DISTRIBUTION AND VARIABILITY OF CERATIUM IN THE NORTHERN AND WESTERN PACIFIC

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By Anton Böhm

INTRODUCTION

SCOPE AND METHOD

This paper presents the results of a study of plankton collected by Dr. Victor Pietschmann in Hawaii (1927-28), during the course of a journey from Honolulu to Yokohama, Moji, Shanghai, Hongkong, and Singapore (June to July, 1928). The material was obtained by using the ship's pump for two or more hours, and then it was filtered through nets.

For a statistical investigation of variation the greatest possible number of measurements is necessary. Because the *Ceratium* population of the Pacific is not large, it is necessary to select those characters that show in themselves a relatively great constancy; that is, transdiameter, total length, and expanse of horns. The interesting question of the variety of apical horns could not be investigated because this feature in itself is highly variable, and also because the number of individuals available is not sufficient. The total number of measurements is about 2200; the number of samples, 48. The temperatures quoted are from the Imperial Marine Observatory, Kobe, computed from the mean average of the month concerned. Most of the drawings are enlarged 690 times with the Zeiss Abbe camera lucida, and then reduced one-half or two-thirds for reproduction.

I am indebted to Dr. Pietschmann for his interest in the progress of my work and for his continuous friendly advice.

THE HORIZONTAL DISTRIBUTION OF CERATIUM

Hydrographically the territory investigated is characterized by two currents: in the north, by the western part of the Kuro-Siwo, and in the south (Singapore to Shanghai along the continental border), by the southwest monsoon current. During the month of July, 1928, the average

[1] Anton Böhm, of Vienna, presents the first of a projected series of publications resulting from investigations of Pacific faunas by Dr. Victor Pietschmann, Bishop Museum Fellow in Yale University 1927-28.

temperature of the Kuro-Siwo was 22.3° to 26.9° C., and of the southwest monsoon current, 24° to 29° C. (most of the month, 27°-29° C.).

Biologically the territory embraces a great number of ceratium associations, which, often sharply distinguished, often mixed together, are a subtle characteristic of the life zone.

SOUTHWEST MONSOON CURRENT

Tropical association (Singapore-Hongkong). (See fig. 1.)

("Association" is here not used in the meaning of phytosociology.)

The tropical association in the monsoon current is distinguished by the two constants of the Indo-Pacific Tropics; *Ceratium dens* and *C. schmidtii*, and in addition by *C. breve* and the occasional associate of these species,

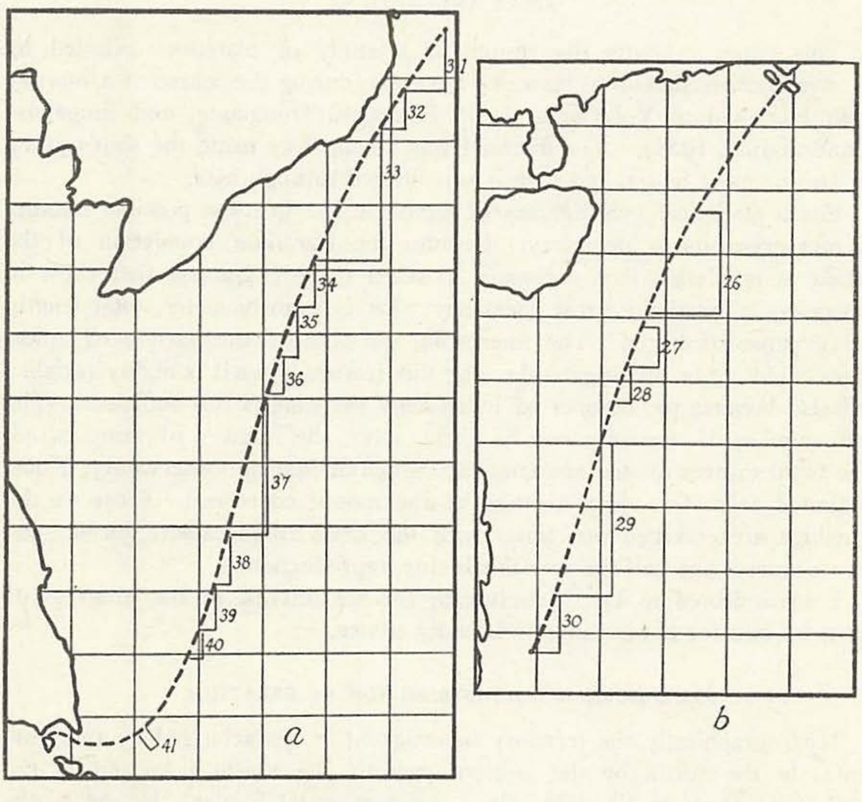

FIGURE 1.—Map of the coast of southeast Asia—the region of the southeast monsoon current—showing the localities at which samples of *Ceratium* were collected: *a*, Singapore to Cape Varella (southwest monsoon current), samples 41-31; *b*, Cape Varella to Hongkong, samples 30-26.

C. contortum var. *saltans*. The temperatures, recorded for *C. dens, C. schmidtii,* and *C. breve* were 27.1° to 29.6° C., on an average 28°-29° C.

This formation furnishes, in addition, a series of cosmopolitan, exclusively tropical forms, which appear to be rather scarce, and often sporadic, and cannot be used as characteristic of a community: *C. incisum, C. platycorne, C. vultur, C. ranipes, C. hexacanthum* f. *spiralis,* and *C. horridum.* More eurythermal are *C. teres, C. concilians, C. gracile, C. carrienese* f. *ceylanicum, C, pentagonum, C. limulus, C. kofoidii, C. marcroceros* (subspecies *gallicum*), *C. arcuatum* α *karstenii.* Most common of all are the most eurythermal and euryhaline species *C. pulchellum, C. massiliense,* and *C. furca.*

A transition zone adjoins this tropical biological community on the north and reaches approximately from Hongkong to latitude 27° N. It harbors the eurythermal forms above named, with the exception of *C. breve, C. schmidtii, C. dens,* and *C. contortum* var. *saltans.* Of special interest here is the appearance of specifically northern species between latitudes 22°-23° N., and Shanghai: the northern race of *C. arcuatum* var. *robustum, C. tripos, C. fusus,* and *C. inflatum*—forms which in the south are either completely lacking or, as *C. fusus* and *C. inflatum,* are found only sporadically. This is doubtless a region of mixed water, characterized on the one hand by southern species which sharply decrease in numbers toward the north and, on the other hand, by this northern vegetation, regarding the origin of which I can only guess. The presence of these forms may be the result of the upwelling of deep water —judging from the high temperatures this is not probable—or these northern forms may be relics of the winter northeast monsoon currents which have maintained themselves for a long time close to the shore. Further investigation on the spot of biological and also of hydrographical questions would be desirable.

The temperatures of this transition zone range from 26.8° to 29.1° C., and average 27.5° to 28.5°. When these values are compared with those which were found for the tropical association, the qualitative alteration of the vegetation appears enormous in comparison with the insignificant changes of temperature. It is clearly shown here how stenothermal the specifically tropical species are and how largely they are fixed in a quite narrowly limited life zone.

Coast association of northern Formosa Strait. (See fig. 2.)

The coast association of Formosa Strait, which is assumed to be present in the Yellow Sea, also claims particular interest. In more southerly latitudes than the Mediterranean Sea, in temperatures which exceed those of the Mediterranean (24.8° to 27.7° C., average 26° to 27°) are found 5 species in contrast to 40 in the Mediterranean and the Adriatic. For this striking condition it is obvious that temperature alone could not be responsible, granted that for the many specifically tropical forms, temperature must be of more vital meaning. Possibly here the relatively lower salinity must be considered.

NORTHWESTERN KURO-SIWO

Biologically the Kuro-Siwo is fundamentally different from the monsoon current. As might be anticipated, it exhibits, in a certain sense, resemblance to the Mediterranean Sea. In the Mediterranean, *Ceratium furca, C. pulchellum, C. massilliense,* rarely *C. inflatum, C. macroceros, C. extensum, C. candelabrum, C. contrarium, C. trichoceros,* and *C. hexacanthum,* belong to the common plastic forms. In the Kuro-Siwo there certainly is associated with them *C. contortum* var. *saltans,* which consequently represents the characteristic form of the region. In the course from Moji to Shanghai, where the Kuro-Siwo first becomes distinct, *C. horridum* and *C. lunula*

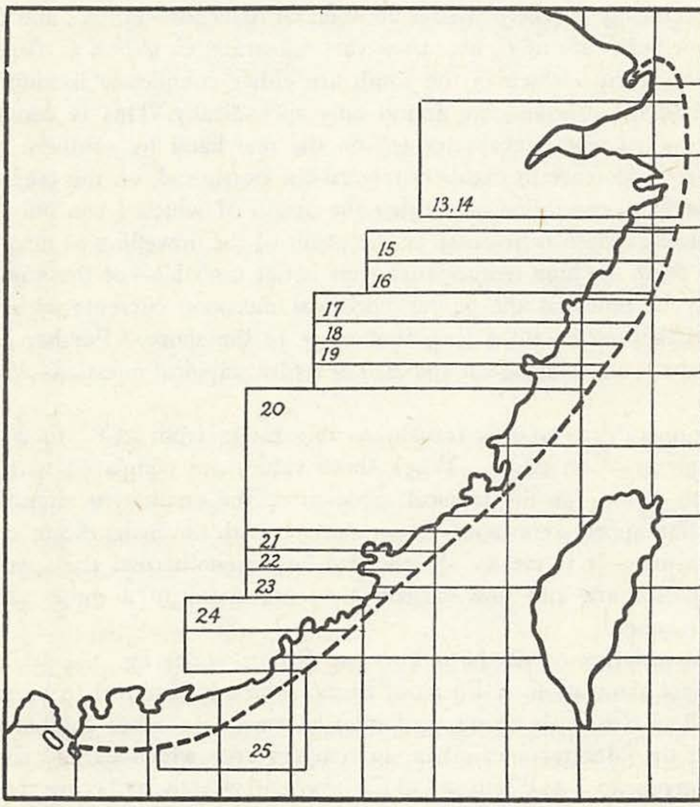

FIGURE 2.—Sketch map of the Asiatic coast from Hongkong to Shanghai, showing localities at which *Ceratium* samples 25-13 were collected.

were also observed. Moreover, Okamura and Nishikawa (10)[2] report *C. platycorne, C. gravidum, C. ranipes,* as well as *C. arcticum,* from Japan. It is clear that these tropical species cannot be indigenous there. As the southwest monsoon current is not to be considered here as the means of conveyance, the north equatorial current should be taken into account. Even in Japan these rare forms were found quite sporadically, and from longitude 150° E. they were entirely lacking. Here also, the paucity of species and of individuals in the constantly high temperatures (22.3° to 26.9° C., average 23.5° to 24.5°) is striking. On the other hand, in contrast to the waters between Moji and Shanghai, which have yet higher temperatures, this region shows three times the number of species. It is also here further shown that simultaneously with temperature in quite significant quantities, other factors influence the horizontal distribution of plankton.

The sample from Nunpia fishpond, Kaneohe Bay, Oahu, contained only two specimens of *C. furca* and two of *C. fusus.*

VARIABILITY OF SPECIES

The problem of variability embraces three questions: is a causal relationship indicated between environment and form?; what meaning has variability for constancy of species?; what are the consequences of variability as regards taxonomy?. For the solution of these questions, only those species could be chosen which, upon the basis of their statistical frequency, warranted usable results. These are: *Ceratium fusus, C. furca, C. breve, C. trichoceros, C. arcuatum.*

In a region of small area, the whole of a species proves itself a phenotypical unit in a statistical sense; a unit which biologically shows a habitat variation (*Lebenslagevariation*). Because it is a question only of phenotypical changes, the diversity of origins of the material is of no importance. In the present work, only those units that were small enough to be practical were analyzed. It was shown that in a uniform current area, even in distances of 50 to 60 kilometers, sharply defined modifications occur, which pass through gradual transitions. Moreover, the alteration in different species or in two varieties with the same hereditary factor can take place in the same or in opposite directions. Alteration in the same direction is shown in the variation in total length of *C. fusus* and *C. furca.* The determination of which factor plays the more important part in this alteration is, of course, only possible by experimental investigation. The fact that modification is brought about by external factors, however, is proved by the demonstration of conformable direction of alteration.

The variability of Ceratium is evidently fluctuating, the alterations being

[2] The numbers in parentheses refer to the bibliography (p.—).

quantitatively ascertainable. They are made possible in the first place by rapid divisions, which give great scope for transformation of body form.

What meaning variability has for constancy of species is a question of genetic investigations. The species have great range of variability, though there are transitions which can not be readily classified, yet there occur with them individuals that are definitely determinable. The great plasticity of many species produces convergencies which might easily be looked upon as actual transitions. That they are not such is evidenced by the conclusions of biogeographical and also of statistical research, which distinctly show how sharp the boundaries are between the different life zones, and how impossible a saltation and a change of hereditary factors appear.

As regards taxonomy, there follows, from the continuous transition of one and the same generically fixed variety, the equivalence of all phenotypes belonging to it. It remains, then, to establish distinct phenotypes as varieties or forms, and in this way to make the system perpetual. After more extensive research it will be better known how to establish for each species hereditary well-defined groups in which divergents not now being recorded may in some way be schematically registered.

SPECIES AND ANALYSIS OF VARIATION

Of the material analyzed, sample 1 was collected in Kaneohe Bay, Oahu, Hawaii. Samples 2 to 10 were taken along the course from Honolulu to Yokohama, samples 11 and 12, along the course from Moji to Shanghai. The localities for the other samples are shown on the maps (figs. 1 and 2).

SUBGENUS BICERATIUM (VANHÖFFEN) OSTENFELD

SECTION CANDELABRA JÖRGENSEN

1. **C. candelabrum** (Ehrenberg) Stein (fig. 3.)
   Sporadic as var. *depressum* (Pouchet), samples 5, 27, 28, 32, 33, 34, 35, 36, 37, 38; as f. *hiemale* (Böhm), samples 3, 4; an intermediate form, sample 6.

