STUDIES ON THE GENUS *CHAETOCEROS* EHRENBERG FROM THE FISHING GROUND OF THE MACKEREL, *PNEUMATOPHORUS JAPONICUS* (HOUTTUYN), OFF THE SHANTUNG COAST FROM CHEFOO TO WEIHAI. PART I. A SYSTEMATIC STUDY

(Abstract)

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Plankton samples collected from the fishing ground of the mackerel, *Pneumatophorus japonicus* (Houttuyn), off the Shantung coast from Chefoo to Weihai show that species of the Genus *Chaetoceros* here constitute one of the most important group in the phytoplankton and are the greatest in number of species as well as of individuals. Furthermore, distribution of many of these species in time and in space often bears some relationship with hydrographic conditions, and also with the distribution of fishes in the area investigated. There is no doubt that ecological and systematic studies of this genus will contribute something in the fields of hydrography and fisheries.

While carrying on ecological investigations we are confronted ever now and then with difficulties in the identification of the species of this genus, not only because of the morphological changes, often caused by environmental conditions, and hence the departure of species from their typical appearance, but also because of the confusion caused by the drawbacks in the present system of taxonomy.

The division of this genus into 18 sections, though generally accepted at pre-

in each cell in quite a number of the specimens investigated being actually 4-10. The size of chromatophore in many specimens of *Chaetoceros compressus* is rather large and not smaller than that in Sections *Oceanica* Ostenfeld and *Dicladia*(Ehrenberg) Gran; the most characteristic feature ascribed to these two sections being that the chromatophores are rather large and 4-10, or 6-10, in number. The difference in cellular structure between these two sections is also questionable. According to literature, Section *Oceanica* Ostenfeld which consists of only one species, *Chaetoceros decipiens*, is distinguished from Section *Dicladia*(Ehrenberg) Gran by the presence of coalesced basal portions of setae and also by the fact that no resting spore has ever been reported. As a matter of fact in both these two sections setae are not always coalesced for a portion of their length, and the fact that resting spore has not yet been observed is not a good reason to create for the species, *Chaetoceros decipiens*, a new Section.

In certain Sections the most important of the characteristics given can not be used for the identification of their species; the most distinguishing feature ascribed to Section *Furcellata* Ostenfeld, for instance, is the paired resting spore equipped with coalesced setae, but in one of the species of this Section, i. e. *Chaetoceros tortissimus* Gran, can not be identified by the structure of resting spore, as it has never been observed so far. Besides, the number of sections is unnecessarily large, many sections consisting of only one, two or three species. It seems, therefore, better system for the classification of Genus *Chaetoceros* is indeed urgently needed.

The present article is the first part of the paper and deals mainly with the classification of the species of *Chaetoceros* studied during the investigation of the mackerel fishing ground basing on a new system of classification and to some extent from the standpoint of evolution. The second part dealing with the ecology of the species studied will be published later.

1. A new system for the classification of *Genus Chaetoceros* Ehrenberg

The morphology of chromatophores of certain planktonic unicellular organisms

ning all the species with two chromatophores in each cell, each chromatophore containing a pyrenoid; (3) Subgenus **Polychromatophorus,** including all the species with chromatophores more than two in each cell, mostly without pyrenoid.

The third subgenus **Polychromatophorus** is again subdivided into two sections according to the manner of distribution of the chromatophores: (1)Section **Achromatocerae,** including all the species without chromatophore in setae, and(2)Section **Chromatocerae,** including all the species with chromatophores distributed in setae. Chromatophores of a few species of Section **Achromatocerae** are comparatively large in size and rather small in number, mostly less than twenty, and may contain a small pyrenoid; but chromatophores of the rest species of this section and of all the species of Section **Chromatocerae** are small and numerous, without pyrenoid.

Comparing with the four types of chromatophores shown by Chu (1947, pp. 78-81), the chromatophores of the first two subgenera of Chaetoceros, **Monochromatophorus** and **Dichromatophorus,** are in general corresponding to Chu's third type, discoidal in form, often lobed, each containing a pyrenoid, parietal in position in the cell; and those of the third subgenus, **Polychromatophorus,** corresponding to a great extent to his fourth type, ovoidal and small, mostly without pyrenoid. Only a few species of the section **Achromatocerae,** as mentioned above, may have chromatophores each containing a small or insignificant pyrenoid. While his first and most primitive type, axile stellate chromatophore, though observed in some other diatoms, has not yet been observed in Chaetoceros. Neither has his second type, parietal stellate chromatophore , been observed in this genus.

In dealing with the species within each subgenus or sections, great efforts have been made to arrange them in order according to morphological differences in structures other than chromatophores; differences which may in some way or other bear some relationship with evolution. The most important of such differences are in:

(1) The degree of compactness with which the cells are connected together. Species with cells living singly are considered as more primitive, and species with

for instance, is considered as more evolved than any of the other species here studied; as it is more complex in organization, with anterior and posterior ends distinctly differ from each other, with anterior terminal setae peculiarly curved as well developed bovine horns and short thick posterior terminal setae with complex patern of arrangement of spines; and furthermore, usually living in association with a particular kind of animals, *Vorticella*, which are attached on its cells. A chain of *Chaetoceros coarctatus* actually appears as a well organized multicellular plant. Naturally the degree of complexity in organization is closely related to the degree of differentiation of structures.

