916, 10 fathom tow.

Graph 2. *C. finmarchicus IV.*

Curve showing variation in number of coxal teeth in the 116 individuals employed in graph I.

Graph 3. *C. finmarchicus IV.*

Curve showing correlation between length and coxal teeth in the series employed in graphs 1 and 2.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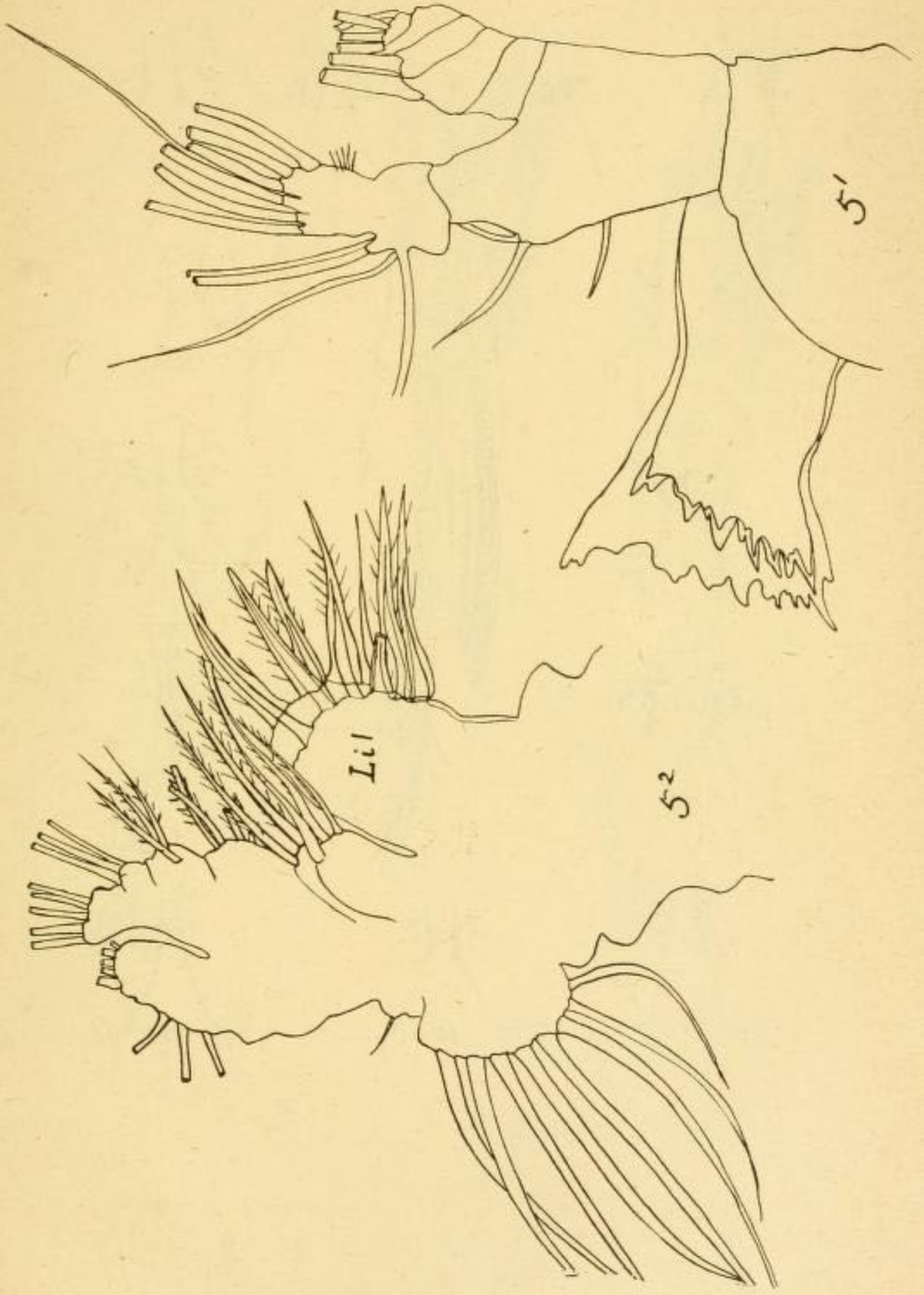
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