SECTION FURCIFORMIA JÖRGENSEN

2. **C. furca** (Ehrenberg) Claparède and Lachmann.
   Common both in the Kuro-Siwo and in the southwest monsoon current.

No light could be thrown on the taxonomy of this most variable species. In the Pacific two form groups are found, which appear side by side and are genotypically distinct. The total lengths of the forms of the small group amounted to 130–168 μ, that of the large group 170 to 244 μ, both evidently belong to the warm-water subspecies *eugrammum*. See figs. 4-8.)

The study of statistics of variation yielded the following results:

(1) Habitat variations were indicated (see unit series).

(2) A certain environment causes in the two-form groups the same mode of alteration: from sample to sample the modifications of dimensions in both groups show the same tendency.

(3) The direction of dimensional alteration of the total length of *C. furca* takes a course in conformity with the alteration of *C. fusus* which produces a similar geometric configuration. As, however, in *C. fusus* a clear separation of two groups was not possible, the general tendency in a north-to-south direction is indistinct.

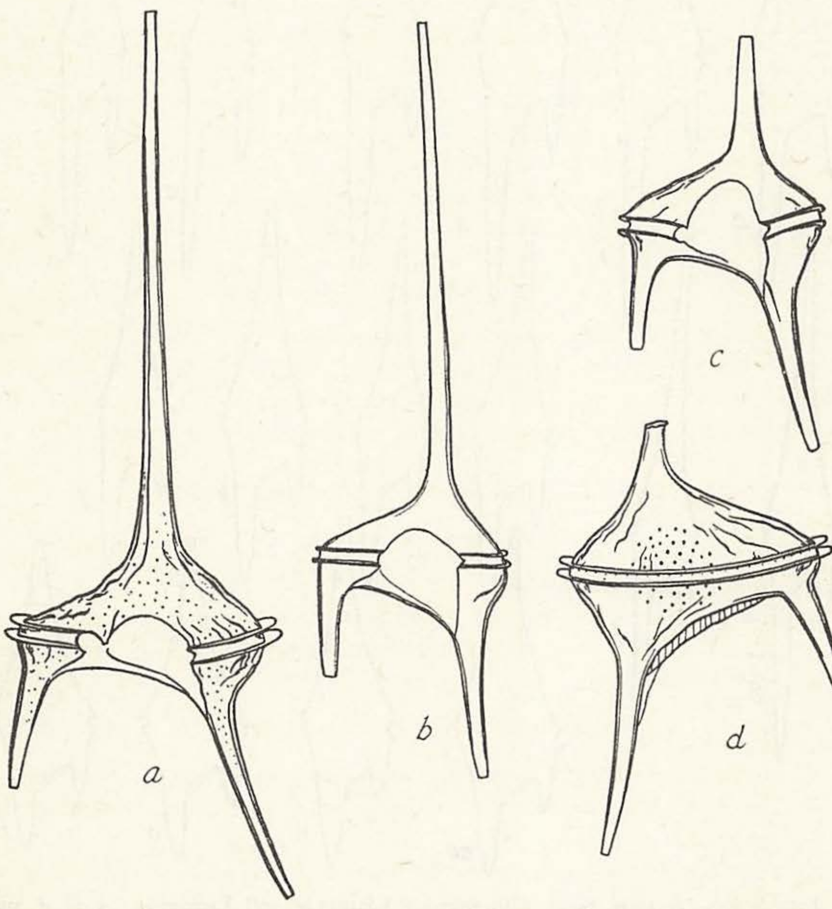

FIGURE 3.—*Ceratium candelabrum* (Ehrenberg) Stein: *a*, typical form of var. *depressum* (Pouchet); *b*, intermediate form between form *hiemale* (Böhm) and variety *depressum*, young individual; *c*, small individual of variety *depressum*; *d*, specimen from the association of a chain with short apical horn.

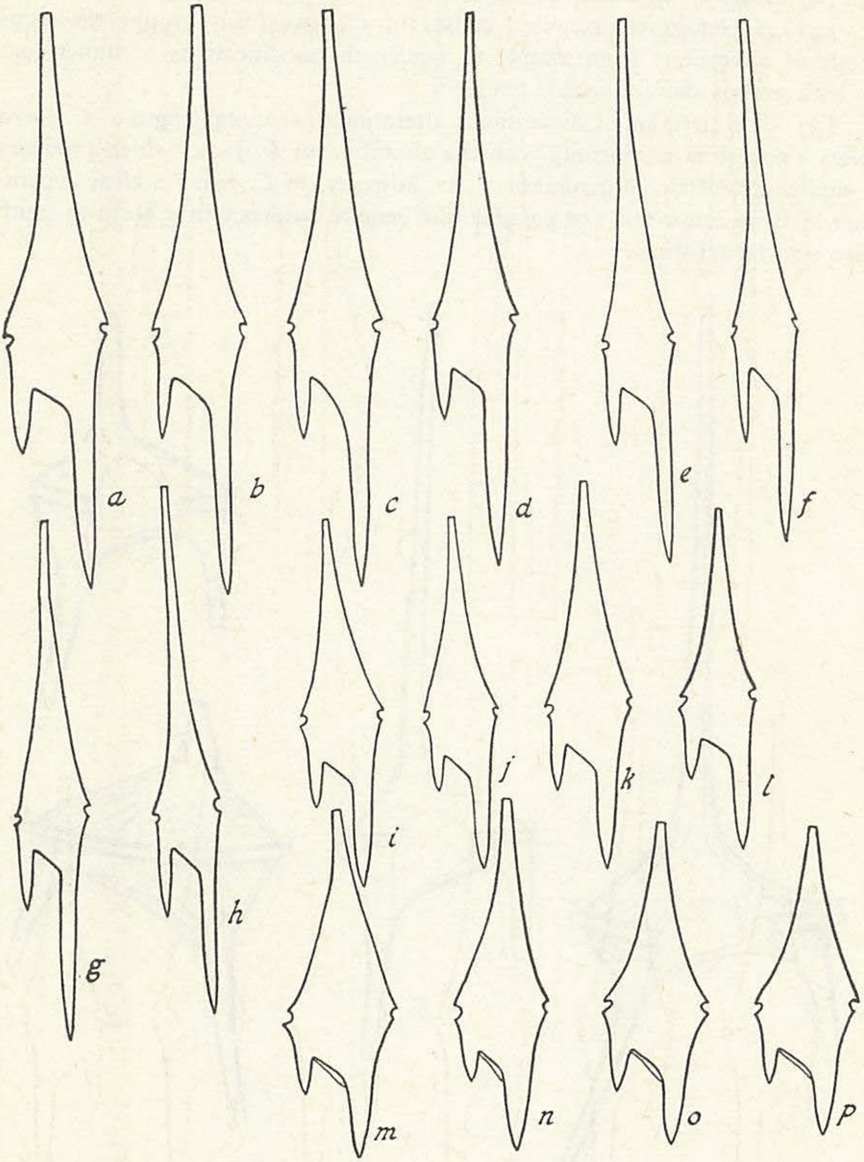

FIGURE 4.—*Ceratium furca* (Ehrenberg) Claparede and Lachmann: *a* to *d*, unit series from sample 19; *e* to *h*, unit series from sample 13; *i* to *l*, unit series from sample 17; *m* to *p*, unit series from sample 20.

(4) The two groups, which differ, therefore, in their hereditary factor, have such an amplitude of variation that their extreme forms meet and can not be distinguished. Here a pure schematic analysis is needed.

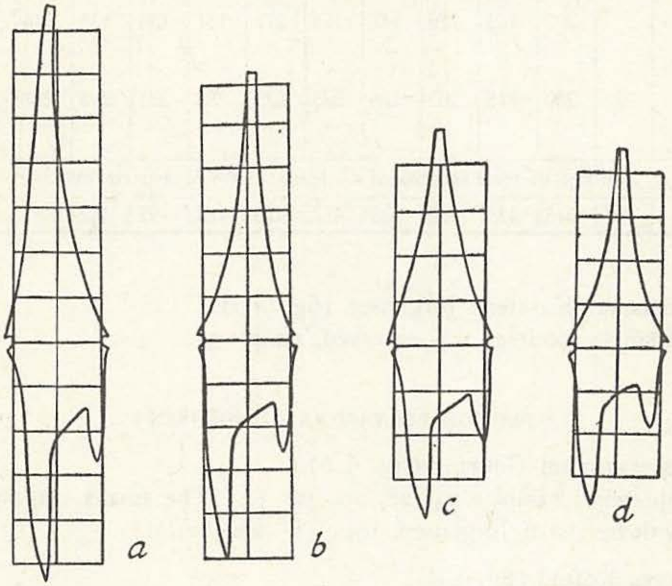

FIGURE 5.—*Ceratium furca* Rasterseries

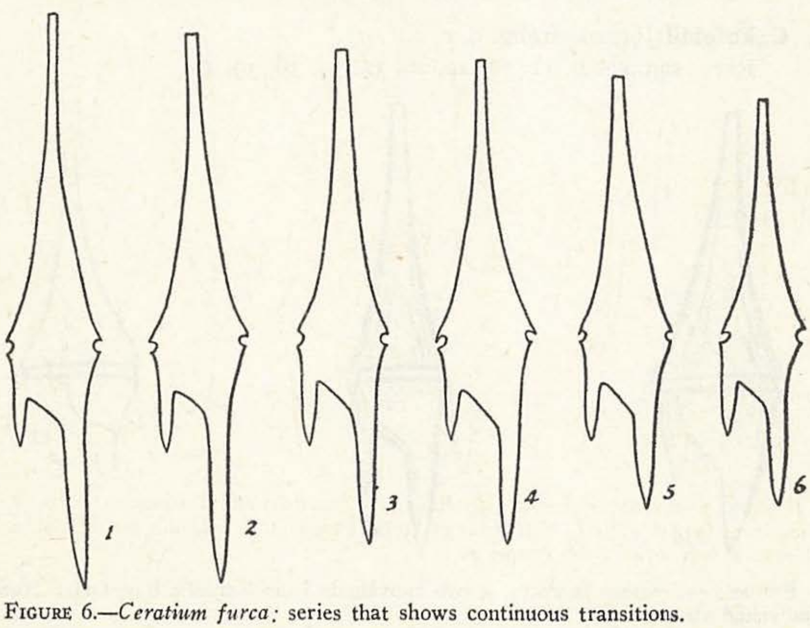

FIGURE 6.—*Ceratium furca*: series that shows continuous transitions.

TABLE 1.—AVERAGE OF TOTAL LENGTHS OF C. FURCA (454 MEASUREMENTS)

Sample	13	14	15	16	17	18	19	20	21	22	23	24	25
Small form		202	163	159	147	154	217	131	136	133	146	145	138
Large form	222	230	215	202	178	223	233	228	221	203	237	242	239
Average of total lengths of C. fusus (1068 Measurements)													
	517	515	435	432	443	477	490	482	495	452	483	498	497

3. **C. incisum** (Karsten) Jörgensen (fig. 9, *a*).
A single specimen was observed, sample 31.

SECTION PENTAGONA (JÖRGENSEN)

4. **C. pentagonum** Gourret (fig. 9, *b*).
Sporadic; samples 24, 28, 29, 32, 34. The forms correspond best with fig. 32 of Jörgensen, 1911 (f. *subrobustum*).

5. **C. teres** Kofoid (fig. 9, *d*).
Sporadic; samples 28, 30, 37, 41.

6. **C. kofoidii** Jörgensen (fig. 9, *c, e, f, g*).
Rare; samples 9, 11, 12, 22, 26, 32, 34, 36, 39, 40.

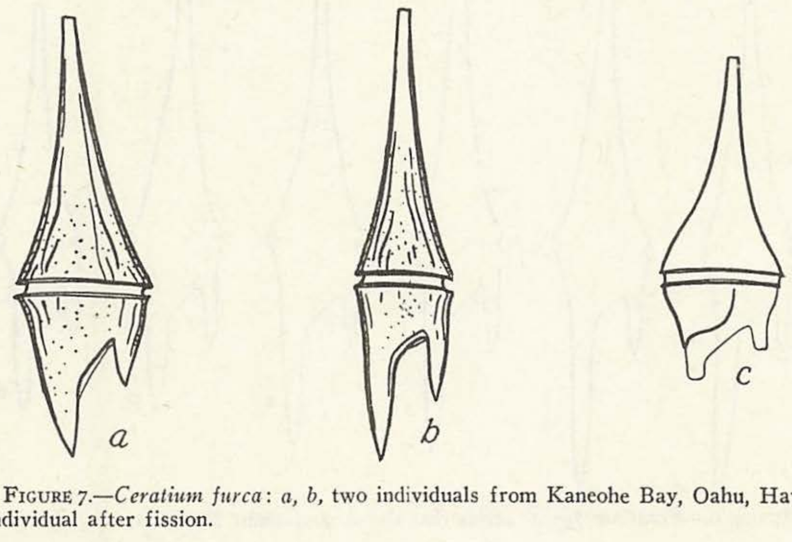

FIGURE 7.—*Ceratium furca*: *a, b,* two individuals from Kaneohe Bay, Oahu, Hawaii; *c,* individual after fission.

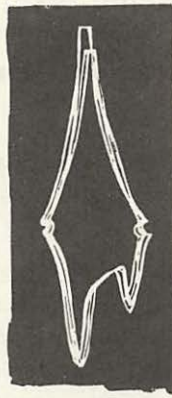

FIGURE 8.—Four superimposed specimens of *Ceratium furca* from sample 20.

The species varies in regard to the length of horns. Most short-horned specimens have greater transdiameters than the long-horned.

