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THE FOOD AND FEEDING OF THE HERRING (CLUPEA HARENGUS L.)

by

W. L. Johnson.

BIOLOGICAL BOARD OF CANADA

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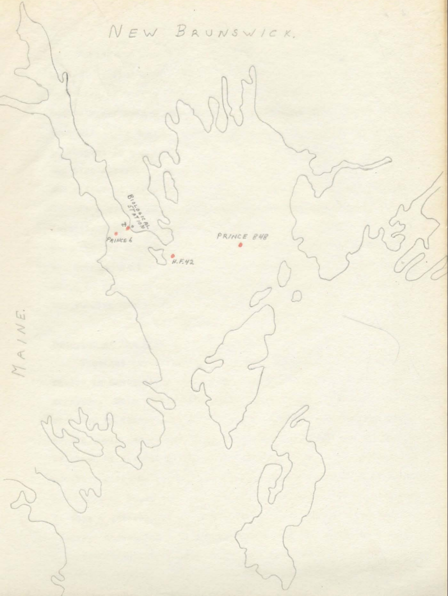
NEW BRUNSWICK.
BIOLOGICAL STATION
PRINCE 6
H.F.42
PRINCE 848
MAINE.

INTRODUCTION.

During the summer of 1933 the stomach contents of fifteen hundred herring were examined in order to determine what the food consisted of during the summer months when these fish are most actively obtained by the fishermen in Passamaquoddy Bay, New Brunswick. It was found that by far the most common food, both in respect to quantity and numbers of species, was Copepods. It was also observed that the herring contained different amounts and different kinds of copepods under different weather conditions.

As a result of the above observations it was decided to begin an investigation during the summer of 1934 with a view of determining what factors make the food available to the herring, or "Where do the herring get their food?" Accordingly it was decided that it would be necessary to study (a) the behavior of the food and (b) the feeding habits of the herring themselves.

METHODS.

Behavior of the Food:

Previous investigations suggested that light is an important factor in controlling the bathymetric distribution of the planktonic copepods. This observation is by no means new as it has long been observed by others in both fresh and salt water in various parts of the world and an excellent review of the literature up to 1930 is given by Kikuchi (1930). All literature up to the present, however, gives no general exploration of the phenomenon of diurnal movements of these copepods but simply shows that it is necessary to make a detailed study of the region in question since the apparent underlying cause in one region may not apply to another.

Accordingly an investigation was begun in order to determine where the copepods are which constitute the food of the herring in this region in different conditions of light. A preliminary investigation was made in two ways:

(1) By collecting the food at the surface only, in different conditions of light, in order to see if the forms present at a definite place actually did alter under different light intensities. This was done by collecting samples at the same place (a definite station established about 100 yards straight out from the Biological Station wharf in the St. Croix river - station 1 on map), with the same net (20 inch No.0), for the same length of time (10 minutes), and at the same time in respect to the tide (within ½ hour before high water), but in the following condition of light intensity: dusk, extreme darkness, bright noon sunlight, weak moonlight, and strong moonlight.

(2) By collecting the food at four different depths simultaneously but under different conditions of light intensity in order to determine the depths at which the various forms occur under the following conditions of light intensity; bright sunlight, dusk, starlight, and moonlight. The four depths at which the tows were made were : surface, 2 meters, half-way to bottom, and close to bottom. The only type of closing mechanism available for the nets were such that the nets were only closed while being raised and were used only on the two deeper nets, thus introducing a possible source of error which, however, was somewhat minimized by lowering the nets as fast as possible. It is hoped to obtain a closing mechánism for both raising and lowering the nets in future work.

The nets used were 30 inch no.0 plankton nets. In the latter part of the summer one of the nets was very unfortunately lost before the series was completed. As this could not be replaced at the time it was necessary to use the only other available net which was a 20 inch no.0 net. This was used in the remaining 2 meter tows and so resulted in the straining of a slightly smaller column of water. This fact was kept in mind in drawing final conclusions. The red marks on Tables I to IV shows where this net was used.

The three localities chosen for the tows are indicated on the map as Prince 848, Prince 6, and H.F. 42. The first station (Prince 848) is in the middle of Inner Passamaquoddy Bay and was chosen so as to include the usually deep and cold water form - Calanus finmarchicus. Station Prince 6 is in the deepest part of the mouth of the St. Croix River and was chosen since it usually contains an abundance of Tortanus discaudatus, Acartia clausii, and Eurytemora herdmani. The third station - H.F. 42 - is more or less intermediate between the other two being neither as deep as Prince 848 nor as brackish as Prince 6. In this way it was hoped to include all the common Copepods which, from previous investigations, form the outstanding food of the herring. A similar series of tows was made at each of the three stations under similar light conditions and were all carried out with the same motor-boat, at the same speed (as judged by the number of revolutions of the engine), and for the same length of time (10 min.).

Each tow was preserved in 5% formalin and later treated as follows: Total volume determined by settling in a graduate; placed in tall glass cylindrical jar and diluted to a known convenient volume; thoroughly shaken so as to produce a homogeneous mixture, and exactly 5 cc. removed by means of a Stempel pipette; placed on a specially constructed counting cell and the Copepods identified and counted. Two counts were always made (except when there was so little plankton present that the whole tow was counted without making use of the Stempel pipette) and the results of the two counts were averaged.

Each Copepod was identified as to whether it was male, female, or young. For the purpose of identification of the fully formed or adult (male and female) Copepods the following authors were used: (a) Sars-"Crustacea of Norway". (b) Wilson-"Copepods of the Woods Hole Region". (c) Herdman, Thompson and Scott-"North Atlantic Plankton". By the term "young" Copepod is meant one which is sufficiently advanced so as not to be confused with other species but is not, however, fully developed. The six species of Copepods here investigated were the only common free-swimming Copepods of this region and after much practice the author became quite able to rapidly identify these species. The life histories of four of these six species have been worked out (as far as the author is aware of), namely (i) Tortanus discaudatus--by M.W. Johnson-1934. (ii) Calanus finmarchicus--by M.V. Lebour-1916. (iv) Temora longicornis--by Oberg-1906. The above literature was made use of for the identification of the young Copepods. Such identification was, however, not difficult as no very young forms were present in the tows so that the young were sufficiently like the adults so as not to be easily confused. The size, shape of fifth leg, antennule, and number of segments of urosome were the characters mostly used for such determinations. The counting cell was so shallow that the Copepods usually laid on their sides thus exposing the fifth leg. A drop of a dilute aqueous solution fo Methylene Blue added to the contents of the counting cell greatly facilitated the counting of segments and the recognition of the shape of the fifth legs, and other parts of the Copepods.

Controlled laboratory experiments were also carried out so as to study the behaviour of the individual food forms in respect to:

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(1). Their characteristic movements as they moved either toward or away from light. To do this about fifty Copepods of each species were placed in separate tall glass museum jars containing water at $13^{o}C$. The experiments were carried out in the cool basement of the laboratory where the temperature was close to $16^{o}C$. The outside of the jars were covered with black tar paper except at the top and the bottom and a narrow strip at the side through which the individuals could be observed. A 50-watt electric bulb was first placed at the bottom of the jar for the forms to distribute themselves accordingly. The bulb was then placed close to the surface and the movements of the forms observed (by means of a hand lens) as they responded to the changed position of the source of light. The room was in complete darkness except for the source of light used in the experiments and which could be raised or lowered by means of a pully on the ceiling.

(11). Phototropic behaviour.

Experiments were carried out in order to study the response of the Copepods to different conditions of light. A "white-fish hatchery jar" was blackened on the inside (to prevent reflection) except for a narrow strip on one side through which the individuals could be observed. This jar was placed inside a light proof box which had a hole over the top of the jar so that the light could pass into the jar from above only. One side of the box was missing and this side was covered over with black cloth which could be draped over the shoulders thus allowing one's head to be placed inside the box and so to observe the Copepods. In this manner the light could only enter the jar from above. The whole arrangement could be tipped so that the rays from the source of illumination passed vertically down the jar. About ten individuals of the species under examination at the time were placed in the jar and their resultant distribution noted after having been exposed to the light for five minutes. The temperature of the water in the jar was never more than 2°C. higher than that of the water of the St. Croix River from which the Copepods had been removed at least two hours previously.