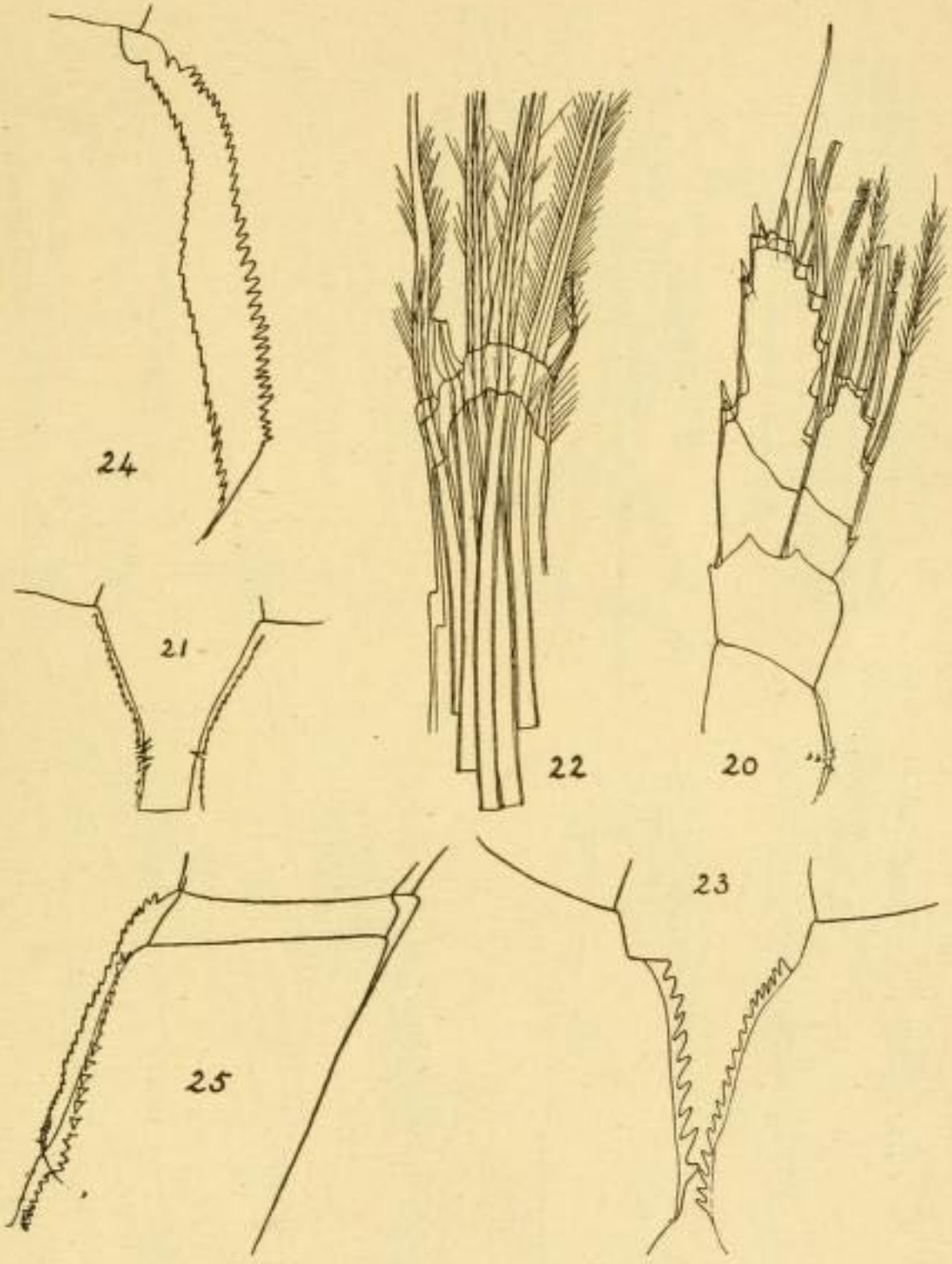
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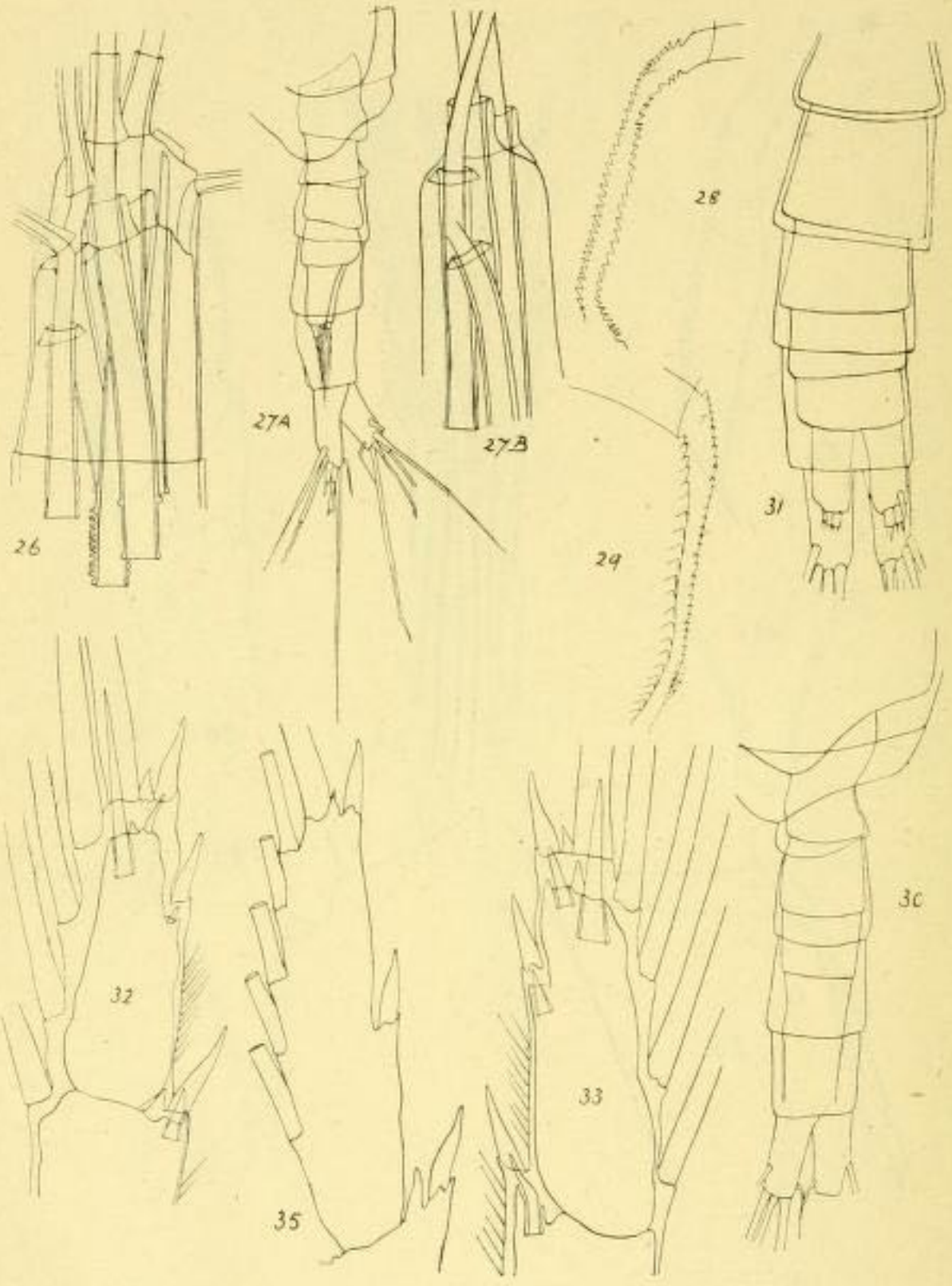
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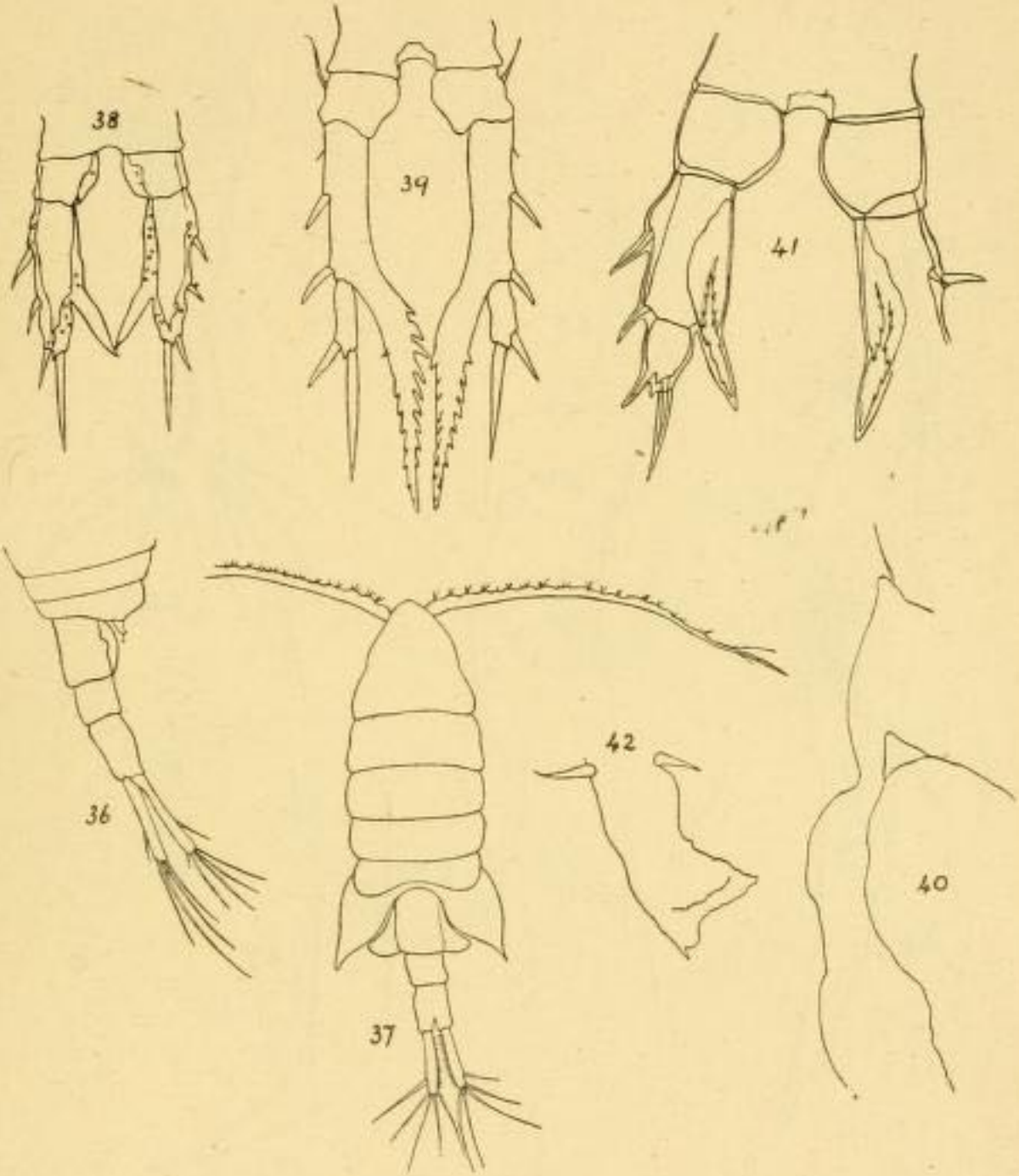