As a result of investigations outlined above the species of *Chaetoceros* here studied are arranged in the form of a key as follows.

Key to Genus *Chaetoceros* Ehrenberg, 1844.

I. Only one chromatophore in each cell·····Subgenus **Monochromatophorus**

2. Chains straight or slightly bent, setae not all bent to one side of the chain.

3. Cells rotated on chain somewhat in order in one direction·····
·····1. *Chaetoceros tortissimus.*

3. Cells not apparently rotated on chain.

4. Apertures large, intersecting point of setae of neighbouring cells apparently away from cell body.

5. Resting spore single.

6. Resting spore without dichotomous spines.

7. Sulcus between valve mantle and girdle straight.

8. Both valves of resting spore smooth.·····2. *Ch. brevis.*

8. Both valves of resting spore with spines.·····3. *Ch. seiracanthus.*

7. Sulci curved toward opposite valves. ·····4. *Ch. distans.*

6. First valve with several thick dichotomous spines, second valve smooth·····5. *Ch. subsecundus.*

5. Resting spores in pairs close together with thick setae coalesced at basal portion, distal portions surrounding spores ·····6. *Ch. cinctus.*

11. Inner setae all curving around the chain in a semicircle····· ····· 8a. *Ch. affinis* var. *circinalis*

9. Valve with four protuberances touching those of the neighbouring valve····· ····· 9. *Ch. costatus*

2. Chain spirally curved, setae all curved toward one side of the chain.

12. Cells not connected with protuberances of valves.

13. Point of intersection of setae apparently away from cell body, cell corners not touching with those of neighbouring cell, aperture roughly rectangular or slightly narrower in middle portion····· 10. *Ch. dibilis*

13. Point of intersection of setae not away from cell body, cell corners touching those of neighbouring cell, aperture elliptical or nearly circular····· ····· 11. *Ch. curvisetus*

12. Valve with four protuberances connected with those of adjacent cell····· ····· 12. *Ch. pseudocurvisetus*

I. Chromatophores more than one in each cell.

14. Chromatophores two in each cell·····Subgenus **Dichromatophorus**

15. Chain usually with 2-5 cells, or unicellular, valve with central raised region touching similar region of adjacent valve thus dividing the aperture into two parts····· 13. *Ch. similis*

15. Chain long, valve without centrally raised connecting region.

16. Setae not intersecting directly with those of adjacent cell, but connected by a crossing bar····· 14. *Ch. anastomosans*

16. Setae intersecting directly with those of adjacent cell, without crossing bar.

17. Valve with semispherical protuberance····· 15. *Ch. didymus*

17. Valve without such protuberance.

18. Valve surface without notches.

19. Aperture large, roughly square in shape, setae intersecting away from cell body; sulcus insignificant····· 16. *Ch. laciniosus*

19. Aperture small, fusiform, setae intersecting at base and not away from cell body; sulcus deep and conspicuous.

20. Setae stretched out in direction perpendicular to long axis of valve

22. Setae without chromatophore ..... Section **Achromatocerae**

23. Setae usually coalesced for some length at basal portion (coalesced portion may be very short in summer) ..... 21. *Ch. decipiens*

23. Setae not coalesced for some length at basal portion.

24. Setae all with distinct sculpture ..... 22. *Ch. Lorenzianus*

24. Inner setae without distinct sculpture.

25. Cells connected at cell corners, all setae alike.

26. Sulcus not decernible, resting spore smooth with only fine fibrils at margin of second valve ..... 23. *Ch. teres*

26. Sulcus distinct, resting spore with spines on both valves ..... 24. *Ch. nipponica*

25. Cells not connected at cell corners but at intersecting point of setae away from cell body; two forms of inner setae, one thinner normal and the other thickened and twisted ..... 25. *Ch. compressus*

22. Setae with chromatophores ..... Section **Chromatocerae**

27. Terminal setae similar with inner setae in form and structure.

28. Cells rotated on chain, distinct angle being formed between long axes of valves of adjacent cells; setae stretched out in direction perpendicular to chain axis ..... 26. *Ch castracanei*

28. Cells not noticeably rotated on chain, setae not perpendicular to chain axis but curved toward ends of chain.

29. Cell with morphologically similar valves, setae growing out from both valves at similar positions.

30. Aperture large, elliptical; valve with central spine ..... 27. *Ch. Eibenii*

30. Aperture small and narrow; valve without central spine ..... 28. *Ch. densus*

29. Cell with morphologically different valves; upper rounded, with setae growing out from near the center of valve surface, lower flat, with setae growing out further away from center of valve.