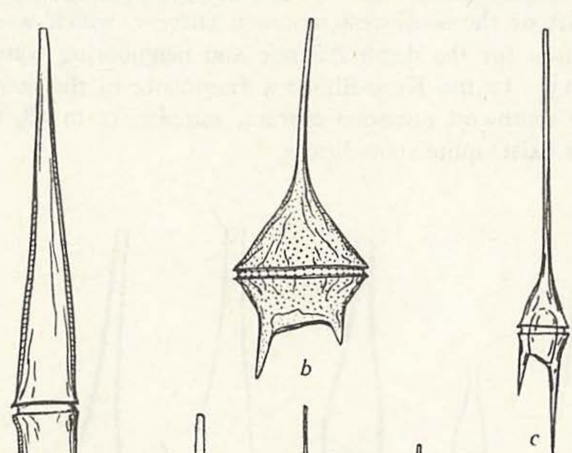

FIGURE 9.—Species of *Ceratium: a, C. incisum* (Karsten) Jörgensen; *b, C. pentagonum* Gourret; *d, C. teres* Kofoid (from Jörgensen 1911); *c, e, f, g, C. kofoidii* Jörgensen; *g,* uncertain form.

SUBGENUS AMPHICERATIUM (VANHÖFFEN) OSTENFELD

SECTION FUSIFORMIA JÖRGENSEN

7. **C. bigelowii** Kofoid.
According to Jörgensen, the species has been found only by Kofoid between the Galapagos and the Tuamotus. I found in the Pacific a single specimen, sample 34.

8. **C. inflatum** (Kofoid) Jörgensen (fig. 10, *a*, *b*).
Not rare upon the Moji-Shanghai-Hongkong course: Samples 3, 4, 6, 13-26. Sporadic in the Gulf of Siam; samples 33, 35, 38-40. One specimen was found in sample 32 corresponding to figure 46 in Jörgensen (6). The total lengths amounted to 500-670 μ, with the maximum from 590-600 μ.

9. **C. fusus** (Ehrenberg) Dujardin (fig. 10, *c-f*).
Common and numerous. This is the principal species in the northern part of the southwest monsoon current, which was reported by Jörgensen for the north Atlantic and neighboring waters. Samples 26 to 13. In the Kuro-Shiwo a fragment; in the southern portion of the southwest monsoon current, samples 41 to 38, the little subspecies exists quite sporadically.

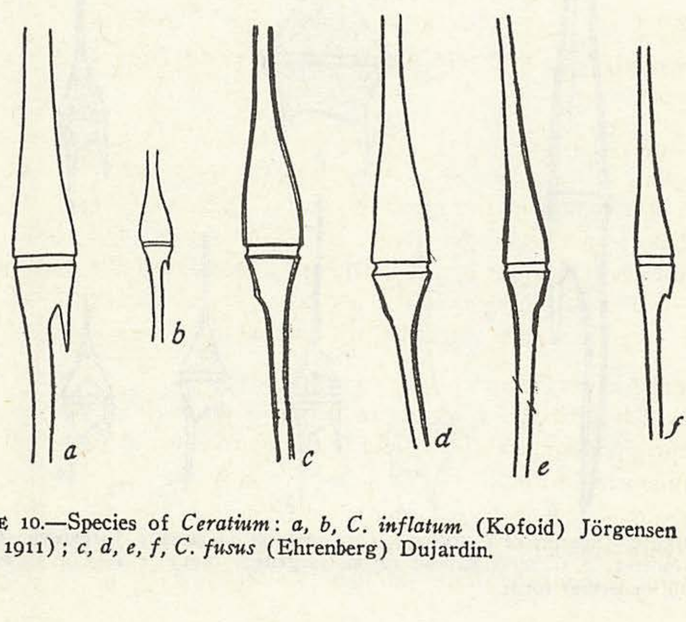

FIGURE 10.—Species of *Ceratium*: *a*, *b*, *C. inflatum* (Kofoid) Jörgensen (*b*, from Jörgensen 1911); *c*, *d*, *e*, *f*, *C. fusus* (Ehrenberg) Dujardin.

Statistical studies of variations were instituted for the total length. It was shown that sharply pronounced environment variations exist in this regard and that the variation runs in conformity with the variation of the total length of *C. furca.* (See Table 1, for *C. furca.*)

10. **C. extensum** (Gourret) Cleve.
    Sporadic on the course Honolulu-Moji. Also samples 24, 27, 35, 36, 38, 39.

11. **C. strictum** (Okamura and Nishikawa) Kofoid.
    A single specimen was seen in sample 39.

SUBGENUS EUCERATIUM (VANHÖFFEN) OSTENFELD

SECTION DENS JÖRGENSEN

12. **C. dens** Ostenfeld and Schmidt (fig. 11).
    This specifically tropical form is common from sample 33 on southward, where without exception it is associated with *C. schmidtii.*

Although the species varies greatly, no certain habitat variations could be proved. Annexed series showed variations in the left posterior horn. Chain formation is frequent, yet no dimorphism of single members was found. Figure 11*e* shows a heteromorphic member of a chain.

SECTION TRIPOS OSTENFELD

13 **C. tripos** (O. F. Müller) Nitzsch (fig. 12).
    Sporadic in the southwest monsoon current from sample 25 northward.

The individuals resemble f. *atlanticum* (Ostenfeld) picture in figure 36 (Jörgensen, 7); they show, however, straight posterior horns. The species varies in this region in the direction, respectively, of *C. breve* and of the intermediate forms between *C. breve* and *C. arcuatum.* The tendency which thereby becomes apparent is a broadening of the base of the posterior horns. The appearance of *C. tripos* in the northern part of the southwest monsoon current is entirely isolated, like that of *C. arcuatum.*

14. **C. pulchellum** Schröder-Jörgensen (figs. 13-15).
    Widely distributed but not numerous, both in the southwest monsoon current (samples 41-19) and in the Kuro-Siwo in four distinctly distinguished forms:

f. *tripodioides,* with large, robust bodies, approaching *C. tripos;* f. *tripodioides,* with smaller fragile bodies; f. *semipulchellum,* all three common everywhere; f. α *eupulchellum,* samples, 26, 28.

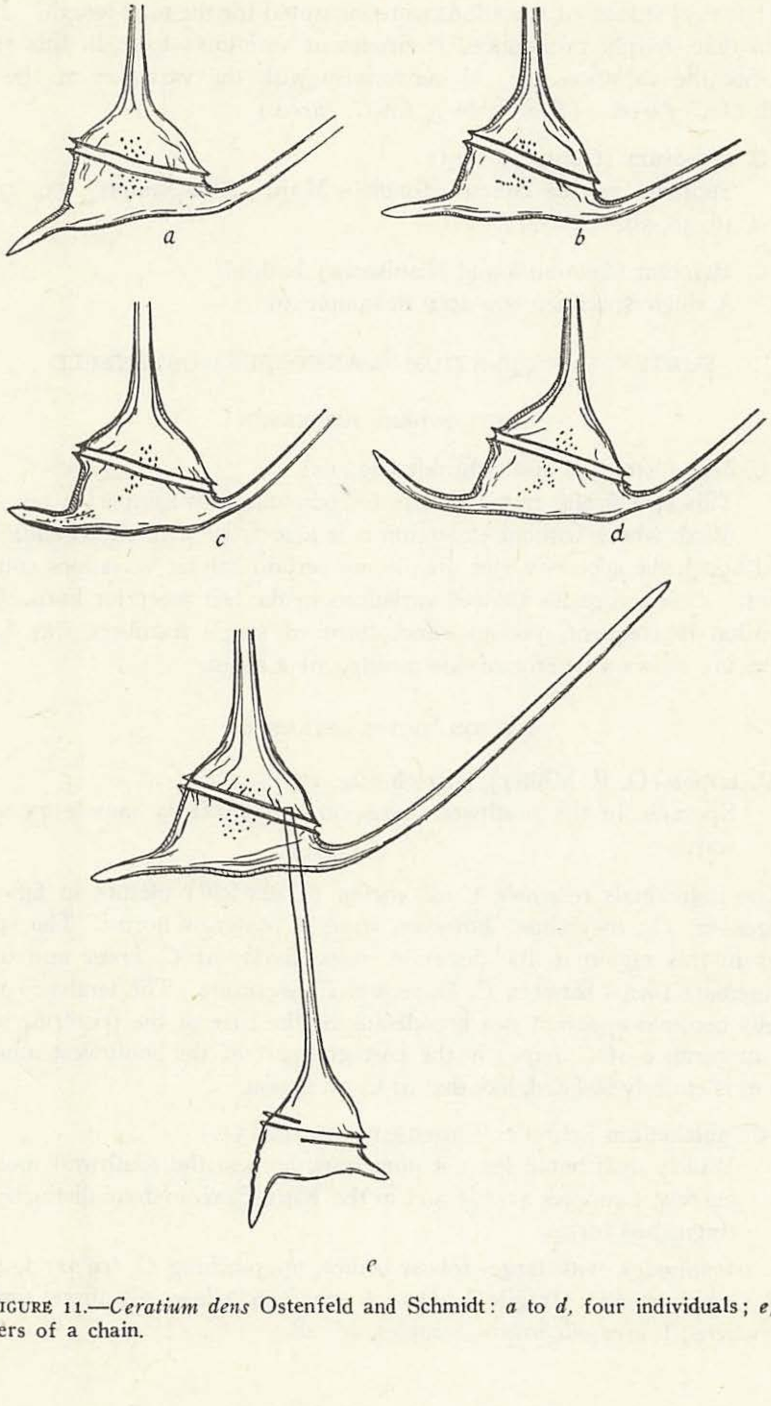

FIGURE 11.—*Ceratium dens* Ostenfeld and Schmidt: *a* to *d*, four individuals; *e*, two members of a chain.

In almost every sample habitat variations could be pointed out, so that a qualitative alteration, not a variation in a north-to-south direction, was observed. Each sample is marked by a fundamental form, which can be illustrated by combining all forms of a series or by reproduction of graphical ranges of variation. (Series I, II=Figs. 13 and 14.) From the figures of Series II the transition from f. *tripodioides* to f. *semipulchellum* is evident. These four types might indeed be hereditarily fixed, and the transitions in reality have come about by the great amplitude of variation of a single form. Beside the analogy with *C. furca,* in this connection, is the circumstance that several types are met with side by side. Noteworthy are some forms of f. *tripodioides,* which in cold water show considerable thickening of posterior horns. (See fig. 15, *d.*)

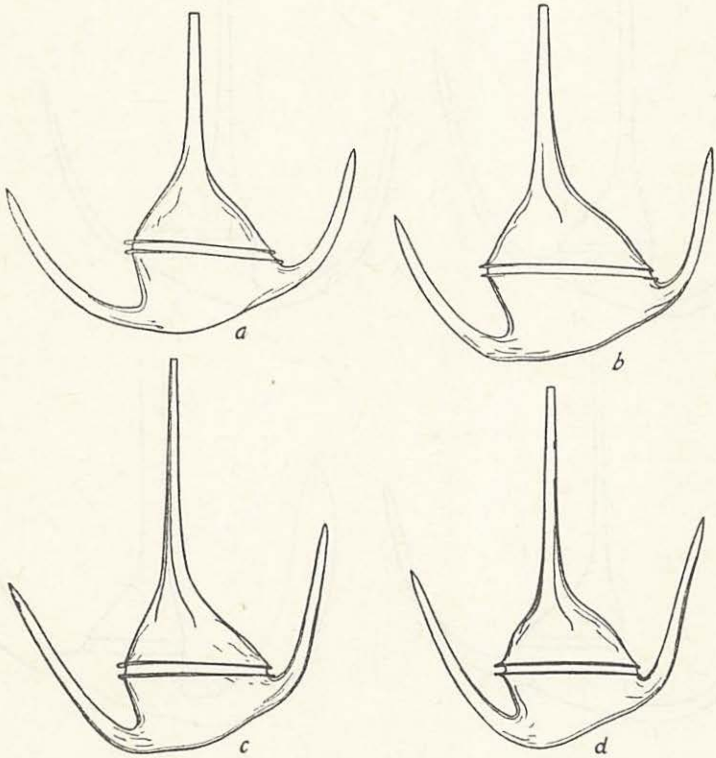

FIGURE 12.—*Ceratium tripos* (O. F. Müller) Nitzsch: *a* to *d.*

15. **C. breve** (Ostenfeld and Schmidt) Schröder.

Not previously reported from the Pacific Ocean. From about sample 25 southward, not superabundant, but common.

The species varies somewhat irregularly in body outline as well as in the spread of the posterior horns, which normally measure 135 to 145 μ, maximum 150 to 160 μ. (See *C. arcuatum.*) The most abundant form is that designated as var. *curvulum* (Jörgensen), though these varieties are by no means sharply separated. (See figs. 17, 18.)

In two tracts in which this species appeared somewhat numerous, the transdiameters of the specimens were measured. It was shown that those in the north are smaller than those in the south.