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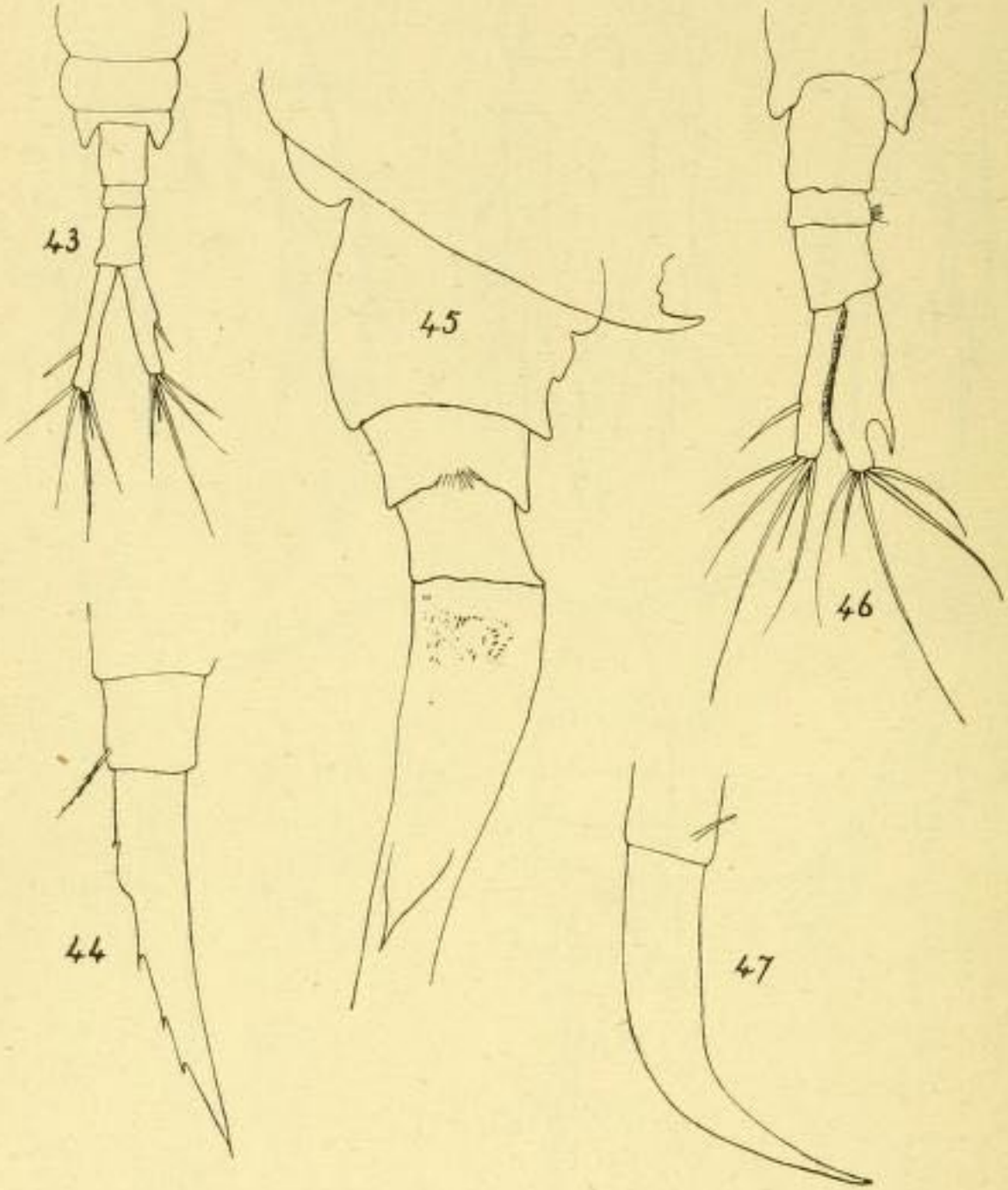
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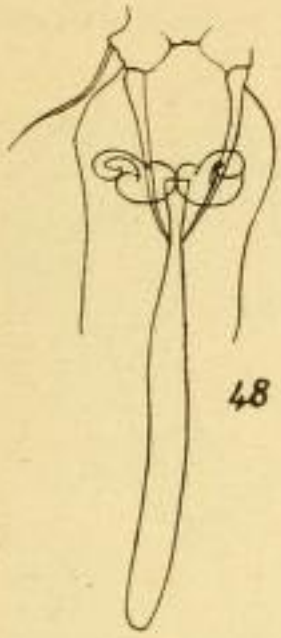
