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Observations on the Plankton of Puget Sound.

By **J. I. Peck** and **N. R. Harrington.**

In consequence of former studies in planktonic work in the shallow waters of Buzzards Bay, on the Southern coast of Massachusetts[1]), the authors of this paper have sought opportunity of studying some of the facts of the vertical distribution of similar forms over greater depths. Such an opportunity came during the Summer of 1896, through the Columbia University Zoological Expedition of that year[2]) in Puget Sound, on the northwestern, Pacific Coast, of the United States, where our collections were made by the junior author with a simple apparatus designed in advance by us both but constructed and operated by him.

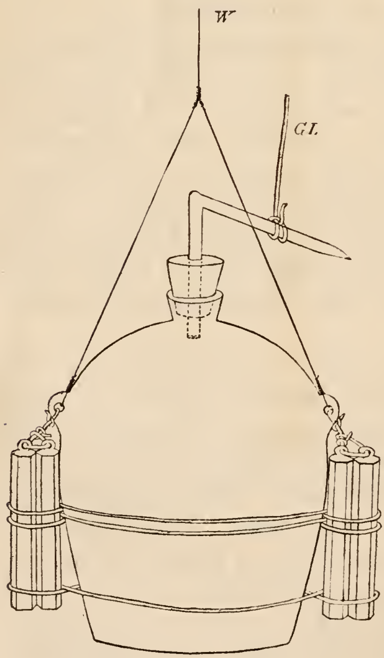
The most recent interpretation[3]) of the very irregular coast line of the Puget Sound district is that the Cretaceous areas of Oregon have been here turned on edge, while numerous depressions and emergencies of Eocene times — augmented by glacial action — have resulted in the very deep bays with their many islands, and the deep inland fresh-water lakes of the State of Washington. Other authorities attribute more of these conditions to the action of glaciers alone. In many instances precipitous cliffs dip perpendicularly into the sound for a depth of from 600 to 900 feet, and in water of 30 fathoms average depth there may be a sudden drop over a very limited area to 150 or 200 fathoms.

1) Sources of Marine Food, U. S. Fish Com. Bulletin, 1895, p. 356.
2) Described in Trans. N. Y. Acad. Sci., Vol. XVI, p. 33—42.
3) See American Geologist for March and April, 1897.

Over one such depression of the bottom, at Lat. 48° 5′ N., Long. 122° 38′ W. samples of water were taken for quantitative estimate of the plankton through a vertical of 112 fathoms. The date was September 1, 1896, at 2 o′ clock in the afternoon, at low water slack tide, with the sky overcast, breeze slight, and practically no sea. The distance of 112 fathoms was divided into four equal parts, so that three intermediate samples were taken at regular intervals between the surface and bottom collections.

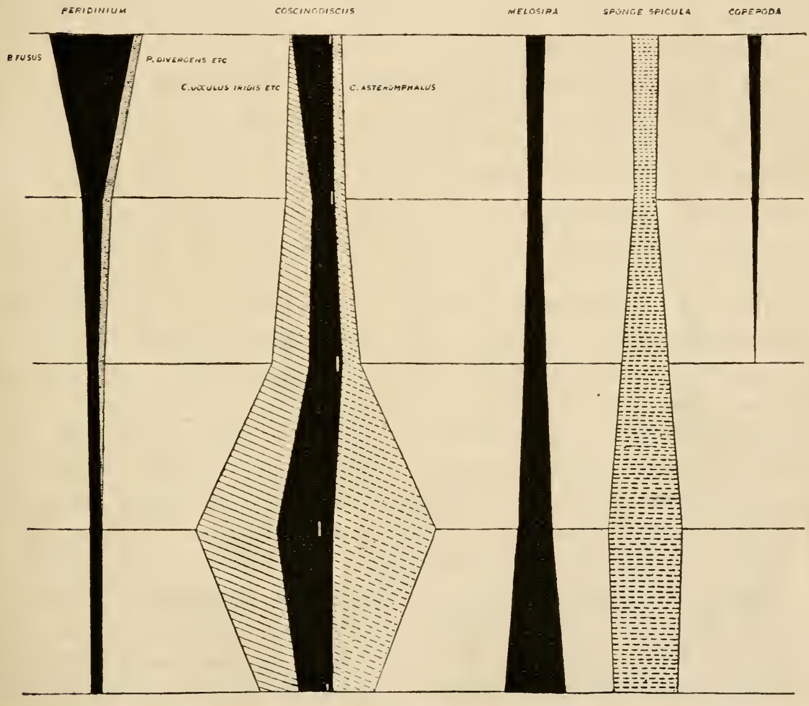
The apparatus used in obtaining the samples of water from the several depths was constructed from an earthenware jug containing two litres, closed with a hard rubber cork of the largest size that could be urged into the opening. This cork is bored and fitted with a piece of glass tubing bent just above the cork and hermetically sealed at the outer end. A thermometer should also have been placed in the jar through a second perforation of the cork but we lacked this important accessory. The jar is then heavily weighted with bars of pig-iron, and swung with fine steel wire suitably measured off into fathoms, and a light guide line also attached to the bent glass tube. Such a device is represented in the accompanying cut, Fig. 1, showing the jar in readiness for lowering. *W* is the steel wire by which the stone jar is suspended, *GL* being the guide line attached to the bent glass tube. The iron weights are so attached as to keep the jar in its perpendicular position. The apparatus may then be rapidly lowered to any given depth from the deck of the boat by means of a windlass, while the guide line is simultaneously paid out in excess. In our collections the water being smooth the guide line was issued from a kiff drifting a few yards away. As the required depth is reached the guide line is carefully hauled taut and then given a sharp pull which breaks the bent glass tube at the angle and so allows the water to rush rapidly in, because of the surrounding pressure, and fill the jug which is then drawn to the surface. We believe that there is practically no intermixture of water from other levels as the jar ascends, even in the short glass tube that remains in the cork; there