III. Phototropic behaviour at different temperatures.

Experiments were carried out to determine whether temperature (between 6°and 15°C) had any effect in altering the phototropic behaviour. A shallow dish-"finger bowl"-and horizontal rays of light (50 watts) were used. The dish was blackened on the inside except for a small slit on one side and was placed inside a cylinder of black tar paper which had a small opening through which the light could pass. By such an arrangement half the dish could be illuminated while the other half remained dark. The water in the dish, which contained the Copepods, was kept at the desired temperature by placing the bowl in a still larger bowl containing ice and water at the proper temperature. About ten copepods were used in each e experiment and after ten minutes the numbers of individuals in the lighted and darkened areas were counted. (a flash-light suddenly flashed on enabled the counting in the dark area.)

(1V). Effect of temperature on duration of life.

Experiments were carried out to observe the effect of various temperatures on the duration of life on these Copepods, the intention being that such results might be applicable to an understanding of the effect of the environment on the Copepods at various depths and at various times of the year. Ten individuals were placed in each of five different pint jars filled with sea water from the locality from where the Copepods were taken (off Biological Station wharf), and hence avoiding any injurious effect due to change in salinity or pH. Each jar was placed in a separate compartment of a constant temperature box, where the temperatures were constant at 0.7; 4.8; 10; 14.7; and 21.3°C. All jars were kept open except for the one at 0.7°C. Complete darkness existed in the box hence any possible injurious effect due to light was avoided. Every other day food was added in the form of diatoms and part of the water was replaced by fresh. The Copepods used were all adults and the time when the last of the individuals in each jar died was noted.

(VI). Reaction of male Acartia to different intensities of light at 15°C.

Experiments were carried out to understand whether a form which is attracted by bright light is likely to have its rate of movement toward light dependent upon the light intensity. For this purpose only adult male Acartia were used. Two hours previous to the experiment ten individuals were placed in a tall glass museum jars containing water at 15°C. The experiments were carried out in the basement of the laboratory where the temperature was close to 16°C., so that the temperature of the water varied but little. The room was in darkness except for the one source of illumination- a 50 watt bulb. Two pieces of string were tied around the jar at a known distance apart. The Acartia were drawn to the bottom of the jar by placing the light at the bottom. The bulb was then quickly raised to the desired height above the jar and the time taken for one individual to move between the two strings determined by means of a stop-watch. Ten readings were taken with the bulb at surface 2, 4, and 6 feet. As the intensity of light varies inversely as the square of the distance it was thus possible to produce different intensities of light with the same bulb by altering the distance of the light from the surface of the water.

Feeding of the herring.

The "sardine" size herring of commerce are being kept in tanks of running sea water, both during the summer and winter and observations made on their feeding habits. During the past summer and winter their feeding was studied in relation to light, temperature, and nature of food, so that the results might be applicable to an understanding of the feeding of the herring in nature.

The herring were kept in a tank of the following dimensions: length-72.5 inches; width-37.5 inches; depth-24.25 inches. The running sea water kept the temperature close to 13°C. during the summer when observations were made on their selection and method of capture of food. For illumination a 60 watt bulb was placed 3 ft. above the center of the tank.

A small "search light" was made using a 50 watt bulb and a planoconvex lens. Food was dropped into the tank in the form of mashed Meganyctiphanes norvegica and it was noted where the herring seized the food particles under different directions of illumination.

In order to understand the feeding of the herring in nature at different temperatures experiments were begun with this end in view, the intention being that any results obtained might be applicable to an understanding of their feeding both at different depths and at different seasons of the year. Three fish were used at each temperature (3°; 4.5°; 8°; and 13°C.). Three fish were carefully removed from the main tank in a bucket of sea water and transferred to a smaller tank in which the experiments were conducted. This smaller tank was thickly insulated with cork and the inside water dimensions were 18 x 19 x 20 inches. This tank also contained running sea water at 13°C. The fish, when first placed in the tank were quite timid and refused to eat but after a period of two days they would accept food greedily. Hence the fish were left alone in this tank for at least two days before the experiment was conducted. The incoming sea water first passed through a U-shaped aluminum tube before entering the small tank. This tube rested horizontally in a large wooden box containing a freezing mixture of ice, salt and water, which could be so proportionately mixed as to cool the incoming sea water in the aluminum tube to the desired temperature. By this method and by regulating the flow of incoming water, it was possible to cool the water in the small tank to as low as 3°C. Hence the water was rapidly cooled to the desired temperature and kept at that temperature for two hours, during which time the food was offered to the fish (by means of a large pipette at the surface) in the form of dead Calanus and mashed Meganyctiphanes norvegica. The fish were then removed and preserved in 10% formalin, and the stomach contents later examined.

It is realixed, however, that by the above method the herring experience more rapid changes in temperature than would occur due to the cooling of the water at any depth as a result of change of season, although the fish could experience such rapid temperature changes by swimming to greater depths even during the summer. Accordingly it was decided to broaden the significance of the above results by keeping the herring in the tanks throughout the winter and to make similar observations as the temperature of the incoming sea water lowered naturally with the coming of winter. This latter experiment has been carried out during the past winter during the author's absence and the results which are being kept for his return are hence not available at the time of writing.

RESULTS AND DISCUSSION

Behaviour of the food.

(1) Collection of the food at surface only.

The results of these tows are given in Table I. A summary of these results is given in the table below:

	Bright Sunlight	Bright Sunlight	Faint Sunlight	Dusk	Starlight	Moonlight ($\frac{3}{4}$ full)	Weak Moonlight
al nos, epods.	420	900	8,100	34,600	65,800	95,000	54,540

This summary shows that there is a tremendous increase in the total number of Copepods at the surface in conditions of light weaker than sunlight. As all the tows were taken at the same place, for the same length of time, with the same het, and at the same time in respect to the tide then the only variable factor is the light intensity. Hence, evidently a considerable migration has taken place to the surface from the lower depths as the light intensity decreased from sunlight to starlight. This would suggest that the forms which were repelled from the surface by strong light are now attracted there by weaker light. The greatest number of individuals present at the surface at any one time was during bright moonlight when there were 29,200 more than during starlight when the next greatest number was present.

As the table shows, two tows were made during the bright sunlight, but one was carried out two hours before noon(10 a.m.) and the other at a much later hour (6:15 p.m.), the former showing more than twice as many individuals at the surface. With the exception of Calanus there were more of each species present in the earlier part of the day than during the later part. Esterley (1919), while working with Acartia, found these animals largely on the bottom of a glass tube when kept in the dark durihg the day but from 6-8 p.m.

there was a noteworthy increase in the animals toward the top even when the surrounding conditions were kept the same as before. He is quite positive in that, in Acartia at least, the rhythm of the animals ought to be considered as the primary cause affecting the upward movement in the evening. He also believes that there is some evidence for a similar condition in Calanus. Just how far such a possible rhythm is influential in controlling the distribution of the Copepods here studied is as yet not known. Further investigations will go into this question by making a series of tows extending over a period of twenty-four hours and also by making a further laboratory controlled experiment.

The change in the numbers of each species at the surface under different conditions of light can be seen from Table I:

Calanus:

Adult specimens only occurred at the surface during moonlight. Young ones were only present in large numbers during weak light, none at all being present during sunlight except at 6:15 p.m. when a few were present.

Pseudocalanus:

Adult males only occurred at the surface during weak light, the greatest number being at dusk and the least during bright moonlight. Adult females occurred at the surface at all times there being, however, a large increase during weak light. The greatest number occurred during bright moonlight and the least during bright sunlight. The young forms were also present in greatest numbers during weak light, the greatest number occurring during bright moonlight and the least during sunlight.

Temora:

This form was scarcer at any time than were the other forms. Only adults occurred and these were never present during bright sunlight. The adult males were mostly present at dusk while the adult female only occurred during moonlight.

Eurytemora:

These occurred in greatest numbers during weak light. The adult males occurred in vast numbers during bright moonlight, whereas the smallest numbers occurred during bright sunlight. The adult females occurred in the same way as the males there being, however, at all times a smaller number. The same may also be said for the young individuals, there being still less at all times.