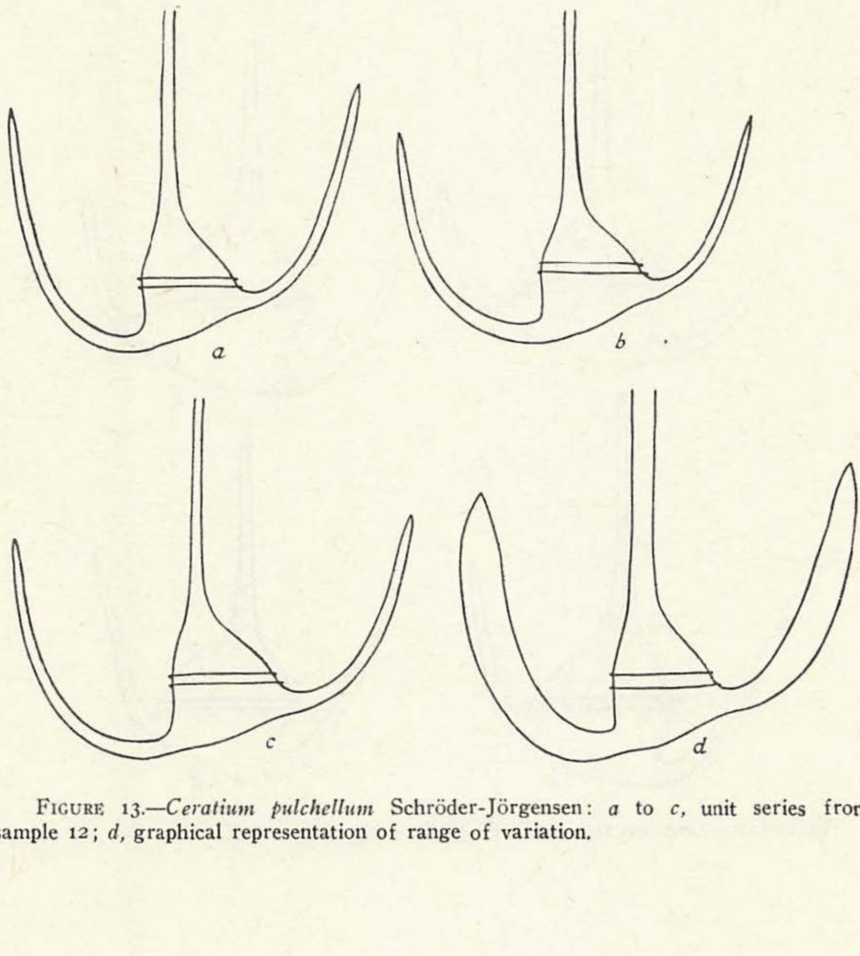

FIGURE 13.—*Ceratium pulchellum* Schröder-Jörgensen: *a* to *c*, unit series from sample 12; *d*, graphical representation of range of variation.

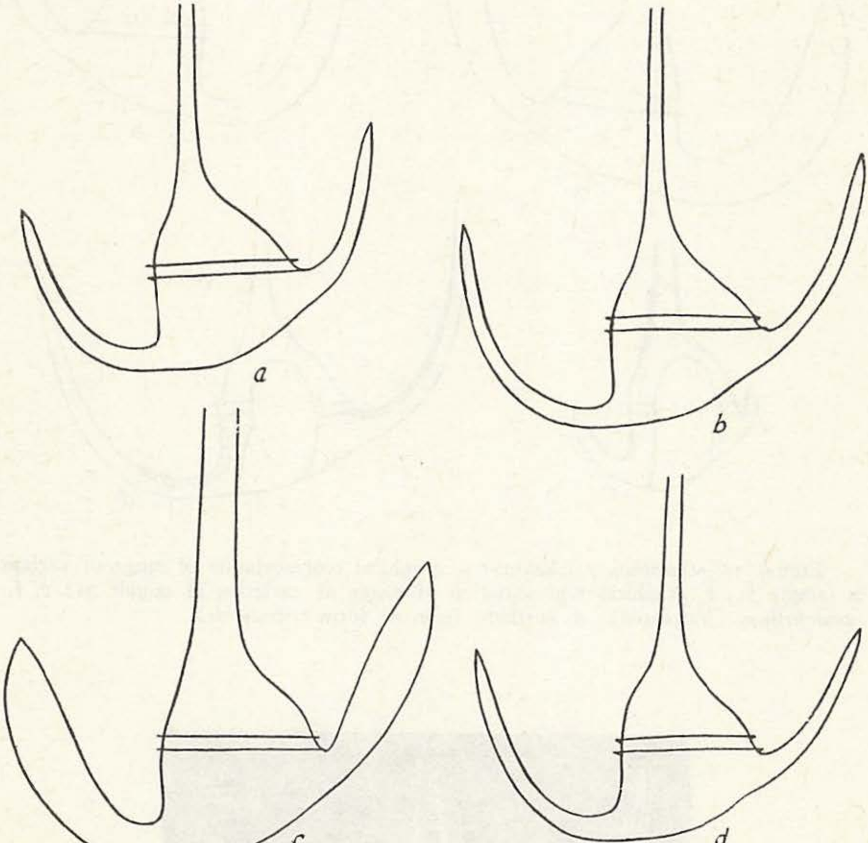

FIGURE 14.—*Ceratium pulchellum: a, b, d,* unit series from sample 32; *c,* graphical representation of range of variation.

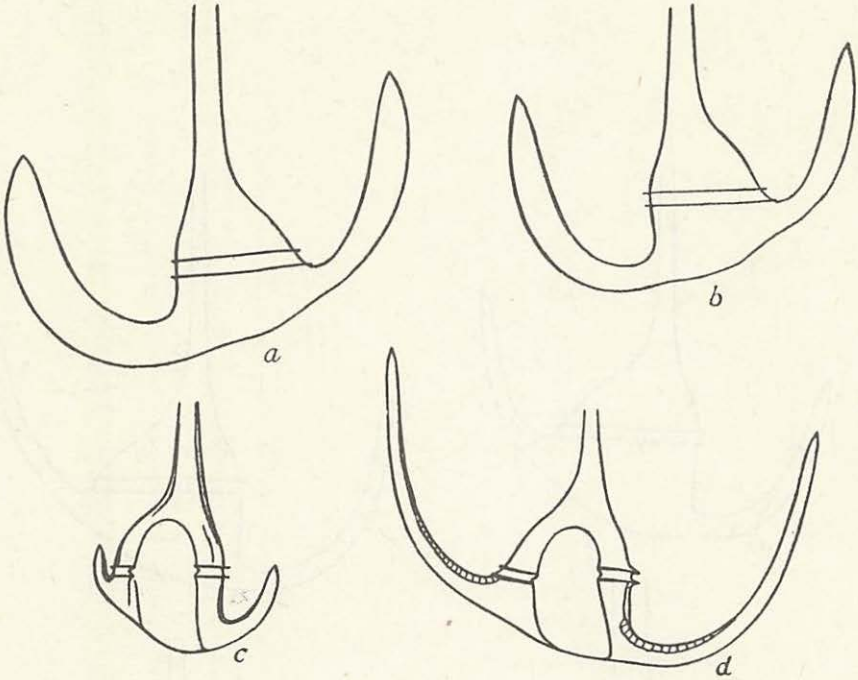

FIGURE 15.—*Ceratium pulchellum*: *a*, graphical representation of range of variation in sample 34; *b*, graphical representation of range of variation in sample 31; *c*, *f.* α *eupulchellum* (Jörgensen); *d*, northern form of form *tripodioides*.

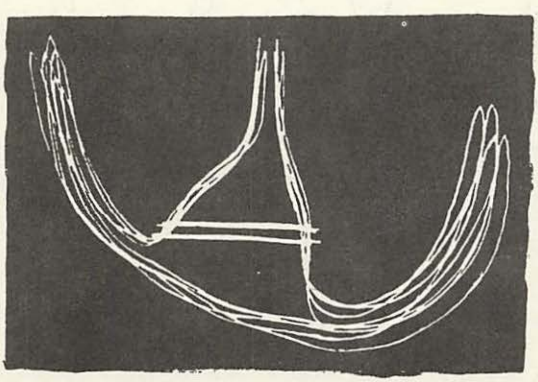

FIGURE 16.—Superimposed specimens of *Ceratium pulchellum* from sample 34.

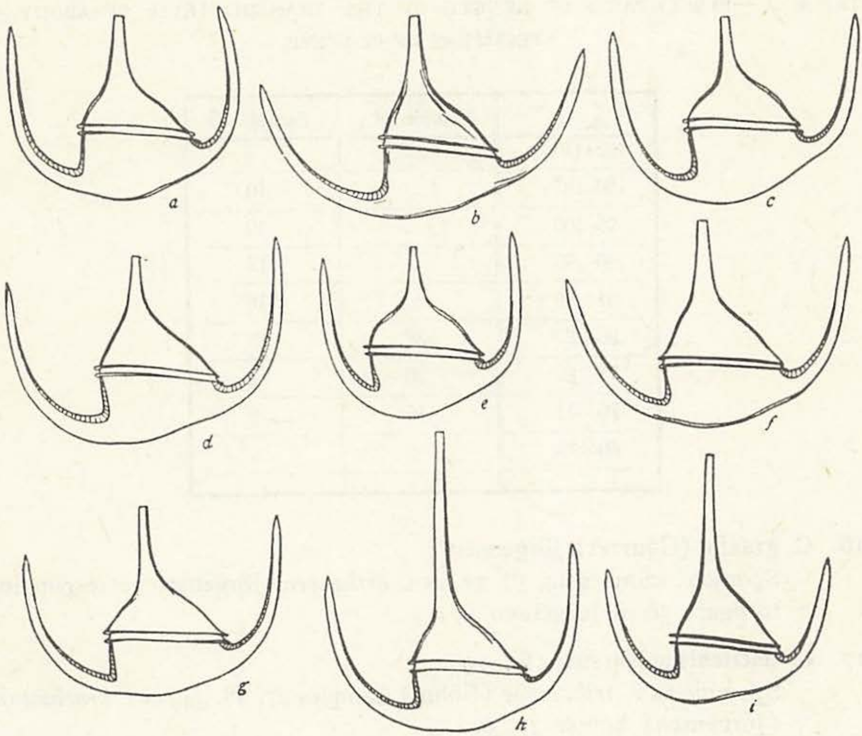

FIGURE 17.—Forms of var. *parallelum* of *C. breve* (Ostenfeld and Schmidt) Schröder.

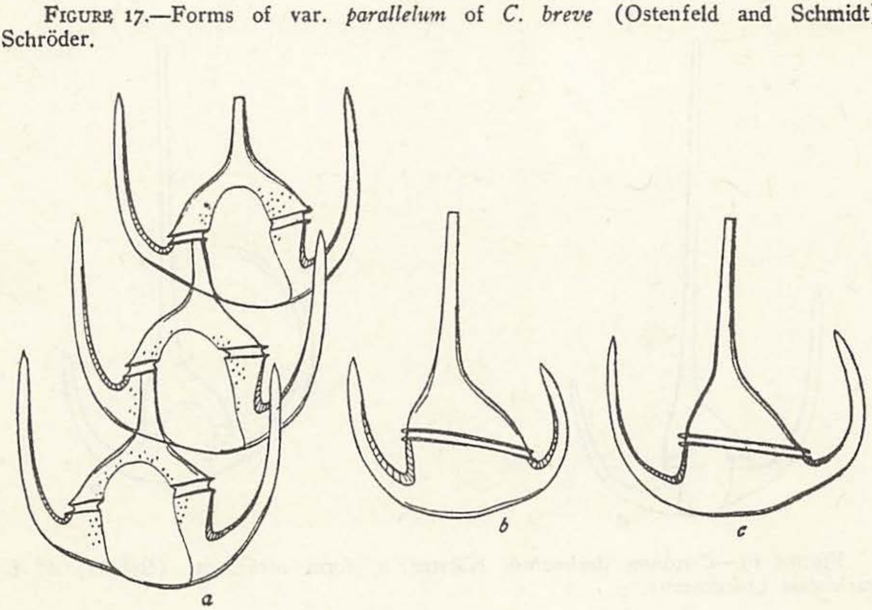

FIGURE 18.—*Ceratium breve: a*, chain of variety *parallelum; b*, variety *curvulum* (Jörgensen) of *C. breve; c*, transition form between variety *parallelum* and variety *curvulum*.

TABLE 2.—PERCENTAGES OF LENGTH OF THE TRANSDIAMETER OF ABOUT 50 SPECIMENS OF C. BREVE

μ	Sample 24	Sample 35
105–110	....	2
100–105	....	10
95–100	....	10
90– 95	....	12
85– 90	....	18
80– 85	28	28
75– 80	30	12
70– 75	36	8
60– 70	6	....

16. **C. gracile** (Gourret) Jörgensen.
Sporadic, samples 24, 32, 33, as f. *orthoceras* Jörgensen corresponding to figure 56 in Jörgensen (7).

17. **C. declinatum** Karsten (fig. 19).
Sporadic as f. *orthoceras* (Böhm), samples 27, 28, 34, as f. *brachiatum* (Jörgensen) sample 37, 39.

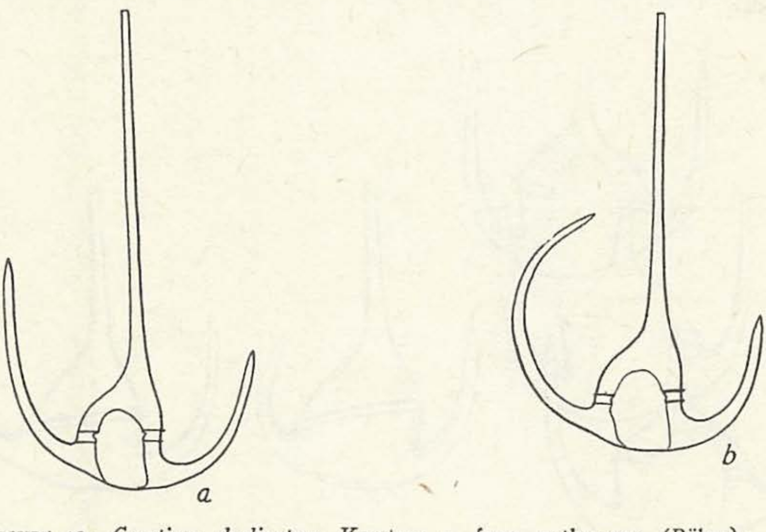

FIGURE 19.—*Ceratium declinatum* Karsten: *a*, form *orthoceras* (Böhm); *b*, f. *brachiatum* (Jörgensen).

18. **C. contortum** (Gourret) Cleve (fig. 20).

The species is represented exclusively by var. *saltans* (Schröder). The right posterior horn may be bent in one plane, and also twisted.. The last-mentioned forms were not observed in the north. Distribution is limited; samples 2*, 32, 34-36, 38, 39. With more material more definite results can be obtained concerning the variation in transdiameters.