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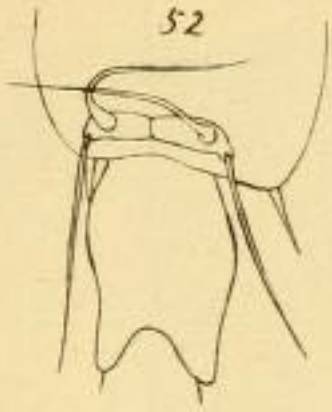
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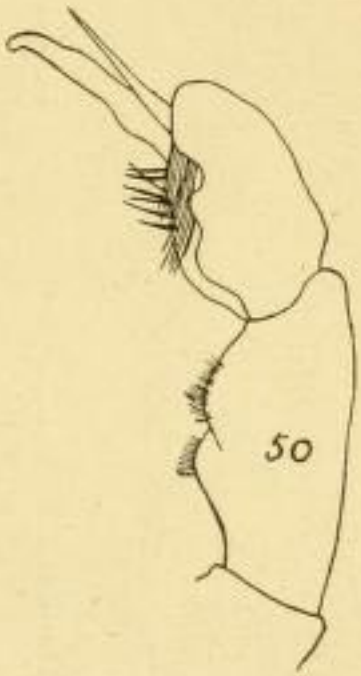
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