Fig. 1.



is indeed an escape of fine bubbles from the contents of the jar because of the diminishing pressure in its ascent, and we believe that the displacement from a full jar through so small a column of water as fills the tube is corrected by simply emptying the tube and neck of the jar as soon as it is received, and that there is then a representative sample secured by this means. The apparatus was tested each time by lowering it to the bottom and returning it without breaking the tube, and it was found that its strength was sufficient. Great care is necessary in the adjustment of the cork before lowering as the pressure at considerable depths is very great.

Fig. 2.



Plotting to show vertical distribution of fine elements of Plankton in 112 fathoms. Surface bottom and three intermediate levels are represented by the horizontal lines upon which are laid off widths, corresponding to the numbers taken in each case. These widths at the varions levels are made the basis for the construction of the several columns which show the facts of distribution. On the first column the black area denotes living portion and the stippled area the larger species. On the second column, black area denotes living portion and the oblique-lined areas the dead and mutilated parts, while the small white bars in the black areas denote the separation of the two type species. On the third column the attempt is made to show distinction of dead and living material.

The method of obtaining samples of water by means of a pump through hose let down to the required depth was used by us in 1894 in Buzzards Bay to a depth of 20 fathoms, and the same method has since been employed by Kofoid[1]) with success in his shallow fresh-water collections, and is recommended by Prof. Joh. Frenzel[2]) as an effective method, but we believe that for the small quantity of water necessary for quantitative analysis by the Sedgwick-Rafter method[3]) as here employed, or for the „planktonocrit"[4]), the above described apparatus is adequate and accurate for collections up to at least 300 metres in depth. To a litre of the water thus obtained is then added 20 cc of commercial formalin, by which the organisms are killed after which the whole amount is filtered and then preserved in 20 cc of a 5 % solution of formalin. Counting is then possible according to the original Sedgwick-Rafter plan.

In order to illustrate the distribution discovered through this vertical in Puget Sound five representative subjects, both plant animal and inorganic, were chosen from the data observed, and these have been recorded by the plotting shown in Fig. 2 of this paper. The most varied of these subjects is the diatoms, which have been somewhat grouped together in this discussion in so far as they generally agree in form and follow the same plan of distribution. Thus under the generic title *Coscinodiscus* have been included in the plotting three species typified by *C. occulus iridis*, while the larger sized forms of the same general shape have been arranged under *Coscinodiscus asteromphalus*, and include a few of the Genus *Arachnodiscus*, and some individuals of *Aulacodiscus*. This plan seems advisable since with the low magnification used in counting it is difficult to separate the constituent parts with certainty, and they all show uniformity throughout, which would tend to group them together in any synthetic treatment. Under the genus *Peridinium* also are given two species.

There are thus laid down on Fig. 2 five horizontal lines indicating the five levels from which material was secured, and on these lines were laid off distances corresponding to the numbers of individuals of each group obtained by us; the points were then connected by lines and the enclosed areas shaded in black to indicate the living and unmutilated condition of the organisms, and by oblique-lined areas to show the certainly lifeless or fragmented individuals of the same forms. The width of the black columns, therefore, at any of the observed levels, indicates the proportionate abundance of the unmutilated

1) Bulletin of Illinois State Lab. Nat. Hist., Vol. V, Art. I.