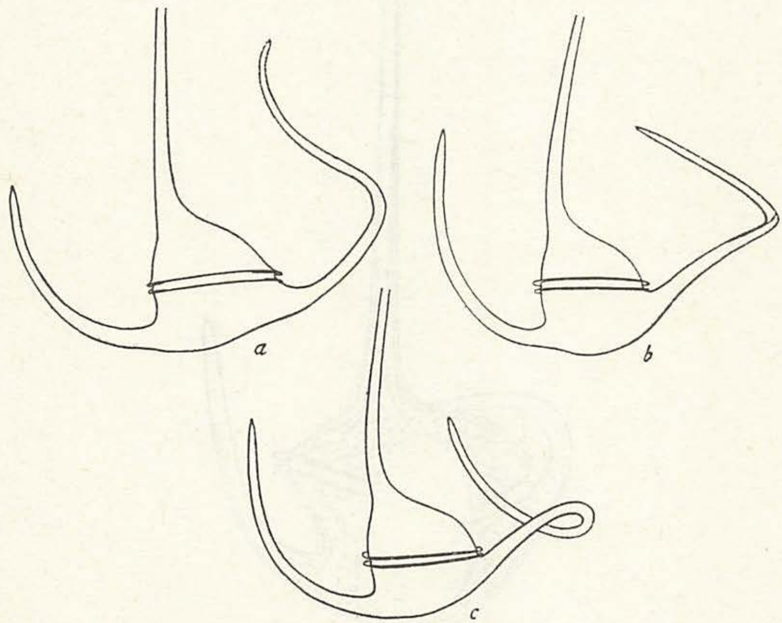

FIGURE 20.—*Ceratium contortum* (Gourret) Cleve variety *saltans* (Schröder).

19. **C. concilians** Jörgensen (fig. 21).

There was observed only f. *dispar* (Pouchet) samples 26, 27, 29, 30, 32, 35 sporadic always in the uniform typical form.

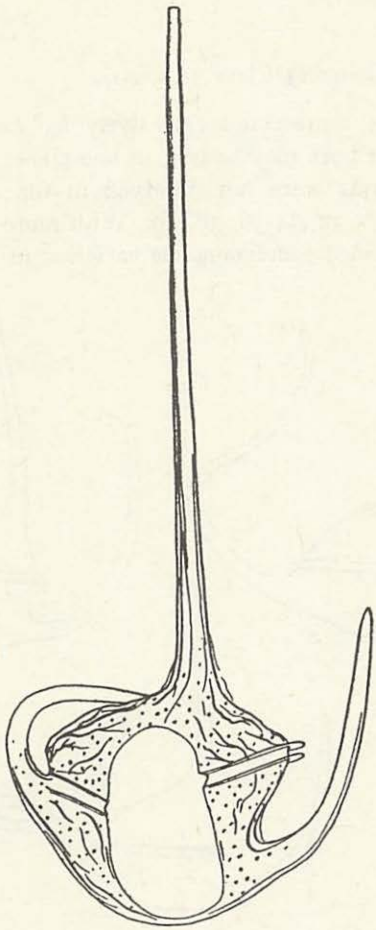

FIGURE 21.—*Ceratium concilians* Jörgensen.

20. **C. schmidtii** Jörgensen (fig. 22).

Rare in samples 32, 35-40.

The base of the posterior horns varies especially and it has a somewhat divergent general appearance as a result. In the elongated bases the posterior body contour is more or less straight; in the short bases it is transformed circularly in the outer contour of the posterior horns, which may be the most specialized.

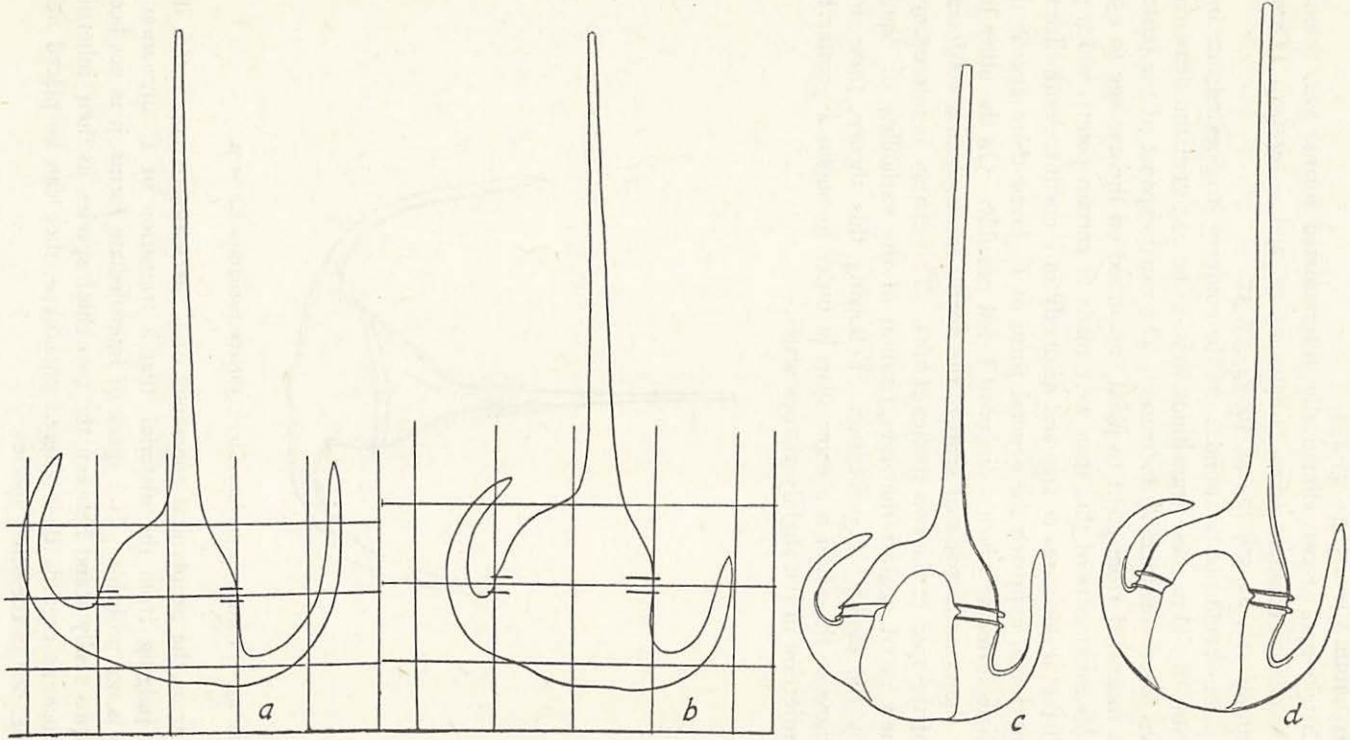

FIGURE 22.—Series of *Ceratium schmidtii* Jörgensen.

21. **C. arcuatum** Cleve (figs. 23-25).

Distribution of two climatically differentiated forms: var. *robustum* (Karsten), common from samples 25-12, and *a karstenii* (*Pavill.*), samples 11, 22, 26, 27, 29, 30, 34, 35, 37.

Transitions could not be found. On the contrary it appeared that in the very territories where these transitions were to be expected the demarcation of the two forms considerably increases. The usual expanse of the posterior horns, as measured from point to point, amounted on the average to 250 to 260 μ. Measurements of this span were made at certain points, which gave the result that it decreases clearly and distinctly in a north-to-south direction.

As the forms approach the general form of *C. breve* there appear those intermediate forms of which a diagnosis is not possible. On the other hand, *C. breve* shows an increase of span to the north, from which a conformable change of the span in the two species results. This change is interesting for it is a new proof against the interpretation of the variability of plankton purely by the theory of suspension. Following this theory, these forms should show to the south a greater span in order to obtain a greater horizontal projection in the slightly viscous water.

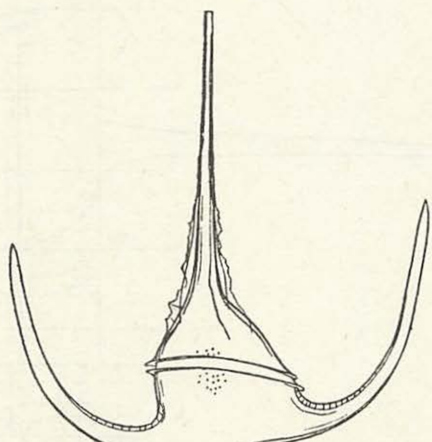

FIGURE 23.—*Ceratium arcuatum* Cleve, variety *robustum* Karsten.

So far as the genotypical constancy of *C. arcuatum* is concerned, it can be said, judging from the material, that a transition of *C. arcuatum* into *C. breve* is not probable. If I speak of intermediate forms, it is not because these forms really stand between the two chief species in their inheritance, but because, as regards their altered phenotype, they can be placed neither in the one, nor in the other species.

TABLE 3.—PERCENTAGES OF LENGTH OF THE HORN SPAN OF C. ARCUATUM—C. BREVE

No. of Measure ments	24	20	20	16	16	8	9	6	13	16	9	12	16	Total 185
Sample	13	14	15	16		17		18		19	24	34	36	
Species Length in μ	arcu-atum	arcu-atum	arcu-atum	arcu-atum	inter-mediate form	arcu-atum	inter-mediate form	arcu-atum	inter-mediate form	inter-mediate form	inter-mediate form	breve	breve	
281-290	4	....	....	....	....	....	....	....	....	....	....	....	....	
271-280	9	5	....	....	....	....	....	....	....	....	....	....	....	
261-270	16	20	10	....	....	....	....	....	....	....	....	....	....	
251-260	21	25	5	6	....	....	....	....	....	....	....	....	....	
241-250	28	5	10	....	....	....	....	....	....	....	....	....	....	
231-240	9	5	20	25	....	....	....	....	....	....	....	....	....	
221-230	4	35	20	13	....	....	....	17	....	....	....	....	....	
211-220	9	5	30	31	6	....	....	49	....	....	....	....	....	
201-210	....	....	5	13	....	12	....	17	14	6	....	....	....	
191-200	....	....	....	6	....	50	....	17	....	13	....	....	....	
181-190	....	....	....	6	18	26	33	....	31	....	44	....	....	
171-180	....	....	....	....	63	12	....	....	39	44	22	....	....	
161-170	....	....	....	....	13	....	12	....	8	25	34	....	....	
151-160	....	....	....	....	....	....	22	....	8	6	....	8	....	
141-150	....	....	....	....	....	....	33	....	....	6	....	84	50	
131-140	....	....	....	....	....	....	....	....	....	....	....	8	32	
121-130	....	....	....	....	....	....	....	....	....	....	....	....	18	

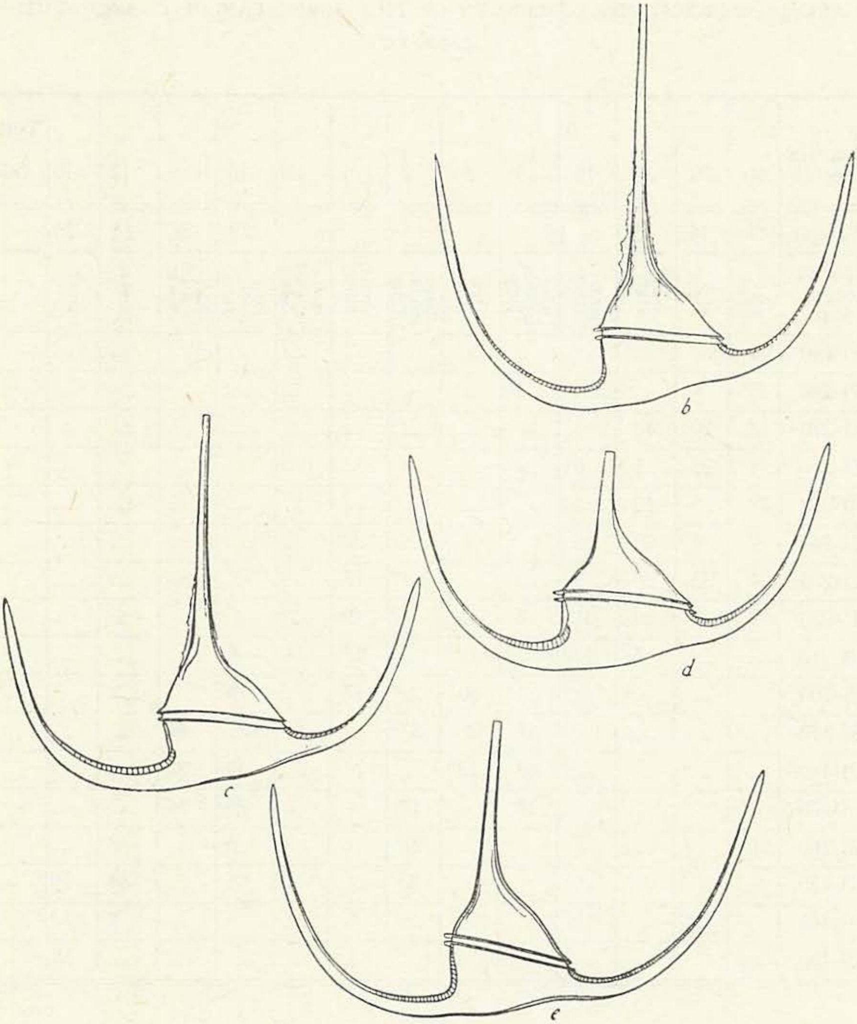

FIGURE 24.—*Ceratium arcuatum* Cleve, variety *robustum* Karsten: *b,-e,* northern forms with great expanse of horns.