Acartia:

This form, which is probably the most abundant Copepod in this locality, was found at the surface at all times. Adult males, females, and young were most abundant during starlight and least so during bright sunlight. In all cases the young were less abundant than the adults. The table suggests that the time of the day may be quite important in connection with the distribution of the forms, as mentioned previously, since the two taken at the surface in bright sunlight at 10 a.m. shows over nine times as many adult females as adult males, in addition to a number of young, while the tow taken at the surface in bright sunlight but at 6:15 p.m. shows now three times as many males as females and no young at all. It is proposed in future to measure the intensity of the light by means of a sensitive photometer and also to determine the degree of penetration of light into the water in addition to plans mentioned previously.

Tortanus:

This form is also usually very abundant at this vicinity. Males, females, and young were all most abundant during weak light and least so during strong light (sunlight). The adult males and females showed a maximum abundance during bright moonlight the males being, however, at all times considerable more abundant than the females. The young were most abundant during starlight and, with the exception of bright moonlight, they were at all times more abundant than the adults.

Nauplii:

As the writer does not feel capable at this time of identifying with certainty any of the Nauplii (larval Copepods) found in these tows they have simply been designated as unknown nauplii and are being preserved for future identification. Nauplii here only occur during faint sunlight (sun covered by a thin layer of clouds).

(2). Vertical distribution of the food under different conditions of light

The results of the tows taken simultaneously at four different depths but under different light conditions are given in Tables II to IV and show the results from three different stations:

H.F.STATION 42 (Table II):

Calanus:

No adult males were found at any time.

The adult females were only found at the surface during starlight, otherwise occurring at the bottom during starlight, while at 7½ meters and at the bottom during moonlight.

The young, which occurred at all depths during dusk and darkness, showed a maximum distribution at 7.5 meters at dusk, although if a larger net had been used at 2 meters it is possible that the largest amount would have occurred there. In any case the maximum was above 7.5 meters. During starlight these young now showed a maximum near the surface, while during moonlight they were equally distributed at 2 and 7.5 meters.

In general no Calanus were present at any of the four depths during sunlight. There of course still remains the possibility at the depths not sampled. In future investigations an oblique (comprehensive) tow will also be made to determine this. It seems, however, that these facts show that Calanus tend to move up toward the surface as the light intensity decreases. Further investigations are required to compare the effect of moonlight with other light intensities.

Pseudocalanus:

The adult male occurred in appreciable numbers at the surface during starlight and moonlight, its maximum being at 7.5 meters during sunlight and at the surface during moonlight.

The female had its maximum at the bottom during sunlight, while it tended to become more evenly distributed up to the surface during dusk, starlight, and moonlight.

The young were not as abundant as the adults but always occurred within 7.5 meters of the surface where they were most abundant during weak light. Their maximum was always within 2 meters of the surface.

In general, this form occurred at all depths at all times, the male seeming to be scarcer at any time and any place than the female. The young always occurred higher up than the females.

Temora:

This form was relatively scarce here at all times, and only adult females were found. Their maximum during starlight was at the surface, while during moonlight they occurred uniformly from 7.5 meters to the bottom. Their occurrence at this Station was in such small numbers that nothing definite can be concluded.

Eurytemora:

Adult males were only present at 7.5 meters during dusk and at 2 and 7.5 meters during moonlight, while at all depths during starlight, at which time they showed a maximum, within 2 meters of the surface.

Adult females were only found at the bottom during sunlight. They showed a maximum at the bottom during dusk although present in appreciable numbers at 2 and 7.5 meters. During moonlight the maximum was at 7.5 meters while present in appreciable numbers at 2 and 7.5 meters. During starlight they now showed a maximum at the surface and were present in large numbers at the other depths.

The young were not found at any depth during sunlight, showed a maximum at 2 meters during dusk and moonlight, while only present in large numbers within 2 meters of the surface during starlight.

In general these facts show for the adult female that they move progressively closer toward the surface as the light changes in the following order: bright sunlight, dusk, moonlight, and starlight. It seems that Eurytemora is a form which prefers very weak light intensities never having been found anywhere near the surface during bright sunlight, and weak light causes them to move upwards reaching the surface only during starlight. The maximum of the males was never as high up in the water as the females. The young were never found in large numbers below 2 meters and possibly preferred a higher light intensity than the adults at all times.

Acartia:

The adult males were only found at 7.5 meters during sunlight. At dusk none were at the surface when their maximum was at 2 meters while they occurred in decreasing numbers with increase in depth.

During starlight their maxim m was at 2 meters also, but now they were in large numbers also at the surface, below 2 meters they occurred in decreasing numbers. During moonlight only a few were at the surface, while from 2 meters down they were more or less evenly distributed.

The adult females showed a maximum at 15 meters during sunlight although they occurred in almost as great numbers at 2 meters, while they occurred in least numbers at 7.5 meters. During dusk their maximum had moved up from 2 to 7.5 meters (remembering that the figures shown for 2 meters were probably less than was actually the case due to a smaller net opening being used), while the minimum was now at 15 meters. During starlight the maximum had moved up still farther now being at 2 meters with large numbers also occurring at the surface; from 7.5 meters down they were much less abundant, being at a minimum at 15 meters. During moonlight their maximum was at 7.5 meters and minimum at the surface while they occurred in appreciable numbers at 2 and 15 meters.

The young were only present at 2 meters during sunlight and dusk. During starlight their maximum was also at 2 meters and least at 15 meters while an appreciable number occurred at the surface. During moonlight they occurred largest in numbers at 7.5 meters, a few also being present at 2 and 15 meters.

In general, this form was never found at the surface in large numbers except during starlight. They were always found, however, in largest numbers down to 7.5 meters, while some always occurred at the bottom (15 meters). The males were always less plentiful than the females. It would seem that males, females, and young avoided the surface except during starlight when their maximum was within 2 meters of the surface, while at intensities brighter than starlight they preferred depths from 2 to 7.5 meters.

Tortanus:

The mature males were only found at the bottom during bright sunlight. During dusk it had moved upward being present in appreciable numbers at 2 and 7.5 meters with its maximum still at the bottom. During starlight it was most abundant at the surface occurring in lesser numbers at 7.5 and 15 meters. During moonlight no large numbers were found at any depth, suggesting that they were at some intermediate depths not sampled.

The adult females showed a maximum at the bottom during sunlight, occurring in lesser numbers at 7.5 meters. During dusk they had spread up to 2 meters, occurring in progressively greater numbers from here to the bottom. During starlight they were in largest numbers at the bottom, occurring in next greatest numbers at the surface ans still less at 7.5 meters. During moonlight a few occurred at the surface, twice as many at 2 meters, while eight times as many at 7.5 meters and 15 meters.

The young were only found at the bottom during sunlight. During dusk they were at a maximum at 7.5 meters, occurring in lesser numbers at the bottom. During st rlight they were in greatest numbers from the surface down to 2 meters, very few occurring at 7.5 meters, with an appreciable number at the bottom. During moonlight they were found only at 15 meters, probably also existing at intermediate depths not sampled.

In general, they were all found in greatest numbers at the bottom during sunlight, never occurring in appreciable numbers above 7.5 meters. During weak conditions of light (dusk, starlight, and moonlight) they tend to move toward the surface, only reaching the surface in large numbers during starlight. The females were at all times more abundant than the males. During sunlight and moonlight the females extended higher up than did the males, while during dusk and starlight they existed at the same depths. The young existed near the bottom at all times only extending to the surface during starlight.

Unknown Copepod nauplii were found during dusk, starlight, and moonlight at 2 meters, being most abundant during starlight. A few were found at the bottom during dusk.

Prince Station 848 (Table III):

Calanus:

The adult males were only found during starlight, and in small numbers, at 20 meters and at the bottom (40 meters) and so the results are of little comparative value.

Adult females were found at the bottom only in large numbers during bright sunlight. During starlight and moonlight they were found in small numbers at 20 meters, suggesting that some at least had moved upwards during weak light.

The young showed a maximum at 20 meters during dusk, with a somewhat lesser number at the bottom and a few at the surface. During starlight and moonlight an appreciable number occurred at the surface, increasing in number with depth until a maximum occurred at the bottom.

In general, only the young were present at this locality in sufficient numbers so as to make the results of any significance. These were only found at the surface in light weaker than sunlight (the two occurring during sunlight being of little significance) and then they occurred in greatest numbers from 20 meters to the bottom.