2) Biolog. Centralbl., XVII. Bd., Nr. 5, S. 190.

3) See Kofoid, ibid. p. 21, also Jackson and Whipple in Technology Quarterly, Vol. IX, Nr. 4, 1896.

4) By C. S. Dolley, Proc. Acad. Nat. Sc. Philadelphia. Mai 1896.

individuals at that point, as likewise the width of the oblique-lined belt shows the quantity of the dead and the broken tests of the same.

From the data obtained by us, and represented by the plotting on Fig. 2, it will now be seen that the dinoflagellate *Peridinium* represented in the first column, is very abundant at the surface, also that of the two species represented the one, *P. fusus*, is much more numerous than the other, *P. divergens*, the latter being only about one-tenth as numerous as the former as is here represented by the stippled portion on the right side of the column. At the one-quarter depth (28 fathoms) the decrease in this organism is very marked, while the falling off continues thence gradually to the bottom. It is plain, however, that *P. fusus* can maintain itself alive at the bottom, and that the larger species, *P. divergens*, shows a more uniform distribution throughout the upper half of the vertical but runs rapidly out in the lower half, being absent at the last two levels.

The distribution of the diatoms included under the heading *Coscinodiscus* is much more varied as is shown in the second column of the plate; taking all the elements together there is shown a uniform increase from surface to middepth, then a rapid increase to the three-quarters depth, with a final falling off in the last quarter distance of the vertical. It will be seen, however, that there is a large element of dead and broken débris here included (represented by the oblique-lined sides of the column), which we assume to have settled from surface strata, and which would thus naturally increase towards the bottom. In the living and uninjured part of the material one sees the same plan, except that the proportion of living to dead organisms is much greater at the surface than at any other level. The living diatoms of this group are over 82% of the whole number at surface, as against 23% at the three-quarter depth, and as against 29% at the bottom.

It may be that some currents at superficial levels are at work in shiftig off the material, so causing it to be settled or eddied into belts and strata below, and it may be that there is also a higher rate of disintegration in the bottom strata to account for the lessening quantity there but this seems hardly possible within these short limits, and we believe that this difference in quantity at different levels is rather due to those circumstances which cause a sudden loss in the rate of reproduction in the upper strata, and from which there is a subsequent settling of the débris into the lower. As will appear upon a following page the diatoms here considered are very variable in quantity at the surface, being at some times very abundant and at others (as on the day when this vertical was taken) hardly perceptible. From this it is certain that the column in black as here plotted would on another day, during a period of rapid growth at the surface, have been much wider, and would in fact have been more nearly like that represented for the *Peridinium* of column I. If now they were to die suddenly out at the surface and the débris were to gradually settle into deeper layers an irregularity would there be caused such as is here evident at the three-quarters depth. Such irregular periods of growth are doubtless less common in the deeper layers of water since the conditions must be more stable in these depths, and this striking increase of *Coscinodiscus* at the 84 fathom depth, therefore, probably represents a previous period of active growth in the upper strata, and if one were to restore to life and the former conditions of growth all the dead and crushed débris of the three-quarters level here brought out it would doubtless form such a column as is given in the one just described for *Peridinium.* And conversely if conditions of active reproduction were suddenly to become unfavorable at the surface for the two species of *Peridinium* here plotted (column I), and they were provided with a resistent test like that of the large diatom, their vertical distribution would tend to assume, by cessation of growth and settling of débris, that which has now been described for *Coscinodiscus.*

The dividing line between the two type species — *i. e.*, between the quantity of *Coscinodiscus occulus iridis* and that of the large and beautiful *C. asteromphalus* — in this second column is shown for each level by a small white vertical bar placed in the black areas. All to the left of these bars is *C. occulus iridis* (with a few individuals of similar size from other species or genera), while all to the right of these white bars is *C. asteromphalus.*

In the third column of Fig. 2 portraying the distribution of the diatom *Melosira*, is shown a very uniform increase in the numbers of that organism from surface to bottom with a slight falling off at the one-quarter depth. The individuals of this species here enumerated were laid in short chains and each short chain was counted as a unit in the determination, but they are so small and transparent that it did not seen advisable to attempt the separation of those living at the time of the collection from the dead, and the whole, therefore, is plotted as living material. It is certain, however, that the diatom can live at this depth as many healthy chains can be found at the bottom stratum and we here conclude also that under other conditions the abundance of this form would be much greater in the overlying strata of water, and that the more rapid change of conditions above has left a larger quota alive in the slower-changing depths. That is to say the increase is not so much due to conditions of active growth below as to the disappearance of a large proportion of those in the superficial layers, together with a settling of the débris into the levels below although this latter process in this delicate form must be much slower than in the diatoms of the preceding illustration. In the three types now discussed, *Peridinium*, *Concinodiscus* and *Melosira*, the same causes may be operating 'to produce the differences in their distribution, *i. e.*, irregular periods of growth and settling of dead tests where such are resistent enough, and much of the vertical distribution here in question is due to a greater or less extent to the specific gravity of the various elements. One encounters at the lower levels not only the immediate occupants of such water but also the indefinite accumulations of sediment from the upper water in which so much débris of organic origin is formed.