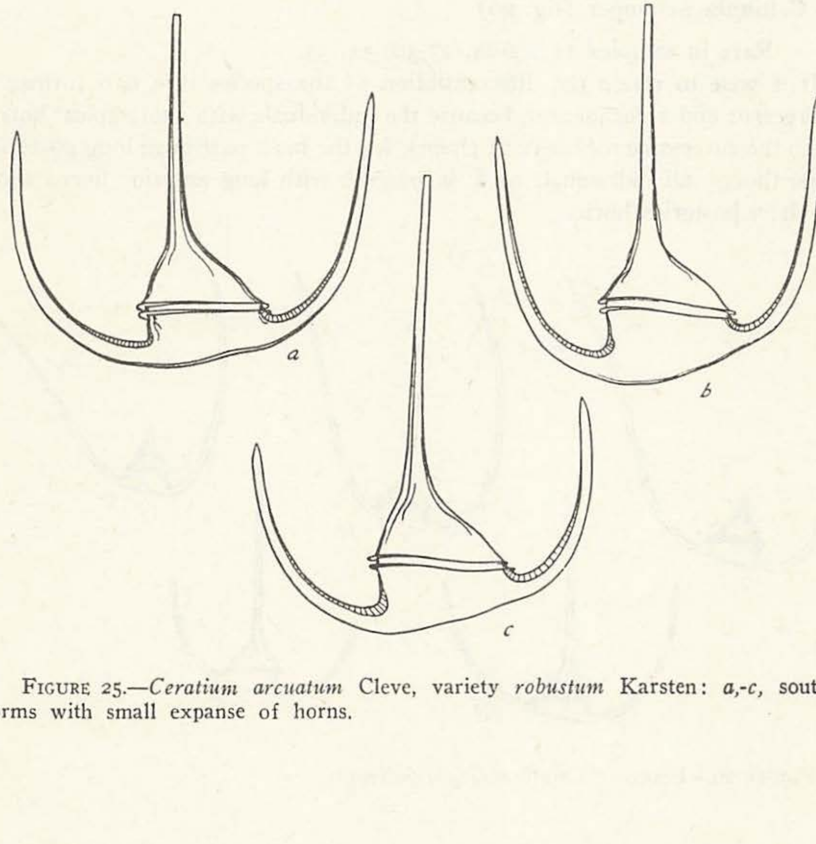

FIGURE 25.—*Ceratium arcuatum* Cleve, variety *robustum* Karsten: *a,-c,* southern forms with small expanse of horns.

22. **C. lunula** Schimper (fig. 26).

Rare in samples 11, 22-24, 27-30, 32, 33.

It is wise to retain the differentiation of the species into two forms; f. *brachyceros* and f. *megaceros,* because the individuals with short apical horns, and so the successive members of chains, for the most part have long posterior horns, though all individuals of f. *megaceros* with long anterior horns show also short posterior horns.

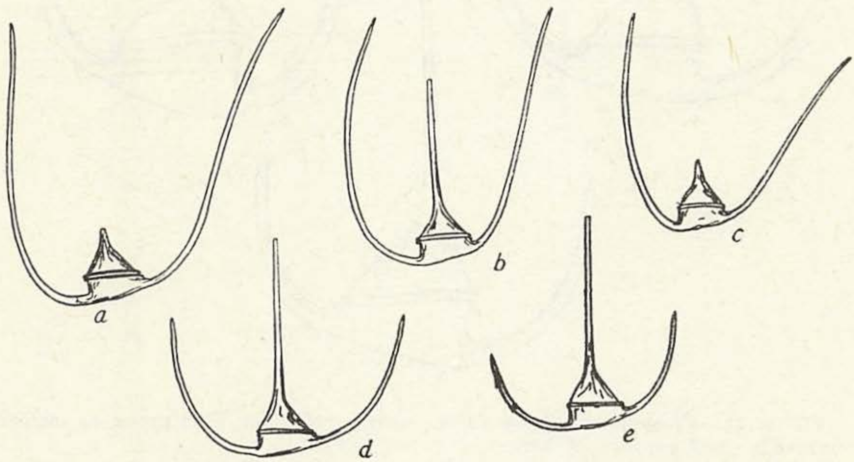

FIGURE 26.—Forms of *Ceratium lunula* Schimper.

SECTION LIMULUS JÖRGENSEN

23. **C. limulus** Gourret (fig. 27, *b*).
Sporadic, samples 28, 32.

SECTION PLATYCORNIA JÖRGENSEN

24. **C. platycorne** v. Daday (fig. 27, *a*).
A single specimen, sample 33.

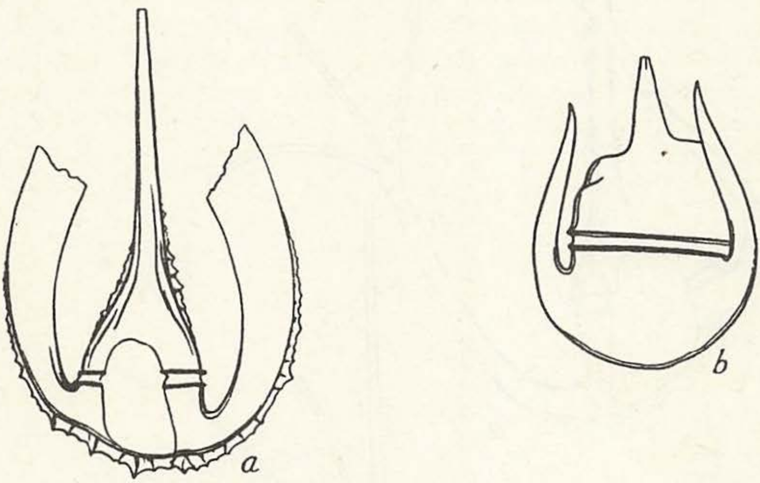

FIGURE 27.—Forms of *Ceratium: a, C. platycorne* v. *Daday; b, C. limulus* Gourret.

SECTION PALAMATA (PAVILL.) JÖRGENSEN

25. **C. ranipes** Cleve (figs. 28-31).
Distribution: Sporadic; samples 22-24, 27.

I again connect here the two species *C. ranipes* and *C. palmatum* on the basis of transitions which do not warrant a definite allocation to either one of the two species. None the less there appear to be two independently fluctuating variable groups. Collection of much material will be necessary. Transdiameter 55-58 μ.

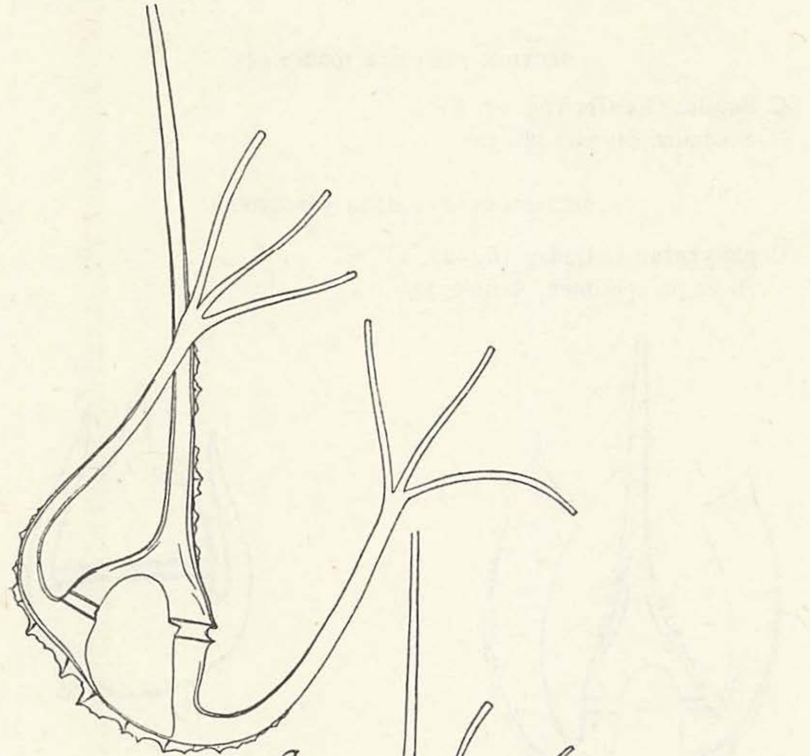

FIGURE 28.—*Ceratium ranipes* Cleve: *a, b,* transitions toward variety *palmatum.*

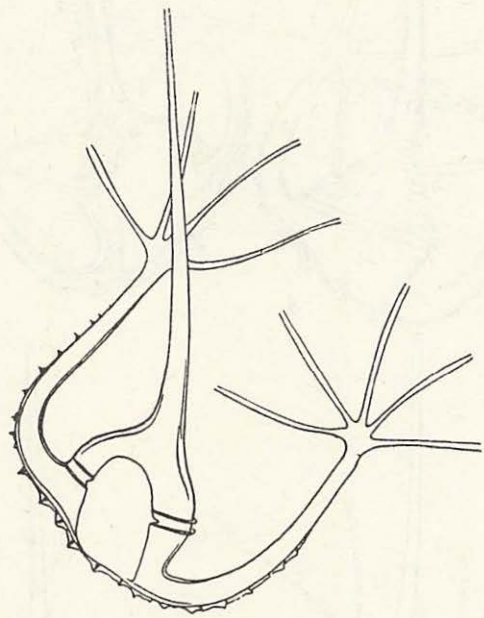

FIGURE 29.—Continuation of figure 28 (*Ceratium ranipes*).

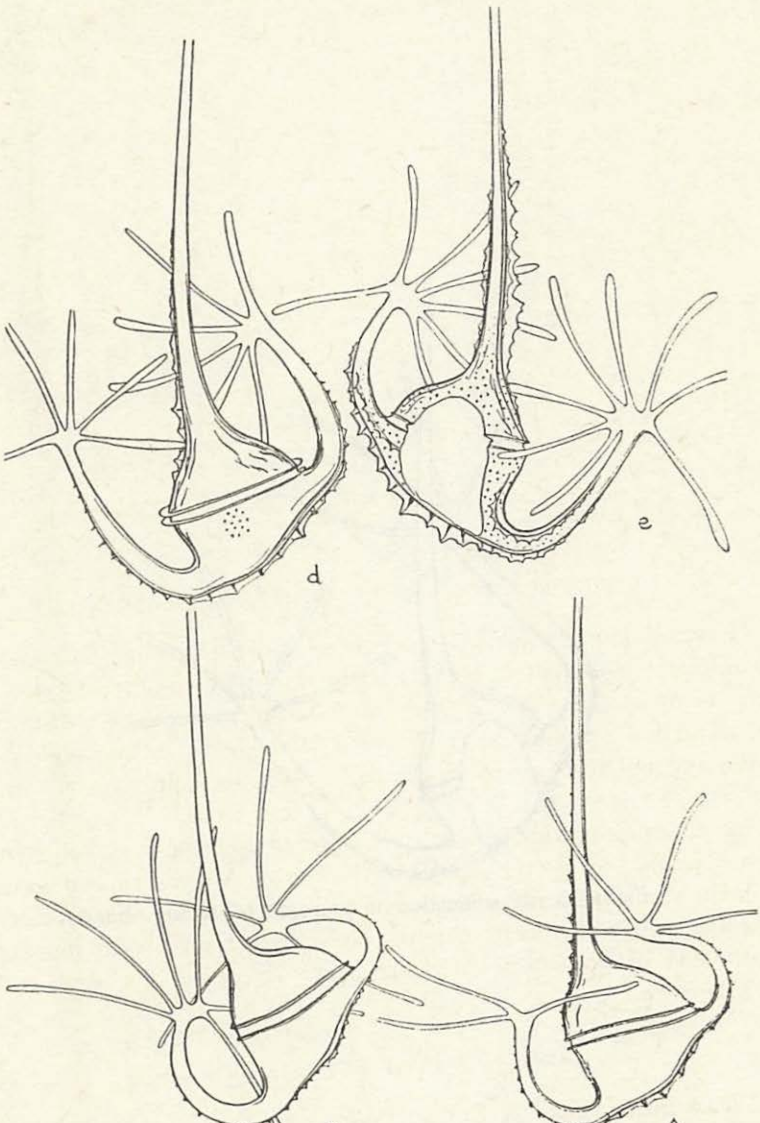

FIGURE 30.—Continuation of figures 28 and 29.

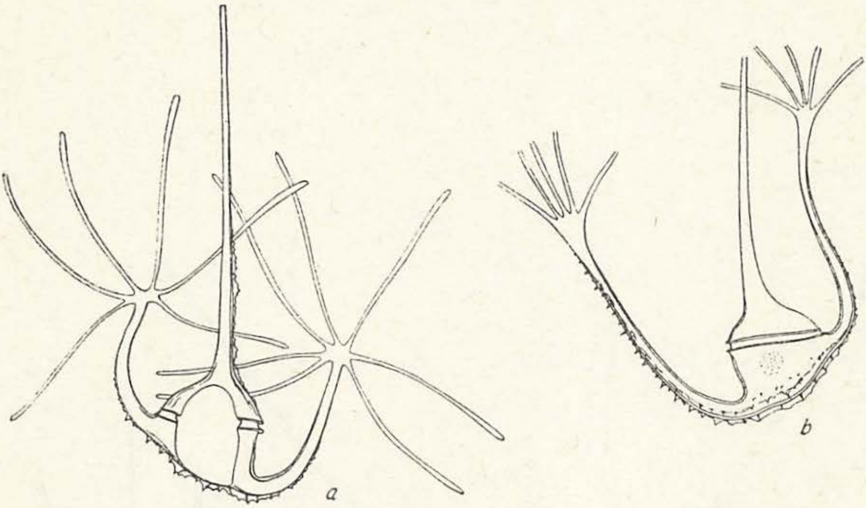

FIGURE 31.—*Ceratium ranipes* from Indian Ocean: *a*, var. *palmatum*; *b*, variety *furcellatum* (Lemmermann).

SUBGENUS MACROCERATIUM (NEW NAME)

Macroceratium is distinguished from the subgenus *Euceratium* by the considerably elongated and generally thinly-drawn-out posterior horns, which are open at the ends. The posterior horns are always distinctly set off at an angle from the posterior contour of the body, so that angle β varies between 45° and 165°, of which the high values are quite rare (*C. hexacanthum*, 150-180°).