Pseudocalanus:

The adult males were not found in significant numbers.

The adult females were practically entirely limited to the bottom during bright sunlight. During dusk their maximum had moved up to 20 meters, being found in appreciable numbers both at the surface and at the bottom. During starlight their maximum was at the bottom with second largest numbers at 2 meters, and an appreciable number at 20 meters and at the surface. During moonlight they occurred in increasing numbers from the surface down with the maximum at the bottom.

The young were only found at 20 meters during dusk and moonlight, while at 2 meters at starlight.

In general, only the females occurred in large numbers. These were at all times mainly limited to the depths from 20 meters to the bottom some, however, tending to move up to the surface in lights weaker than sunlight. Further observations are necessary in order to determine why the maximum was at 20 meters during dusk, while at all other times it was at the bottom. The young seemed to limit themselves closer to the surface than did the adults at all times, coming nearest to the surface (2 meters) during starlight.

Temora:

Only adult females were found but never in large numbers. These were scarcely present during sunlight at any depth either due to the depth at which the tows were taken or tothe possibility of their scarcity at the time. Further investigation is necessary in connection with seasonal fluctuations in abundance. In any case they occurred at the surface during dusk, starlight, and moonlight, occurring close to the bottom during dusk and starlight in small numbers.

In general their maximum abundance was within 2 meters of the surface during weak light while they were not found appreciably at any depth during sunlight.

Eurytemora:

No adult males were found during sunlight at any depth. During dusk their maximum was at 2 meters, also occurring in appreciable numbers at the surface. During starlight their maximum was also at 2 meters occurring in much lesser numbers at 20 meters and at the surface. During moonlight they occurred in slightly increasing numbers from the surface down to 20 meters.

The adult females were practically limited to the bottom during sunlight where they occurred in large numbers. During dusk their maximum was at 2 meters, occurring also at all other depths, the minimum being at the surface. During starlight the maximum was also at 2 meters, occurring in appreciable numbers at all other depths. During moonlight none were at the surface, the maximum now being at 20 meters, while occurring in appreciable numbers at 2 and 40 meters.

No young were found during sunlight at any depth. During dusk the maximum was at 2 meters - a few also occurring at the surface. During starlight the maximum was at 2 meters - occurring also at the surface and at 20 meters. During moonlight the maximum was again at 2 meters - also occurring at the surface and at 20 meters.

In general, the adult male was entirely limited to the upper 20 meters during dusk, starlight, and moonlight, being especially abundant in the upper 2 meters during dusk and starlight, while during moonlight it extended down to 20 meters. This suggests that the weak light condition of dusk and starlight enables it to remain closer to the surface than moonlight. The adult female was found at all times on the bottom, being practically entirely limited to this depth during sunlight, while during weaker light it tends to move up toward the surface, being particularly abundant at 2 meters during dusk and starlight, while at 20 meters during moonlight; this suggests that the female also can remain closer to the surface during dusk and starlight than during moonlight, or sunlight. During dusk, starlight, and moonlight, the young had their maximum at 2 meters and were never found at the bottom; As their maximum was higher than that of both adults during moonlight, it suggests that they enjoy a higher light intensity than do the adults.

Acartia:

The adult male was not found appreciably at any depth during sunlight. During dusk, starlight, and moonlight, they were present in tremendous numbers at 2 meters, being next in abundance at the surface, and in still less numbers at 20 meters. They only occurred at the bottom during dusk.

The adult female only occurred in appreciable numbers at 2 meters during sunlight, when it was not comparitively abundant. During dusk and starlight they occurred at all depths with the maximum at 2 meters, being next in abundance at the surface, thirdly at 20 meters and least of all at the bottom. During moonlight the maximum was at 2 meters, occurring next in abundance at 20 meters, thirdly at the surface with none at the bottom.

The young were not found appreciably at any depth during sunlight. During dusk the maximum was at 2 meters, occurring in considerable less numbers at 20 meters and at the bottom. During starlight the maximum was at 2 meters, being next in abundance at the surface, thirdly at 20 meters, and a few occurred at the bottom. During moonlight the maximum was at 2 meters, next at 20 meters, thirdly at the surface, with none at the bottom.

In general, it seems that whenever this form is found in any abundance its maximum is at 2 meters and minimum at the bottom.

During weak light at least, it is largely found in the upper 20 meters, being relatively scarde at the bottom during dusk and starlight and entirely absent during moonlight. No significant difference in behaviour between male, female, and young was noticed.

Tortanus:

The adult male was only found in significant numbers at the bottom during sunlight. During dusk the maximum was at 2 meters, being next in abundance at the surface, and occurring in much less but equal numbers at 20 meters and at the bottom. During starlight the maximum was at the surface, being absent at 2 meters, and occurring in lesser numbers from 20 meters to the bottom. During moonlight its maximum was at 20 meters, while it occurred in equal numbers at all other depths.

The adult female also only occurred in significant numbers at the bottom during sunlight. During dusk its maximum seemed to be from 20 meters to the bottom although it is possible that had the largest sized net been used at 2 meters the maximum would have occurred there. In any case the results indicate that this form moved upward during dusk occurring also in large numbers in the upper 2 meters. During starlight the maximum was at the bottom with large numbers occurring also at the surface and at 20 meters, none having been found at 2 meters. During moonlight they occurred in increasing numbers from the surface to the bottom.

No young were found anywhere during sunlight. During dusk the maximum was at 2 meters and the minimum at the surface with significant numbers at 20 meters and at the bottom. During starlight the maximum also occurred at 2 meters with very few at the bottom. During moonlight the maximum was at 20 meters, being next in abundance at the bottom, while being very scarce at 2 meters.

In general, the adult male remained at the bottom during btight sunlight, while it moved upward during weaker light showing its maximum at 20 meters during moonlight, while in the upper 2 meters during dusk and starlight. The adult female showed it s maximum at all times in the deeper water (20 meters to the bottom) being only present at the bottom during sunlight and extending upward to the surface during weaker light. The young never showed a maximum at the bottom as did the adults, showing a maximum at 2 meters during dusk and starlight, while at 20 meters during moonlight. Hence it would seem that the young and the adult male preferred a higher light intensity than did the adult females.

Unknown nauplii were found both free and enclosed in the egg, and were preserved for future identification.

Prince Station 6 (Table IV).

Calanus:

The adult male and female were only found during moonlight and in small numbers and occurred at 2 and 15 meters with the maximum at the latter.

The young were found only at 15 meters and at the bottom during bright sunlight, with the maximum at the bottom. During dusk the maximum had moved up to 15 meters, occurring in next greatest numbers at 30 meters and then at the surface. During starlight the maximum was now at the surface, occurring in lesser numbers at 15 meters while entirely absent at the bottom. During moonlight they were only found at 15 meters.

In general only the young were found in comparative quantities. This was present only in the deeper water during sunlight being most abundant at the bottom, while during dusk and starlight it extended up to the surface being most abundant there during starlight.

Pseudocalanus:

The adult male was relatively scarce at all times, only occurring in large quantities at 2 meters during starlight.

The adult female was only found at 15 and 30 meters during sunlight, the maximum being at the bottom (30 meters). During dusk the maximum was at 2 meters occurring in lesser numbers at the bottom and then at the surface. During the starlight the maximum was also at 2 meters, with very large numbers also occurring at the surface, while they were considerably scarcer at 15 and 30 meters. During moonlight the maximum was now at the surface, being next in abundance at 15 meters, with less at 2 and 30 meters.

The young were not found anywhere during sunlight, showing a maximum at 2 meters during dusk and starlight, while at the surface during moonlight.

In general, the adult females were found at the bottom at all times, the maximum, however, only occurring there during sunlight. During weaker light they moved up to the surface with the maximum at 2 meters during dusk and starlight, while at the surface during moonlight. The young behaved in regard to its maximum as did the female adult, differing from the latter, however, in never being found at the bottom (not found during sunlight.)

Temora:

The only occurrence of the adult male was during bright sunlight and at the bottom.

The adult female was not found anywhere during bright sunlight. During dusk it was only found at 2 meters. During starlight the large majority were found in the upper 2 meters with a much lesser number occurring at 15 meters. During moonlight they were only present, and in small numbers at 15 meters.