In illustration of the action of sedimentation alone there is introduced in the fourth column of Fig. 2 a record of the distribution of certain sponge spicula, which of themselves, of course, have no power of independent movement or growth and yet which are constantly found through the water, and which increase quite regularly to the bottom. The source of these is probably in the shallower waters of other localities from which they are introduced hither by tide currents near the surface, and thus sown, as it were, through the whole depth of the channel. There will also be noticed in this column showing the sponge spicula a slight falling off in the numbers at the one-quarter depth as in *Melosira*, and at the bottom as in *Coscinodiscus*, and it is therefore reasonable to suppose that they are obedient to the same influences in these respects, although we assume that the greater part of this very regular distribution of the sponge spicula is due to the gradual accumulation of material, for long periods, by sedimentation from the whole volume of water in which they are mixed by currents and other modes of diffusion. The spicules here recognized are of the striaght bi-radiate type of some calcareous sponge not identified by us. The important place filled in all planktonic studies by the *Copepoda* is not vacant here since they are abundant at surface, one half as numerous at the one quarter depth (28 fathoms), and rare at the middepth, only a single individual having been found there in one of the analyses of that level. There were also Nauplii of this form in association with the adult stages, one Nauplius on an average to two adult individuals at each level.

Besides these organisms thus plotted and described in the foregoing, account was taken of many other similar forms that occur less regularly and abundantly, such as diatoms *Foraminifera*, *Infusoria* etc. Among these also may be mentioned certain other objects of organic origin but which are not properly to be classed as marine. Thus the detritus in suspension in this water includes many bits of epidermis of plants, many of the epidermal stellate hairs like those upon many forms. There is also the almost constant presence of wing scales from *Lepidoptera*, and back of all the blackish or brownish granular silt etc. This last named detritus (sometimes called „amorphous matter“) is indeed one of the hardest elements to understand. It is, to be sure, not strictly speaking a part of the Plankton, and yet it constantly gives character to every sample of water, and often outnumbers by many times the actually living material. It is most varied in its appearance, from a light brown flocculent basis to finely divided grit and sand. In this particular vertical the one-quarter depth showed more of this débris than any other level, and as has been seen this is correlated with a decrease in the quantity of living plankton or the material derived immediately from it. The relation of living organisms to detritus is not always constant, and for the reason that the relation between them is so inconstant we believe that it largely vitiates any volumetric estimate based upon merely the bulk of a filtrate obtained from the water by net, planktonokrit or filter. A sample may look, in gross, rich and promising, but on examination prove almost barren of living plankton, although much of the débris may be, more or less remotely, organic in origin.

The observed numbers upon which this analysis rests may be tabulated as follows:

	Surf.	1/4 Depth	Middepth	3/4 Depth	Bottom
Peridinium	39	10	5	6	5
P. divergens . . .	4	4	3	—	—
Coscin. occulus irid.	19 (1)	22 (12)	32 (18)	56 (37)	31 (18)
C. asteromphalus .	4 (3)	5 (4)	8 (6)	53 (47)	21 (19)
Melosira chains . .	9	6	10	16	28
Copepoda	4	2	—	—	—
Nauplius	2	1	—	—	—
Sponge spicula . .	12	10	21	33	29
Totals	93	60	79	164	114

Under the item *Coscinodiscus* of the above table are seen certain bracketed numbers at the right of the column. These denote the dead individuals of that level, thus: *Cos. occulus iridis* has 19 at surface level of which one (1) is dead. At the one-quarter depth there are 22 of which twelve (12) are dead. At middepth there are 32, of which eighteen (18) are dead, and so on for all the items with following bracketed numbers.

If now there be desired the numbers of these forms living in each litre of ocean water in this region such a result may be obtained by multiplying any of the above items by 50, since the organic filtrate from the 1000 cc of water from each level is lodged in 20 cc of the formalin preservative, while the above figures are taken from the counting of 1 cc of such filtrate, or 1/50th part of the whole litre of ocean water treated, at each level.