I have introduced this new subspecies partly because it is well characterized, and partly because the species in the section *Macroceros*, on account of their great size, fitted only with difficulty in the subgenus *Euceratium*. Following this change, there will naturally be required a subdivision into sections, as postulated by Jörgensen (6), and it is, of course, the same with the other subgenera.

SECTION MACROCERAS OSTENFELD

26. **C. massiliense** (Gourret-Karsten) Jörgensen (fig. 32).
Universally distributed, but for the most part somewhat sparsely.

Variable in regard to body size, and length, configuration, and divergence of posterior horns. The forms often approach *C. deflexum*; f. *protuberans* (Karsten) in Kuro-Siwo, samples 4-6; *a macroceroides* (Karsten), samples 3, 10, as well as from 17 southward.

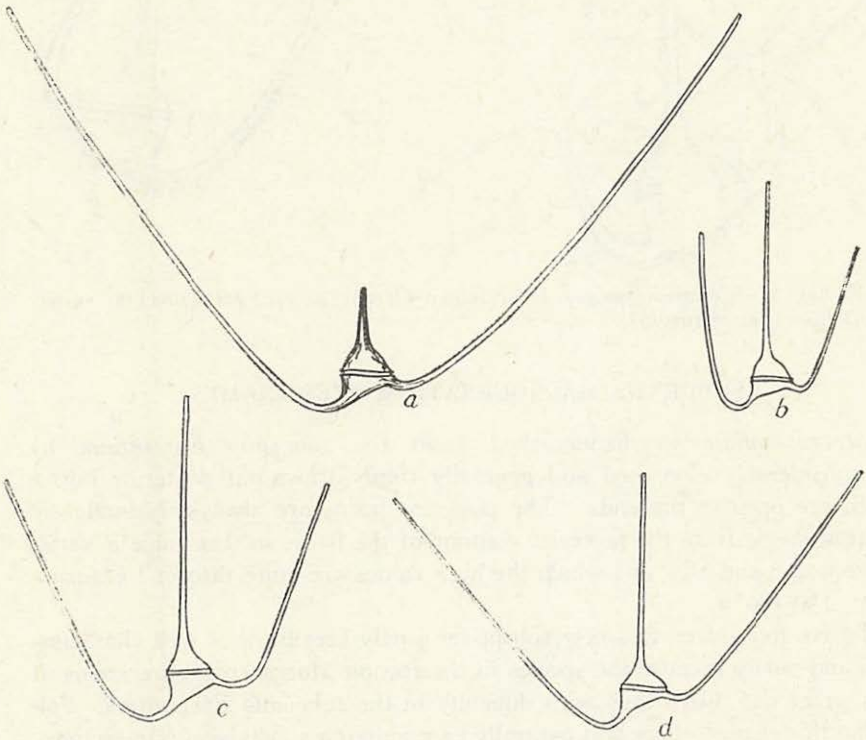

FIGURE 32.—*Ceratium massiliense* (Gourret-Karsten): forms of α *macroceroides* (Karsten).

27. **C. carriense** Gourret.
    Sporadic as f. *ceylanicum* (Schröder), samples 24, 29, 37-39.

28. **C. deflexum** (Kofoid) (figs. 33, 34).
    The species lives only in the southwest monsoon current from the position of sample 26 southward.

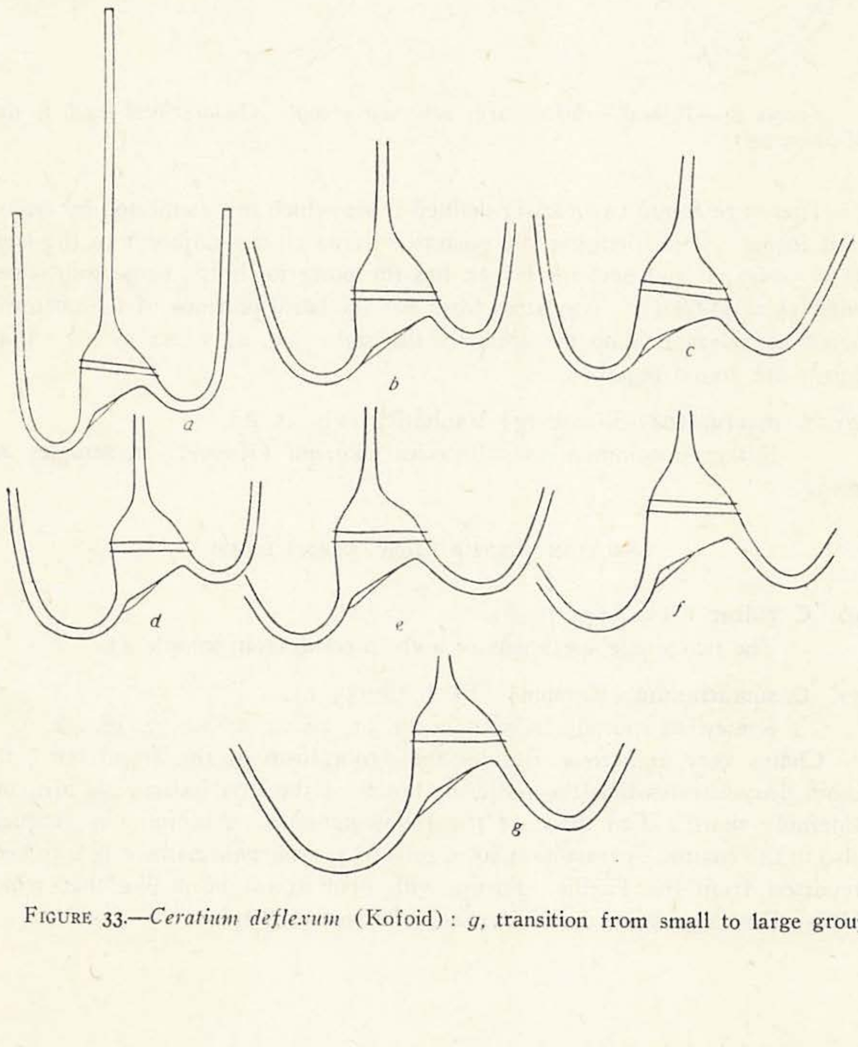

FIGURE 33.—*Ceratium deflexum* (Kofoid): *g*, transition from small to large group.

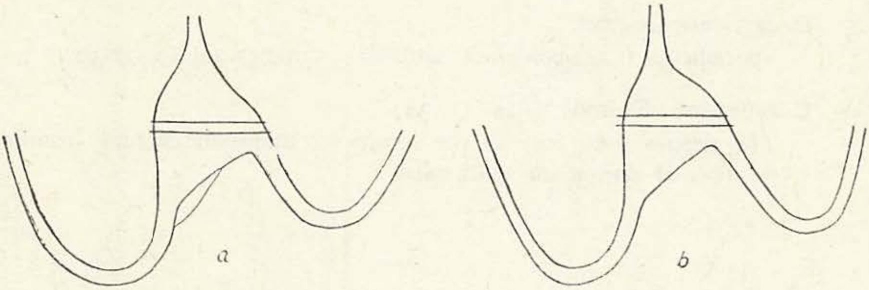

FIGURE 34.—Typical forms of large *deflexum* groups. (Enlargement equal to that of figure 33.)

There are found two clearly-defined types which are connected by transition forms. One form has the posterior horns closely adjacent to the body ($t = 50\text{-}60\,\mu$), and one, far larger, has the posterior horns projecting somewhat ($t = 60\text{-}68\,\mu$). The latter form has the basal portions of the posterior horns considerably longer; especially the right one, x, y = t to 2 t. Both forms are found together.

29. **C. macroceros** (Ehrenberg) Vanhöffen (fig. 35, *a*).

Rather uncommon, as subspecies *gallicum* (Kofoid) in samples 22, 26-32.

SECTION VULTUR (JÖRGENSEN) BÖHM

30. **C. vultur** Cleve (fig. 35, *b*).

The two single specimens of a chain come from sample 23.

31. **C. sumatranum** (Karsten) (Pl. I; fig. 35, *c*).

Somewhat sporadic in samples 19, 21, 22, 24, 27-32, 37, 38, 40.

Chains very numerous. Besides the dimorphism of the apical horn, the chain demonstrates that the posterior horns of the first individuals are considerably shorter than those of the following ones. Autotomy is frequent also in the chains. A transition form toward f. *recurvum* has not before been reported from the Pacific. Forms with bent apical horn like that which Huber-Pestalozzi gives for *C. hirundinella* were observed.

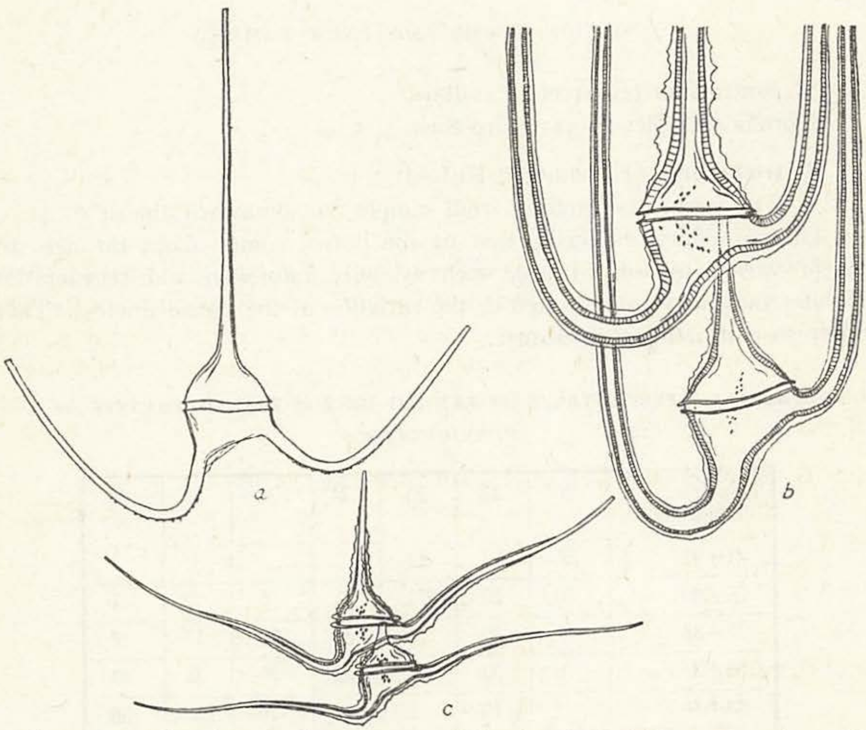

FIGURE 35.—*Ceratium: a, C. macroceros* (Ehrenberg) Vanhöffen, subspecies *gallicum* (Kofoid); *b, C. vultur* Cleve, two members of a chain; *c, C. sumatranum* (Karsten), two members of a chain, which approach form *recurvum* (Jörgensen).

SECTION TRICHOCEROS (NEW NAME)

32. **C. contrarium** (Gourret) Pavillard
Sporadic, samples 27-31; Kuro-Siwo 3, 5, 9.

33. **C. trichoceros** (Ehrenberg) Kofoid.

The species is common from sample 20, southward almost to 41. The variability, especially that of the horns, comes about through different various phases of age, such as, age, autotomy, and regeneration. Habitat variations are indicated by the variation of the transdiameters. These diminish with rising temperature.

TABLE 4.—PERCENTAGES OF LENGTH OF 208 TRANSDIAMETERS OF C. TRICHOCEROS

Sample: Length in μ	20	22	23	24	35	37	39
41+42	27	10	23	....	....	....	....
39+40	20	20	31	21	6	2	1
37+38	47	30	23	36	29	17	7
35+36	6	30	23	32	39	38	44
33+34	....	10	....	11	26	38	36
31+32	....	....	....	....	....	5	12

34. **C. horridum** Gran. (fig. 36).

Two types appear which are partially united by transition forms: var. *molle*, samples 22-24, 34; var. *tenue*, samples 21, 24, 27, 31, 33, 35, 38-40.

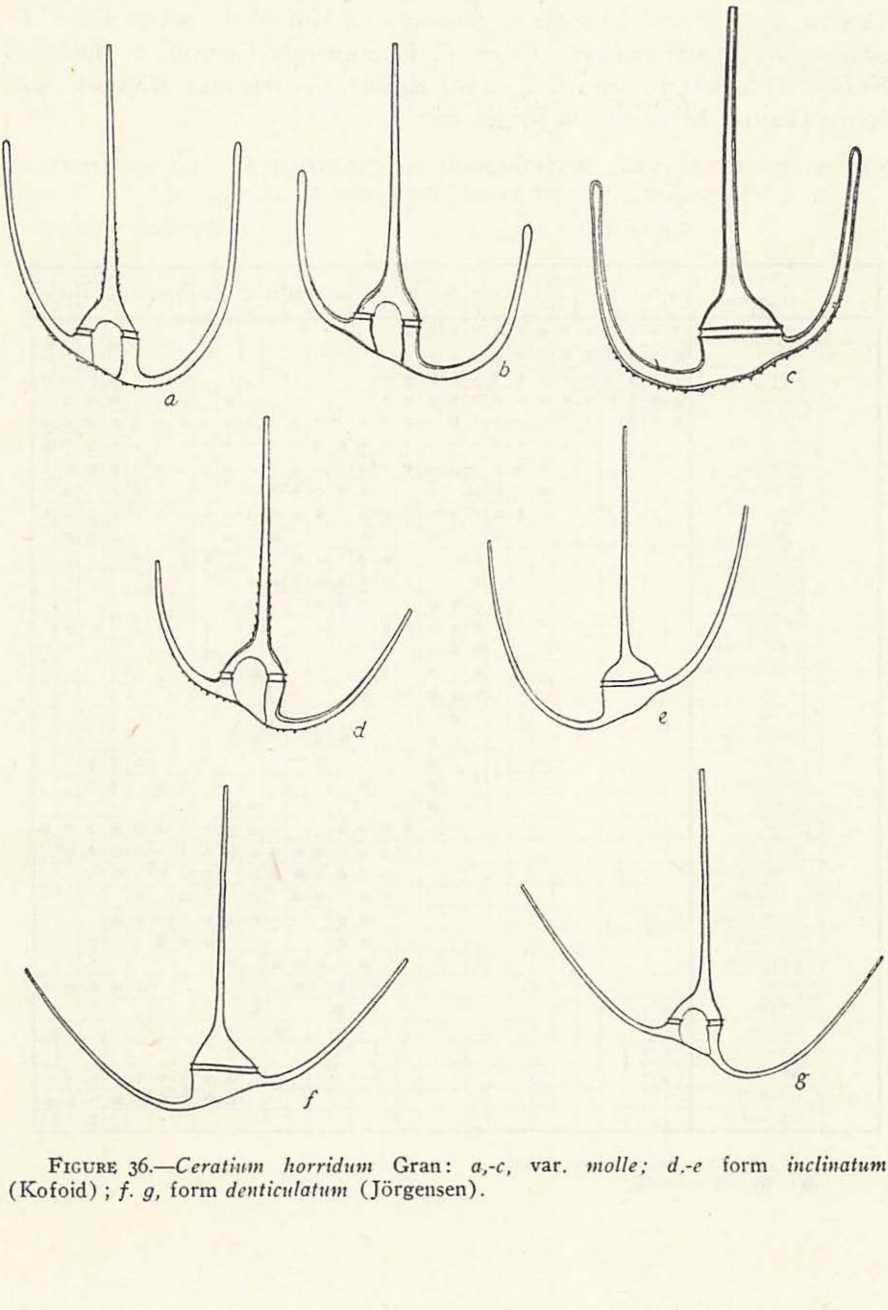

FIGURE 36.—*Ceratium horridum* Gran: *a,-c,* var. *molle; d,-e* form *inclinatum* (Kofoid); *f. g,* form *denticulatum* (Jörgensen).