The young were found: during dusk at 15 meters, during starlight at 2 meters; and in scarce numbers during moonlight at the bottom.

In general, only the adult female occurred at more than one depth at any one time, and then during starlight when its maximum occurred in the upper 2 meters. All that can be said is that the male was entirely on the bottom during bright sunlight; the female was in the upper 2 meters during starlight, while the young were nearer the surface (2 meters) during starlight than during dusk (15 meters).

Eurytemora:

The adult male was only found at 15 meters during sunlight, and at 2 meters during dusk. During starlight the maximum was at 2 meters, being next in abundance at the surface and at the bottom, with the least at 15 meters. During moonlight they occurred in the following order of abundance: 15, 30, and 2 meters, with none at the surface.

The adult female showed a maximum at the bottom during sunlight, occurring in lesser quantities at 15 meters, while very rare at 2 meters. During dusk the maximum had moved up to 15 meters, occurring also but in lesser numbers at all other depths. During starlight they showed a maximum at 2 meters, being very abundant at the surface and less so at all other depths. During moonlight the maximum had moved back down to 15 meters, making them more abundant in the deeper water than in the upper 2 meters.

No young were found either during sunlight or moonlight. During dusk they only occurred at 2 meters. During starlight their maximum was also at 2 meters, occurring in less but similar numbers at the surface and the bottom.

In general the adult male was only found in large numbers at more than one depth during starlight and moonlight when the maximum was closer to the surface (2 meters) during starlight than during moonlight. The adult female showed a maximum at the bottom during sunlight, moving up to 15 meters during dusk, still closer to the surface during starlight, while tending to move down deeper during moonlight. The young were only found during dusk and starlight when they were at a maximum at 2 meters. Hence it would seem that for the adult male and female at least a preference is exercised for very weak light intensities occurring closest to the surface during starlight, while farther down during moonlight and dusk, and for the female at least, nearest the bottom during sunlight. The young also preferred weak light occurring closer to the surface during starlight than during dusk.

Acartia:

Adult males were only found in appreciable numbers at 15 meters during sunlight. During dusk the maximum was at 2 meters, occurring in much lesser numbers at 15 meters. During starlight the maximum was at 2 meters also, occurring in large numbers at all other depths, including the surface for the only time. During moonlight the maximum had moved down to 15 meters none occurring at the surface, while occurring next in abundance at 30 meters and then at 2 meters.

The adult female was only absent from the surface during sunlight when it was almost entirely limited to the deeper water extending from 15 meters to the bottom with the maximum at the bottom. During dusk the maximum was at 2 meters with less occurring at 15 meters and a few at the surface. During starlight the maximum was 2 meters but large numbers also occurred at the surface and at the bottom with the minimum at 15 meters. During moonlight the maximum was at 15 meters, with considerable numbers occurring at all other depths. The young were only found in abundance during dusk and starlight when their maximum was at 2 meters.

In general the adult male was only found at the surface during starlight, with its maximum at 2 meters during starlight and dusk while at 15 meters during sunlight and moonlight. The adult female was only absent from the surface during sunlight with it s maximum at the bottom, while during moonlight the maximum had moved up to 15 meters, while during dusk and starlight it had moved up to 2 meters. Hence, for the adults at least, it seems that bright sunlight repels them to the deeper water, while they move closer to the surface during moonlight, and still closer during dusk and starlight when they may be found in large numbers in the upper two meters. No significant difference was noticed between adult males, females, or young.

Tortanus:

The adult male only occurred in appreciable numbers in the deep water during sunlight, showing a maximum at 15 meters and occurring in large numbers at the bottom. During dusk it had moved up to the surface where it occurred in large numbers, increasing, however, with depth down to 15 meters, while the minimum occurred at the bottom. During sunlight the maximum had moved up to 2 meters, being next in abundance at the surface, next at the bottom, with the minimum at 15 meters. During moonlight they occurred in largest numbers at the surface and at 15 meters, being next in abundance at 30 meters with the minimum at 2 meters.

The adult female was found at all depths during sunlight, being very scarce at the surface, appreciable at 2 meters, while exceedingly abundant at 15 meters and 30 meters, the maximum being at the latter depth. During dusk the maximum moved up to 15 meters with second largest numbers at the bottom, while large numbers now occurred at 2 meters and at the surface. The maximum was at the surface during starlight, with large numbers occurring at all other depths. During moonlight the largest numbers occurred at the bottom and surface, the next being at 15 meters, and the least at 2 meters.

The young were found largely in the deep water during sunlight with the maximum at 15 meters. During dusk the maximum was also at 15 meters, but large numbers were also found at 2 meters and appreciable numbers at the surface and bottom. During starlight the maximum was at 2 meters, being next in abundance at the bottom, while large numbers occurred both at the surface and at 15 meters. During moonlight the maximum was down to 15 meters as it was during sunlight, being next in abundance at 30 meters, while it occurred in appreciable numbers in the upper 2 meters.

In general the adult male was limited to the deeper water (from 15 meters down) during sunlight, extending up to the surface during all weaker conditions of light, with the maximum at 15 meters during dusk, at 2 meters during starlight, and at the surface during moonlight. The adult female was present at higher levels during sunlight than was the adult male, it being mainly limited, however, to the deeper water, while during all weaker conditions of light it extended up to the surface with its strongest numbers at 15 meters during dusk, and at the surface and bottom during starlight and moonlight. The young was also mainly limited to the deeper water during sunlight when its maximum occurred at 15 meters, while it extended up to the surface during all weaker conditions of light, with its maximum at 15 meters during dusk and at 2 meters during starlight, and at 15 meters during moonlight. Hence, it appears that this form prefers the deeper depths during bright sunlight, moving up to the surface during all weaker conditions of light, coming closer to the surface during starlight and moonlight than at dusk (i.e. the adults at least). During sunlight, at least, the adult females came closer to the surface than did the adult males. Further investigations are necessary in order to determine why the young were mainly distributed deeper during moonlight than either of the adults.

Prince STATION 6:

Table V shows the results of the successive tows taken during bright sunlight at a time when the young were believed to be abundant in order to compare their behaviour with the adults.

Calanus:

Only young occurred during bright sunlight when they werer found only in deep water with twice as many occurring at 15 meters as at the bottom.

Pseudocalanus:

The adult male was only found at 15 meters.

The adult female occurred from 5 meters to the bottom with the maximum at 15 meters and équal numbers at 5 meters and the bottom.

The young showed a maximum at 15 meters with next greatest numbers at 5 meters, and the least at the bottom.

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Hence, in general, it seems that during bright sunlight both adults and young enjoyed a maximum at 15 meters, with the adult females extending nearer to the surface than the adult males. No difference was exhibited between young and adults.

Temora:

The adult males were only present in the deeper water being equally distributed at 15 meters and at the bottom.

No adult females were found.

The young were found only at the bottom.

In general, the adult males extended higher up than did the young.

Eurytemora:

The adult males were found at all depths being most abundant at 5 meters, next at the botton, then at 15 meters, with the minimum at the surface.

The adult females were not found at the surface at all, the maximum being at the bottom, while they decreased in numbers upwards to 5 meters.

The young were found at all levels with the maximum at 5 meters, being next in abundance at the surface, next at the bottom, while the minimum occurred at 15 meters.

In general, the young were found in proportionately greater numbers in the upper 5 meters than were the adults, with the main distribution of the adult females being largely deeper than the adult males.

Acartia:

Both young and adults were found at all depths and they all showed a maximum at 5 meters, being next in abundance at the surface, then at 15 meters, with the minimum occurring at the bottom.

Hence, it would seem that this form is able to withstand high intensities of light, and no outstanding difference was noticed between young and adults.

Tortanus:

No adult males occurred at the surface, the maximum occurring at the bottom, while they were next in abundance at 5 meters and least at 15 meters.

The adult females also showed a maximum at the bottom decreasing in numbers upwards to 5 meters, with none at the surface.

The young occurred at all depths with the maximum at 5 meters, being next in abundance at 15 meters, next at the bottom, and the minimum at the surface.

In general, only young were found at the surface and their maximum was considerably higher up (5 meters) than either of the adults (at the bottom-30 meters).