It is not to be assumed, of course, that this reduces the analysis of the contents of the water to a mathematical basis, as it only furnishes ground for estimates, based upon actual counts; but we do believe that it gives a true picture of the vertical distribution of certain forms at the time the samples were taken.

In notes taken in connection with the collections upon which this paper is based Harrington says: „Tow taken in Port Townsend Harbor varied greatly on successive evenings. It was noticed after a rain that the surface water had a muddled appearance, and that the net was quickly clogged with a brown coating of *Coscinodiscus* and *Arachnodiscus* while on other evenings comparatively few of these were to be seen. The number of medusae varied very noticeably with the roughness of the sea, falling of rain etc., and a strong inshore wind always brought in various organisms such as masses of Noctiluca". He also states that the collection from which the plotting was made was taken at the close of a week in which there had been hardly any rain, and that in a glass jar the water was very transparent, while a few copepods could be seen in some of the samples.

The causes for the sudden appearance of a given pelagic organism and its similar disappearance, in great numbers, are very obscure although the facts have often been observed. Whipple[1]), from observations in the several basins of the water supply of the city of Boston, Mass., has attempted to throw light upon the seasonal increase in certain diatoms by assigning as causes the vertical stirring up of the water, and the necessary presence of Oxygen in connection with the assimilation of nitrates by the growing cells. Many interesting data have thus been brought together by him, concerning the seasonal growth of this organism in shallow fresh waters, but such conditions would with difficulty be applied to marine forms over the much greater depths here described, and it is probably true that there is more fluctuation in shallow water and at the surface than in the deeper strata. We also gather from the work of Prof. Joh. Walther[2]) summarizing the work relating to the depth to which light penetrates, and its various spectrum absorption etc., that the bottom depths reached by our analysis in Puget Sound are only about half the distance to which the suns rays can penetrate under favorable conditions, and also that the vertical sounded by us traverses a variety of colors in the water that are due to the absorption of the several elements of the light.

It may be said in general, therefore, of the vertical distribution here recounted, that the surface strata present the greatest numbers of living individuals and furnish the most favorable, although irregular, conditions for the growth and reproduction of these organisms; but in

1) Some Observations on the Growth of Diatoms in Surface Water, Technology Quarterly, Vol. VII, Nr. 3, 1894.

2) Bionomie des Meeres, Jena 1893, p. 35.

the case of the large diatoms burdened with a large silicious case there is a relatively rapid sinking into the strata beneath, and in other diatoms the conditions of growth seem to be well fulfilled in the lower strata. It is also true that all the forms here treated except the *Copepoda* are found alive throughout the whole extent of our vertical, *i. e.*, 112 fathoms deep.

We believe, moreover, that this is the lowest deph to which this method of quantitative estimate has been carried, and that as it gives analysis of water over such a considerable depths it calls attention to them as recipient areas for material in process of sedimentation as well as for conditions of life and growth in an environment quite removed from the surface.

We refer, in closing, with gratitude to the cooperation of Prof. H. F. Osborn by whose provision in the Zoological Expedition these collections were made possible. The identification of the diatoms was kindly aided by the photographs made by Mr. O. E. Schaffer of Port Townsend, Washington, who furnished very complete data in this respect for that locality. All the labors of procuring apparatus and collecting the materials and furnishing descriptive data referring to such work were done by the junior author of this paper, while the quantitative estimates, plottings and writing are the work of the senior author. [33]

Biological Department, Williams College, Williamstown, Mass.,
Nov. 20, 1896.

Ueber tierisches Potamoplankton.

Vorläufige Mitteilung.

Von Dr. **Carl Zimmer.**

Seit Dezember 1897 bin ich mit einer Untersuchung des Potamoplanktons, wie Schröder und Zacharias das Flussplankton genannt haben, und zwar des Planktons der Oder und einiger Nebenflüsse bei Breslau beschäftigt. Ich habe mich dabei auf das tierische Plankton beschränkt, während Herr Bruno Schröder (Breslau) den botanischen Teil übernommen hat; wir haben uns das Gebiet so geteilt, dass Schröder auch die Flagellaten bearbeitet. Die Untersuchung gedenken wir über ein Jahr auszudehnen und sie dann im nächsten „Plöner Bericht" zu veröffentlichen. Hier will ich eine vorläufige Mitteilung über meine Resultate während des ersten Jahresdrittels geben.

Die Proben, die ich mit dem Walter'schen Planktonnetze dem Flusse entnahm, zeigten eine andere Zusammensetzung, je nachdem sie bei niederem Wasserstande, bei steigendem Wasser oder bei Hochwasser gefischt waren. Manche Formen, die bei normalem Wasserstande zahlreich vorhanden waren, verminderten sich bei steigendem

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