SECTION RETICULATA (JÖRGENSEN) BÖHM

35. **C. hexacanthum** Gourret.

Sporadic, sample 6 as f. *contortum* and species, samples 26, 32, 22, 24 as f. *spiralis*.

For the Pacific there were also reported by Jörgensen, 1911: *C. gravidum* Gourret, *C. schröteri* Schröder, *C. lanceolatum* Kofoid, *C. belone* Cleve, *C. geniculatum* (Lemmermann) Cleve, *C. longirostrum* Gourret, *C. falcatum* Kofoid, *C. humile* Jörgensen, *C. axiale* Kofoid, *C. arrietinum* Cleve, *C. gibberum* Gourret, *C. pavillardii* Jörgensen.

TABLE 5.—HORIZONTAL DISTRIBUTION OF CERATIUM IN THE SOUTHWEST MONSOON CURRENT FROM SINGAPORE TO SHANGHAI.[a]

NORTHERN STATIONS SOUTHERN STATIONS

Sample (Ceratium)	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
arcuatum	+	+	+	+	●	●	●	●	●	●	●	●	●																
tripos	●	●	●	●	●	●	●	●	●	●	●	+	●																
fusus	+	+	+	+	+	+	+	+	+	●	●	●	●	●												●	●	●	●
inflatum	●	●	●	●	●	●	●	●	●	●	●	●	●	●						●	●		●			●	●	●	
furca	+	+	+	+	+	+	+	+	+	+	●	+	+	●	●	+	+	+	+	+	●	+	●	●	●	●	●	●	●
massiliense					+	+	+	+	+	+	+	+	+	+	●	●	●	+	+	+	+	+	+	+	+	+	+	+	●
pulchellum							+	+	●	+	+	●	●	+	+	+	+	+	+	+	●	+	+	●	●	●	●	●	●
sumatranum							●		●	●		●			●	●	●	●	●	●					●	●		●	
trichoceros								●	●	+	+	+	●	●	●		●	●	●	●	+	+	+	+	+	+	+	+	+
var. tenue									●			●			●				●		●		●			●	●	●	
karstenii										●				●	●		●	●				●	●		●				
macroceros										●				●	●	●	●	●	●	●									
lunula										●	●	●			●	●	●			●	●								
kofoidii										●	●	●	●	●						●		●		●			●	●	
var. molle										●	●	●										●							
hexacanthum										●		●		●						●									
ranipes										●	●	●			●														
vultur											●																		
pentagonum												●				●	●			●		●							
carriense												●					●								●	●	●		
extensum												●			●								●	●		●	●		
gracile												●								●	●								
breve													●	●	●	●				●	●	+	+	+	●	●	●	●	●
deflexum														●	●	●	●	●	●	●	●	●	+	+	●	●	●	●	
var. saltans														●	●	●	●	●	●	●		●	●	●		●	●		
f. dispar														●	●		●	●		●			●		●				
candelabrum															●	●				●	●	●	●	●	●	●			
declinatum															●	●						●	●	●			●		
contrarium															●	●	●	●	●		●								
teres																●		●							●	●	●	●	●
limulus																●				●									
incisum																			●										
platycorne																					●								
dens																					●	+	+	+	+	+	+	+	+
schmidtii																					●	●	●	●	●	●	●	●	●
strictum																											●		

[a] + = Of rather frequent appearance.
● = Rare to sporadic.

SUMMARY

1. The northern and western Pacific shows in summer three associations of ceratium: *a*, the tropical, toward the north to Hongkong; *b*, the coast-association of northern Formosa Strait to Shanghai; *c*, the subtropical of the Kuro-Siwo.

The spontaneous appearance of northern forms close to land is peculiar and unexplained between Hongkong and Shanghai in the southwest monsoon current. In the territory studied *Ceratium* exhibits few forms and is relatively sparse and poor in species.

2. The variability of *Ceratium* is correlated with the environment. Habitat variations are shown to be end products of the influence of external factors.

3. For taxonomic purposes, there is necessitated a revision of the numerous names and of the establishment of varieties and forms.

RARE CERATIUM FROM THE INDIAN OCEAN

From material obtained by Dr. Victor Pietschmann, July-August, 1928.

1. **C. praelongum** (Lemmermann) Kofoid (fig. 37, *a*).
   Penang-Colombo, southeast coast of Ceylon.

2. **C. cephalotum**
   Between latitude 10° N., longitude 62° E., and latitude 12° N., longitude 58° E.

3. **C. incisum** (Karsten).
   Penang-Colombo, August 25, southeast coast of Ceylon.

4. **C. geniculatum** (Lemmermann) Cleve (fig. 37, *c-d*).
   Southern point of India.

5. **C. bigelowii** Kofoid (fig. 37, *b*).
   Southern point of India, between latitude 10° N., longitude 62° E., and latitude 12° N., longitude 58° E.

Previously there were known from the Indian Ocean only two uncertain fragments from Station 213 of the Valdive Expedition (latitude 7.1° N., longitude 85.57° E.).

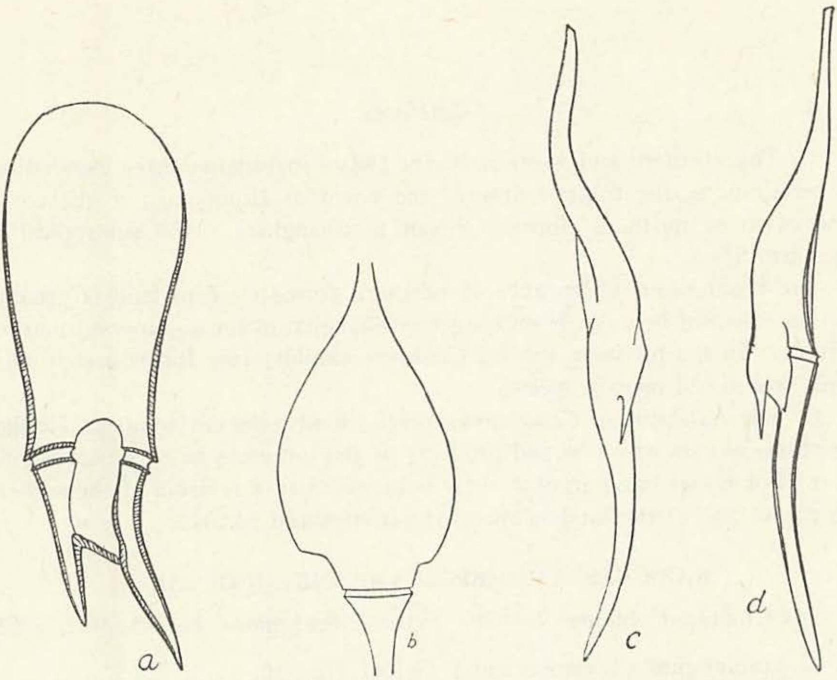

FIGURE 37.—*Ceratium* from the Indian Ocean: *a, C. praelongum; b,* body of *C. biglowii; c-d, C. geniculatum.*

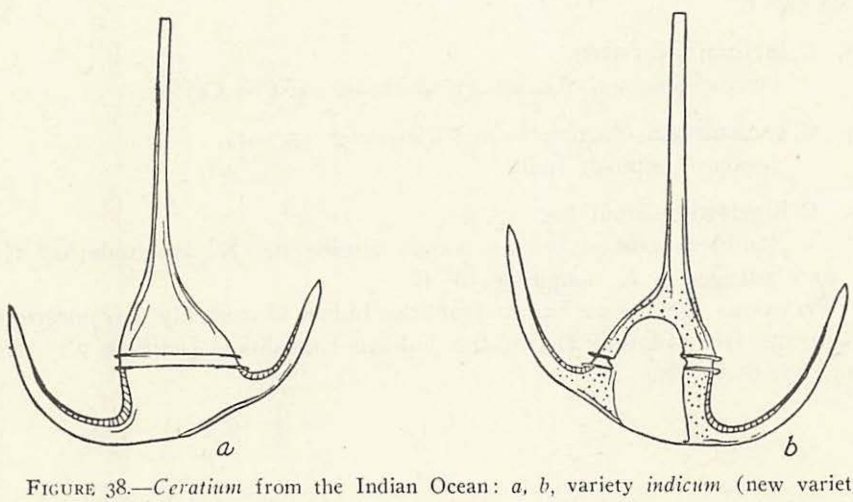

FIGURE 38.—*Ceratium* from the Indian Ocean: *a, b,* variety *indicum* (new variety of *C. pulchellum*).

6. **C. falcatiforme** Jörgensen (Jörgensen, 7, fig. 29).

Between latitude 10° N., longitude 62° E., and latitude 12° N., longitude 58° E.

7. **C. porrectum** Karsten.

Southern point of India, previously known only from the Seychelles.

8. **C. humile** Jörgensen.

Malacca Strait, coast of Sumatra.

The species was not previously known from the Indian Ocean.

9. **C. pulchellum** var. *indicum* (new var.).

In some samples (Colombo-Aden) this variety was found to be common. If it is not an independent species, then it is at any rate a new proof of the variability of *C. pulchellum*, a counterpart to the large form of f. *tripodioides*. The dimensions were: t 50-60 μ (average 54), $v + V = 135\text{-}165\ \mu$ (mostly 145), posterior horns 37-40 μ, angle δ about 15°; angle β approximately 200° (200 measurements). The variety is distinguished also from the type species by the apical horn, which is only half as long and by the considerably smaller transdiameter. It is further distinguished by the solid structure of the body, as well as the relatively short and thick posterior horns. Jörgensen reports in his monograph that young forms of *C. porrectum* should appear like *C. pulchellum*, and are particularly abundant in the Benguela current. Since possibly it is a question here also of similar doubtful forms, I have not for the present established it as a separate species.

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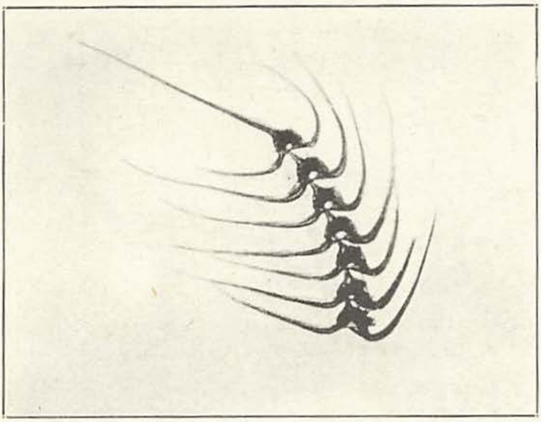
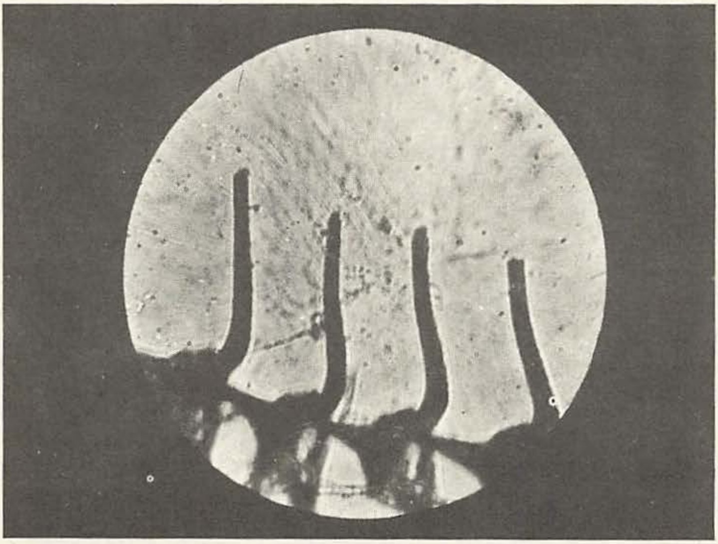


A



B

CERATIUM SUMATRANUM, FROM THE ENTRANCE TO THE GULF OF SIAM: *A*, CHAIN; *B*, AUTOTOMY OF THE POSTERIOR HORNS OF A CHAIN.