LABORATORY EXPERIMENTS

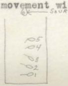
Controlled laboratory experiments were carried out so as to study the behaviour of the individual food forms in respect to:
(1) Characteristic movements as they moved either toward or away from the light.

Acartia:

Some quickly moved toward the light until they reached the surface, while others moved more slowly toward the light but did not reach the surface seeming to be content to remain at a depth of about one-quarter of the jar from the surface. That is, they moved either quickly toward the source of light and reach the surface or move slowly toward the source, seeming to be content to remain in the upper lighted region of the jar, without going to the surface. No difference as regards to sex or age of individuals could be determined on removing individuals exhibiting either the slow or rapid movement.

The more rapid movement was accomplished in either of two ways:
(a) Short jerky movements probably using urosome by inclining it up and down. By such a movement the anterior end is constantly toward the source but the resulting path followed is somewhat zig-zag.
(b) Straight gliding movement toward the source with urosome motionless and probably only using legs.

The slow type of approach toward the light was accomplished thus:
(a) Short jerky movement with dorsal surface toward source:



Position 1 to 3 accomplished by a slow and slight tilt of the body while positions 4 to 5 by a quick flip of urosome downwards, sometimes remaining for some time in any one position.

(b) As above but no urosome motion.

Eurytemora (female):

Movement was distinctly different from Acartia in that it never assumed a horizontal position with the dorsal surface toward source of light. Due to the fact that most of the females were carrying eggs in their characteristic manner under the urosome, it was thought perhaps the weight of the eggs caused the urosome to sink downward. However, this was found not to be the case as females without eggs acted in the same manner. Their movements toward the light are: (a) Moves in a straight line by a series of movements thus:

While at rest the urosome remains perpendicular, while the actual movement is accomplished by a movement of the urosome dorsally only (cf.-Acartia). The positions of rest may last long enough to be quite noticeable or it may move with a series of movements of the urosome without any apparent periods of rest.

(b) The occasional one was seen to walk along the surface of the jar. (Not so in Acartia). (c) Short rapid darts during which no urosome motion was visible. This movement was especially apparent when they came into contact with another Copepod from which it would rapidly dart away. (d) Made sudden rapid movements from side to side of jar and not necessarily toward light, flipping the urosome dorsally. It was always apparent that this form moved with the anterior end toward the direction of movement.

Eurytemora (male):

In their region of optimum intensity their locomotion consisted of slow steady movement in no particular direction. They moved for a considerable distance with anterior end in direction of movement and urosome stretched out motionless. Hence evidently only the appendages were used for locomotion. While motionless the same position is maintained (cf. Tortanus).

The direction of motion could be suddenly changed by a quick movement of the urosome either dorsally or ventrally1 While moving or motionless, the antennae (1st.) remained curled downwards () which was quite unique among the forms studied.

Occasionally a more rapid type of movement was observed when they might fush from one end of the jar to the other. Such a more rapid movement was accomplished by rapid jerky movements but always in one straight line. This type of movement was occasionally interrupted by the slower type.

Occasionally they were observed to "loop the loop". Possibly the curved 1 st. antennae account for such a loop.

Calanus:

As has been previously noted by others this form is attracted by bright light immediately after having been removed from the sea but after remaining for some time in the laboratory it soon resumes the normal negatively prototropic reaction which it exhibits usually in nature. The movements here described are of Calanus which had been kept in the laboratory for two days previous to the experiment.

With a 20 watt electric bulb close to the surface they behave as follows at from 13 to14 °C.

(a) Made a sudden dash away from the light at about 20 cms/sec.

from the surface to the bottom of the jar.

(b) Made slow movements away from the light at about 0.3 cms/sec. Such movements were slow and in a straight line but interrupted by a series of pauses, the actual movement being either horizontal or vertical and accomplished, at least, by a slight movement of the urosome ventrally (cf. Eurytemora). It finally would reach the darkest region but only after a series of movements in no particular direction, sometimes moving for short distances toward the light. The resultant discovery of the darkest region seemed to be as a result of trial and error. (c) Series of slow and gliding movements in a straight line, not necessarily away from the light, (eg.-10 cms/sec.) without using urosome.

On comparing their movements with Acartia, they reached the darkest region only after 5 minutes while by that time the majority of Acartia had accumulated in the brightest region resembling a swarm of moths around a light. Generally, it seemed that when Calanus did move it moved faster than Acartia but only as a result of this possible trial and error type of movement, and so was considerably slower in accomplishing the desired result.

When the light was at the bottom of the jar the Calanus made numerous charges at the surface as if trying to break through. While stationary at any point it was always perpendicular in the water with the head upwards.

Pseudocalanus:

Moved with the anterior end in the direction of movement. Its antennules were spread out straight and motionless during movement which was always very slow, the movement being accomplished by the appendages (not including the antennules).

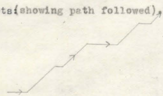
More rapid movements were often accompanied by a change in direction and were definitely seen to be accomplished by flips of the urosome. Such movements were most easily seen in this species due to the long length of the urosome.

Tortanus:

While suspended motionless in the water they remained horizontal with the dorsal surface uppermost and with the urosome inclined dorsally;. Their maxillipedes could always be seen spread out horizontally at right angles to the body. The above was quite characteristic of this species.

Types of movement:

(a) Moved upwards with sunlight coming from above in a series of movements (showing path followed).



The horizontal lines denote when it appeared to be at rest and drifting. The oblique lines represent more rapid movement upwards, with the dorsal surface as above and with urosome more or less motionless, the actual movement seeming to be accomplished by a "walking motion" of the legs.

(b) Short dashes upwards, but more rapid than above, with the dorsal surface uppermost. These movements were too rapid to be easily observed.

(c) Moved down and away from the s ource of light, with the body tilted downwards while in motion, but with the urosome still decidedly tilted dorsally.

The antennules always remained straight and motionless as follows:

(2) Phototropic behaviour.

The results of the experiments described on page 5 are given below:

	Sunlight	Dusk	Darkness	Moonlight
Acartia	80%+			
Tortanus	95%+			

Calanus	90% −
Pseudocal.	95% −
Eurytemora (male)	80% +
Eurytemora (female)	100% +

In the above table + signifies positively phototropic

" " " " − " negatively "

Some additional notes made in connection with phototropic responses are:

Acartia:

Bright sun overhead. Temperature of water-15°C. Fifty Acartia in tall glass cylinder. After five minutes all but three were collected at the surface.

Tortanus:

Bright sun over head. Temperature of water - 14°C. Ten Tortanus in tall glass cylinder. After 5 minutes eight had collected just below the surface and two half way between the surface and the bottom. Of the surface individuals, five were adult females, and three adult males. Of the deeper individuals, they were both adult males.

Hence, although both adult males and females were found at the surface during sunlight only adult males were below the surface.

Eurytemora: (male)

Forty watt bulb at surface. Temperature of water - 13°C. Tall glass cylinder used. Ten individuals. They all showed a positive reaction to the light intensity used moving to within a few inches of the surface. They moved in slow gliding movements - both up and down and sidewards, always remaining within this range and not clustering at the surface (cf. Acartia).

Calanus:

With sunlight overhead and water at 12°C. the typical behaviour was to remain in the light, when suddenly exposed, for a period which varied in the same individual anywhere from 1 to 4 minutes, and then to make a rapid dash to the dark region where it remained. That this is not always the case, however, is evident from what has already been said on page 35 in so far as its rapid progression is concerned.

Eurytemora: (female)

With a 50 watt bulb at the surface and the water at from 13 to 14°C., this form showed a positive phototropic reaction moving to the surface. Again, when this experiemtnt was repeated another time, it was found that while many moved toward the light when it was suddenly snapped on, others remained indefinitely scattered from top to bottom. As only adults were used, it is evident that every adult does not necessarily enjoy the same light intensity!

Pseudocalanus:

With the temperature as above, and with bright sunlight above, they preferred the darker end of the jar.

Tortanus:

Under the same conditions as described above, they showed an upward movement to the surface in general, although some remained in the deeper part of the jar.