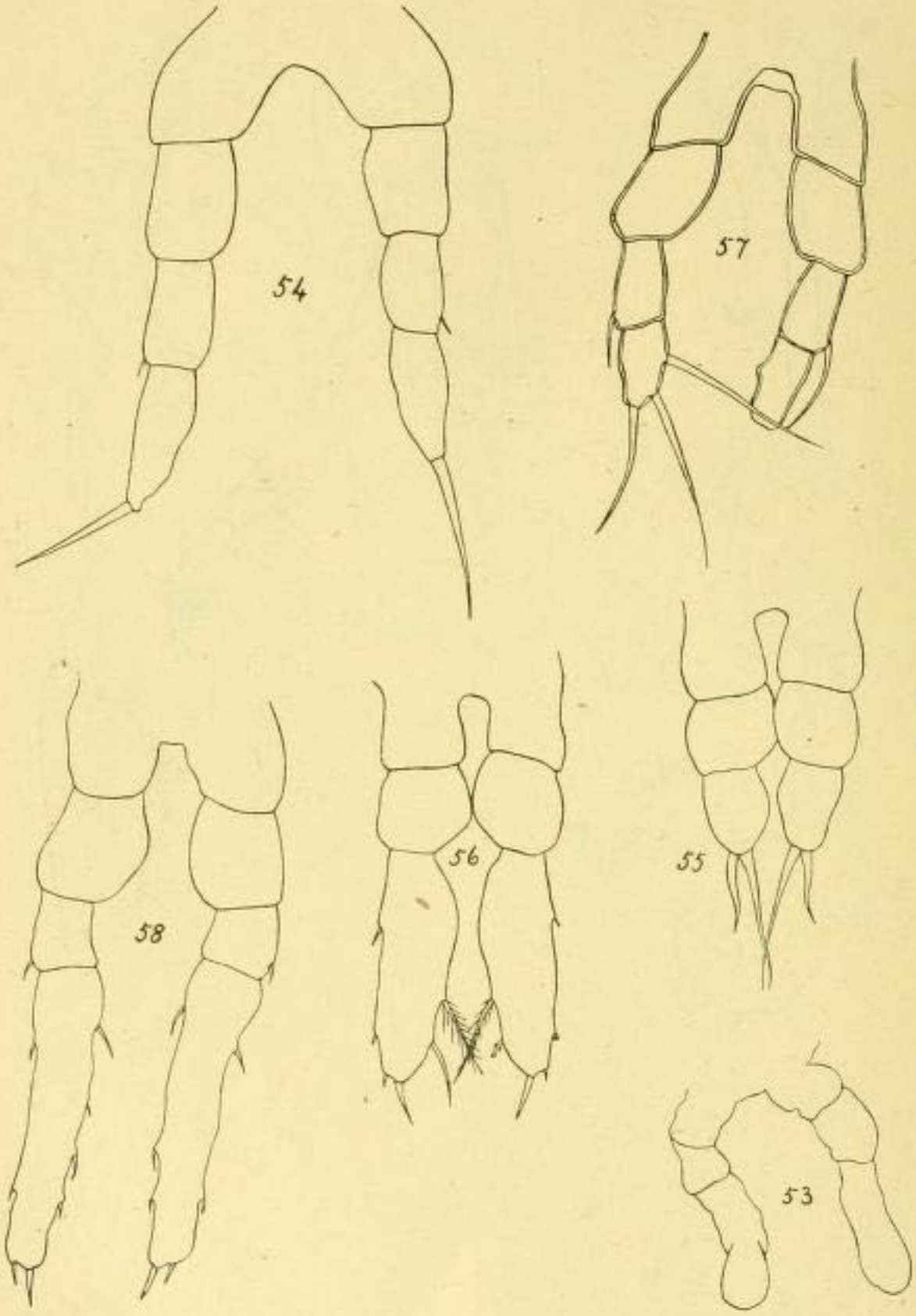
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GRAPH I. *Calanus finmarchicus* stage IV "Prince" Sta. No. 3, June 28, 1916. 10 fm. tow. 116 individuals.