31. Cells usually living singly ..... 29. *Ch. peruvianus*

31. Cells usually in chains ..... 30. *Ch. convolutus*

2. Description of the three new subgenera of Genus *Chaetoceros Ehrenberg*.

(1) Subgenus Monochromatophorus, subg. nov.

Chromatophorus unus pro cellulo.

The outstanding character of the species of this subgenus is the presence in each cell of only a single chromatophore which contains a pyrenoid. Besides being monochromatophoric, the sulcus in the species of this subgenus here studied is not well developed being either indistinct or very shallow, and the member species often have one or more of the following primitive features: (a) cells link together rather loosely being either totiously disposed along the chain axis (*Ch. tortissimus*. Fig. 1, p. 40) or with large apertures (*Ch. brevis*, Fig. 2, p. 40; *Ch. seiracanthus*, Fig. 3, p. 42; *Ch. distans*, Fig. 4, p. 43; *Ch. subsecundus*, Fig. 5, pp. 44-45; *Ch. cinctus*, Fig. 6 p. 46); (b) chain thin and short, all setae alike, thin (*Ch. criuitus*, Fig. 7, p. 47); (c) girdle band not well developed being narrow, less than one third the height of the cell (*Ch. affinis*, Fig. 8, p. 48; *Ch. affinis* var. *circinalis*, Fig. 9, p. 49; *Ch. costatus*, Fig. 10, p. 50); (d) chain spirally cruved, terminal setae not much differentiated from inner setae and all setae curved toward the convex side of the chain (*Ch. debilis*, Fig. 11, p. 50; *Ch. curvisetus*, Fig. 12, p. 51; *Ch. pseudocurvisetus*, Fig. 13, p. 52). Twelve species and a variety of this subgenus are described from the mackerel fishing ground and its vicinities, all neritic.

(2) Subgenus Dichromatophorus, subg. nov.

Chromatophori bini pro cellulo.

The outstanding character of the species of this subgenus is the presence in each cell of two chromatophores each containing a pyrenoid. Besides being dichromatophoric, the species of this subgenus here studied have one or more of the following features: (a) cells living singly or in short chains (*Ch. similis*, Fig. 14, p. 54); (b) apertures large (*Ch. anastomosans*, Fig. 15, p. 56; *Ch. didymus*, Fig. 16, p. 57; *Ch. laciniosus*, Fig. 17, p. 59); (c) sulcus rather wide and deep (*Ch. paradoxus*, Fig. 18, p. 60; *Ch. constrictus*, Fig. 19, p. 61; *Ch. VanHeurckii*, Fig. 20, p. 63; *Ch. siamense*, Fig. 21, p. 64). Species of this subgenus with well developed sulcus are considered as higher on the evolutional scale than other species. Eight species belonging to this subgenus are described from the mackerel fishing ground and its vi-

The outstanding character of this section is the absence of chromatophores in setae. Five species belonging to this section are described from the mackerel fishing ground and its vicinities. They are *Ch. decipiens* (Fig. 22, p. 65), *Ch. Lorenzianus* (Fig. 23, p. 67), *Ch. teres* (Fig. 24, p. 68), *Ch. nipponica* (Fig. 25, p. 69), *Ch. compressus* (Fig. 26, p. 70). *Ch. decipiens* is oceanic, while the other four species are neritic. Chromatophores comparatively larger in size and fewer in number in each cell may contain each a pyrenoid; while all the small chromatophores, numerous in each cell, are without pyrenoid.

Section **Achromatocerae** differs from Subgenus **Hyalochaete** Gran in that it includes only polychromatophoric species without chromatophores in setae, while Subgenus **Hyalochaete** comprises not only the polychromatophoric species without chromatophores in setae, but also all the monochromatophoric and dichromatophoric species as well.

Sectio 2. Chromatocerae, sect. nov.

Cera chromatophoris multis ornata.

The outstanding character of this section is the presence of chromatophores in setae, and its member species constitute the most advanced group on the evolutional scale. Six species belonging to this section are described from the mackerel fishing ground, i. e. *Ch. Castracanei* (Fig. 27, p. 71), *Ch. Eibenii* (Fig. 28, p. 72), *Ch. densus* (Fig. 29, p. 74), *Ch. peruvianus* (Fig. 30, p. 75), *Ch. convolutus* (Fig. 31, p. 77), *Ch coarctatus* (Fig. 32, p. 78); all oceanic in character though they do also occur near the coast.

The field covered by Section **Chromatocerae** is the same as that covered by Subgenus **Phaeoceros** Gran of the old system of classification, both comprising all the species with chromatophores distributed within the setae as well as within the cell body. However, as Section **Chromatocerae** is a section of Subgenus **Polychromatophorus** of the Genus Chaetoceros in this new system of classificafion, a new word **"Chromatocerae"** is therefore created in order to avoid ambiguity with Subgenus **Phaeoceros** Gran of the old system of classification.

Altogether, thirty one species and one variety are described in this paper from the mackerel fishing ground and its vicinities (ref. list of species, pp. 80-81; Key to Genus Chaetoceros, pp. 90-92; Figs. 1-32).