(3) Phototropic behaviour at different temperatures to horizontal light: The results of the experiment described on Page 5 are given below:

	0°C.		0°C.		0°C.		0°C.	
	+	−	+	−	+	−	+	−
Calanus	3	7	4	8	4	9	4	9
Pseudocal.								
Tortanus	10	0	10	2	10	2	30	0
Acartia	10	0	11	1	10	2	10	2
Euryt. male	2	7	Wandering tendency--------					
Euryt. female	10	0	10	0	10	0	10	0

In the above experiment Tortanus and Acartia collected at the source and kept moving against the walls of dish as if wanting to go to the source. In the main the Calanus showed a negative phototropism but the individuals did often wander from the lighted to the darkened area. The wandering tendency showed for the male Eurytemora was confined to the lighted half of the dish and none were found in the dark area. Hence, it seemed to have an optimum in the lighted area but did not collect as definitely at the source as did Tortanus and Acartia.

In general, within the limits used in these experiments, temperature was not found to alter the phototropic behaviour of the forms studied.

(4) Effect of temperature on duration of life.

The results of the experiment described on page 6 are given belo

Genus	0.7°C.	4.8°C.	10°C.	14.7°C.	21.3°(
Acartia	28 days.	24 days.	22 days.	15 days.	3 da
Tortanus	15 days.	13 "	9 "	6 "	3 "
Eurytemora (male)	21 "	19 "	14 "	7 "	3 "
Eurytemora (female)	27 "	26 "	19 "	12 "	7 '

The above resàlts suggest that within the limits of temperàtures used, the lower the temperature the more favourable the effect on the organism, and that temperatures above 20°C, at least would have a lethal effect.

Somewhat similar experiments were carried out here in 1921-22 by A. H. Leim on Pseudocalanus (?) and Calanus finmarchinus. He came to the conclusion that for Calanus fin., 20 to 25°C. had a lethal effect, the duration of life being less than one day, 15° being quite favourable, while 5° and 10° were still more favourable for the prolongation of life. In regard to Pseudocalanus (?) he says, "a temperature of 20°C. seems to be unfavourable reducing the average lengths of life to 62% of the average at 13°C and at the same pH (optimum)" Hence his results, in addition to those here found, stress the importance of a low temperature as being essential for a favourable environment.

(5) Reaction of male Acartia to different intensities of light.

The results of the experiments described on page 6 are given below:

WITH BULB AT SURFACE:

Time	Distance	Velocity	Time	Distance	Velocity
71 secs.	24 cms.	0.34 cm/sec.	143 sec.	29 cms.	0.20 cm/sec.
13 "	24 "	1.85 " "	112 "	29 "	0.25 " "
35 "	29 "	0.82 " "	105 "	29 "	0.27 " "
105 "	29 "	0.27 " "	110 "	29 "	0.25 " "
95 "	29 "	0.30 " "	110 "	29 "	0.26 " "

Average velocity: 0.48 - 0.103 cms/sec.

WITH BULB AT 2 Ft.:

Time	Distance	Velocity	Time	Distance	Velocity
180 secs.	25 cms.	0.11 cm/sec.	34 secs.	25 cms.	0.74 cms/sec.
186 "	25 cms.	0.13 cm/sec.	30 "	25 "	0.36 " "
95 "	25 "	0.26 " "	60 "	25 "	0.42 " "
45 "	25 "	0.55 " "	195 "	25 "	0.13 " "
70 "	25 "	0.36 " "	150 "	25 "	0.17 " "

Average velocity: 32 _0.0c9 cms./sec.

WITH BULB AT 4 Ft.:

Time	Distance	Velocity	Time	Distance	Velocity
60 secs.	35 cms.	0.58 cm/sec.	120 secs.	25 cms.	0.20 cms/sec.
154 "	25 "	0.16 " "	210 "	25 "	0.12 " "
225 "	20 "	0.11 " "	150 "	25 "	0.17 " "
90 "	25 "	0.28 " "	85 "	25 "	0.29 " "
85 "	25 "	0.29 " "	180 "	25 "	0.14 " "

Average Velocity: 0.23 _0.029 cms./sec.

WITH BULB AT 6 Ft.: No effect as were distributed equally throughout jar.

The results show that there is considerable individual variation at the various intensities with the light at the surface, 2 ft., and 4 ft. The averages at the different light intensities with their respective dispersions show that no overlapping occurs between the averages and indicates a very slight increase in average velocity with increase in light intensity.

In general, the results indicate that a certain minimum of light intenisty exists in order to attract this form and increase in intensity above this does not greatly increase the rate at which they move toward the source.

Feeding of the Herring.

(a) Capture of the food:

For the most part they swim around keeping together. The resultant direction is lengthwise along the tank from end to end never loitering long in any particular place. They do not follow any particular path but seem to follow the side of the tank in going from end to end, but just as often they cut diagonally across.

The formation is broken on making attempts to capture food. The fact that it actually sights the food is quite evident as it makes a dash to within a few inches of the food particle. It then slowly glides the remaining distance (generally upwards) until almost touching the particle and then makes a quick snap at it. Such is the behaviour when the herring seem to sight the food from a distance. Another method s eems only to occur when the herring sight the food to one side and then it seems to snap the head sideways and quickly seizes the particle, causing the whole body to partly turn over, giving a sudden flash as the silvery sides are exposed to view from above. Such a twisting movement has often been obsërved in nature while the herring were feeding on Meganyctiphanes near the surface on sunny days.

A herring was observed to make a quick dash the length of the tank toward a piece of white paper about ½ inch square floating at the surface of the water, glide up until the paper was just about touching the snout but quickly turn away and join its fellows again. Another was seen to make a similar move at a piece of silver paper about the size of a pin head but refused to snap at it. On another occasion a herring actually snapped at the shiny bulb of a mercury thermometer which was being used to take the temperature of the water

(b) Selection of food in regard to its size:

Fifty dead Meganyctiphanes were thrown one by one into a tank containing twenty herring ranging in size from 15 to 22 cms. as the "shrimp" slowly settled among the fish, with the exception of two cases the herring made no attempt to catch them. In one case, a herring about 18 cms. long made an attempt to catch a "shrimp", failed, quickly circled back and made another attempt, failed again-seeming to have difficulty in seizing the shrimp. IN another case, one herring about the same size actually succeeded in taking one within its mouth, but after a few seconds it was ejected again; here the difficulty seemed to be in swallowing it. The shrimp used ranged in size from 3.5 to 4.0 cms. in length.

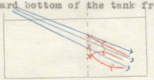
In order to determine whether the size of the shrimp was the reason for its refusal for food, they were cut up into one-half and one-quarter lengths and the portions thrown into the tank. Still no attempt was made, in general, by the herring to devour the portions. On cutting up the shrimp into still smaller portions, however, the herring greedily seized each portion in almost all cases, and none were ejected again.

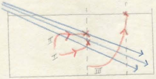
It seemed that the herring undoubtedly used their eyesight in feeding and the size of the food particles seems to be a determining factor. The fact that the particles used in the above experiments were dead shows that the herring are not unnecessarily attracted to certain forms of food by the latter's movements and suggests that certain forms are chosen as food in nature due to either their coloration or some other factor.

It is worth mentioning that large herring have been observed feeding on schools of live "shrimp" (Meganyctiphanes norvegica) brought to the surface by deep tidal mixing currents off Clam Cove. The herring often broke the surface in their attempts to catch the shrimp.

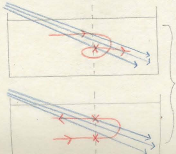
(c) Capture of the food under different directions of illumination:

In the following experiments food was dropped into the tank (as described on page 8) and it was observed where the herring seized the food particles under different directions of illumination. Each experiment is illustrated by a diagram. The red lines show the paths taken by the herring in order to seize the food, the point at which the food is seized being marked by a red X; the position of the food as it dropped from the surface to the bottom of the tank is shown by dotted lines; and the direction of the rays from the source of illumination is shown by purple lines. Thus the diagrams are self explanatory. Experiment I oblique rays passing toward bottom of the tank from the surface:





I-Across tank from side to side.
II-Lengthwise
III-Vertical-food at the surface.

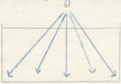


Such movements were oblique spirals downwards or upwards or horizontal but never vertical as the herring was never observed to "loop the loop".

Experiment II. Surface illumination only:

Very rarely would a herring pick food right off the surface.

Experiment III. Divergent illumination from above center of tank.



The capture of the food by the herring took place in this experiment in the following ways:

(a) Horizontal movements:

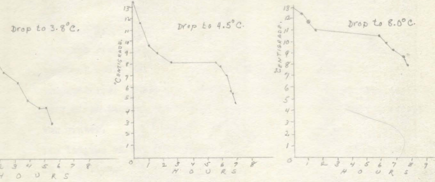
(b) Spiral movements:

(c) Vertical movements:

In general it was noticed that by far the most common method was to move upwards for the food, and if the latter is under them they ignore it. They were occasionally seen to dip slightly downward for the food if the latter is falling. They would only take food suspended in the water, having never been observed to take food off the bottom of the tank. Alteration in the direction of the rays from the source of illumination, whether horizontal, vertical, or oblique, did not prevent the herring from feeding, the feeding only taking place, however, in the regions where the food particles were illuminated.

(d) The effect of temperature on feeding of the herring:

The results now available of the experiments described on page 8 and 9 are only those concerned with rapid temperature changes; The rate of fall of temperature is given in the following graph:



Observations on the feeding at each of the four temperatures are as follows:

(a) 13°C.

At this temperature the herring fed to capacity.

(b) 8.0°C.

The herring fed well and would come to the surface for food. the lengths of the fish used and the amount of food taken by each is as follows:

16.0 cms.-stomach almost full.

15.5 cms.-stomach empty.

15.0 cms.-stomach almost full.

(c) 4.5°C.

The herring would not feed. Their movements, however, were not confined to the bottom of the tank (cf. 3°C.), some of them moving to the surface at times. The lengths of the fish used and the amount of food taken by each is as follows:

12.0 cms.-very slight trace of food.

14.5 cms.-stomach empty.

15.0 cms.-stomach empty.

(d) 3.0°C.

The fish would not feed. They remained on the bottom of the tank and would not come to the surface as they did at higher temperatures. Their movements were very sluggish and they remained very close together (as has been observed by the fishermen during the winter.

The lengths of the fish used and the amount of food taken by each is as follows:

15.5 cms.-stomach empty.

16.0 cms.-stomach empty.

16.5 cms.-stomach empty.

SUMMARY

Behaviour of the food.

(1) Change in amount of food at the surface under different conditions of light:

Collections were made of the free-swimming Copepods at the surface only but under different conditions of light in order to determine whether the forms present at a definite place actually did alter under different conditions of light. The results show that there is a tremendous increase in the total number of Copepods at the surface in conditions of light weaker than sunlight, indicating that a considerable migration has taken place to the surface from the lower depths as the light intensity decreased from sunlight.

Two tows made under the same conditions but at different times of the day gave quite different results and indicate that any possible rhythm of the organisms might be quite important in interpreting such results. Hence it is suggested that future work must be carried out with this end in view.

Critical examination of the tows showed differences between the number of individuals of each species present at the surface under the different conditions of light. They all occurred in minimum numbers during sunlight, Pseudocalanus and Acartia being the only forms which were never absent from the surface at any time. With the exception of Temora (which was never abundant at this locality) they all occurred in relatively large numbers during dusk, starlight, and moonlight, while Acartia and Eurytemora also occurred in large but lesser numbers during faint sunlight.

(2) Vertical distribution of the food under different conditions of light.

On comparing the results of the distribution of three different localities it is evident that differences are exhibited by the different species of Copepods, their actual occurrence being described in the text.

Some interesting generalizations may be made at this time:

Calanus:

Only the young were very abundant at any of the three localities and it seems that this form is to be found in the deeper water during sunlight, while during weaker light it tends to extend upwards toward the surface.

Pseudocalanus:

At each of the three stations the males were relatively scarce. The results, however, suggest that it is to be found in the deeper water during sunlight, while during weaker conditions of light it extends upward toward the surface near and at which it is to be found during starlight and moonlight.

The females were found mostly on the bottom during bright sunlight at each of the three stations tending to spread up to the surface, however, during dusk, starlight, and moonlight. The depth at which the maximum occurred at any one time varied with the locality-e.g. The maximum was never at the surface at H.F.42 and Prince 848 while it did occur there during moonlight at Prince 6. As the depth of the water varied with the station at any one time, future plans must include a measurement of the light intensity at various depths. That the maximum may vary at one place even under the same conditions of light is seen at Prince 6 where, during bright sunlight, the maximum was at the bottom on July 24, while at

15 meters (half way to bottom) on Sept 14th. This further stresses the point mentioned previously, from other evidence, that the time of the day is important in interpreting these results.

The young Pseudocalanus were mainly found higher up than the adults at all times, the depth at which their maximum occurred, however, varied with the locality.

Temora:

This form was relatively scarce at all times.

The male was very scarce at all localities only having been found during sunlight at Prince 6 when it was limited to the deeper water.

All that can be said for the female is that when found in appreciable numbers their maximum was within the upper 2 meters during weak light.

At Prince 6 young were only found at the bottom during sunlight, while at 15 meters during dusk, and at 2 meters during starlight, suggesting that they moveup closer to the surface as the light intensity weakens.

Eurytemora:

In general, it may be said that this is a form which prefers very weak light intensities, being limited to the very deep water during sunlight, tending to move upwards during weak light, being mostly at the surface during starlight; while half way to bottom during moonlight.

Evidence is given for believing that the young are to be found closer to the surface than the adults at any time, thus probably enjoying a higher light intensity. Evidence from HF 42 suggests that the maximum distribution of the adult males was never as high up in the water as the adult females, although at

Prince 6 during sunlight on Sept. 14th the females seemed to be mainly distributed deeper than the males.

Acartia:

In general, the evidence suggests that this is a form which prefers high intensities of light (cf. Eurytemora), and, although never found in largest numbers strictly at the surface, it is mainly limited at all times to the upper depths extending from 2 meters to half way to bottom, occurring closest to the surface during weak light.

No outstanding difference was noticed between males, females, and young.

Tortanus:

In general, this is a form which prefers the deeper water during bright light when it may be found in large numbers at the bottom, while during weaker light it extends closer to the surface, the depth at which the maximum occurs depends on the locality. Evidence from H.F. 42 and Prince 6 suggests that at certain times at least, the females enjoy a higher light intensity than the males, while at Prince 848 the condition is reversed. The evidence makes it difficult to interpret any significant behaviour of the young except that they moved up toward the surface during weak light while existing at lower depths during sunlight, the depth of the main distribution varying with the locality. They seem to be distributed closer to the surface during starlight than during moonlight.

All the Nauplii found in these tows were particularly abundant at Prince 848 where they were mostly enclosed within the egg and were most abundant in the deeper water and never occurred at the surface. They are being preserved for future identification.

Laboratory Experiments.

Controlled experiments were carried out so as to study the behaviour of the individual food forms in respect to:

(1) Characteristic movements as they moved either toward or away from the light.

The descriptions applied to the vafious forms are carefully described on pages 32 to 37, and it seems that each species exhibits several types of movement, each of which is quite characteristic for the species concerned.

(2) Phototropic behaviour.

Experiments indicate that Acartia, Tortanus, and Eurytemora are positively phototropic to the high intensity of bright sunlight while Calanus and Pseudocalanus are genatively phototropic. That this behaviour is not fully carried out in nature is seen from their distribution in nature and suggests that light is not the only faator in controlling distribution.

In no case was the characteristic phototropic response ascribed to a species a 100% response, as always some individuals did not respond as did the majority of its fellows. In any case, of the positively phototropic species, Acartia was found to give the most definite response, rapidly clustering at the source, while Eurytemora and Tortanus showed many individuals scattered throughout the jar. Some evidence is given for believing that the adult males of Tortanus could be expected to be found below the females with bright light overhead.

(3) Phototropic behaviour at different temperatures to horizontal light:

Within the limits used in these experiments, (0^{o} to $15^{o}C$), temperature was not found to alter the phototropic behaviour of the forms studied.

(4) Effect of temperature on duration of life.

The results suggest that within the limits of temperature used (o.7 to 21.3°C.), the lower the temperature the more favourable the effect on the organism, and that temperatures above 20°C. would have a lethal effect.

(5) Reaction of male Acartia to different intensities of light.

The results indicate that a certain minimum of light intensity exists in order to attract this form and increase in intensity above this does not greatly increase the rate at which they move toward the source.

Feeding of the herring.

(a) Capture of the Food.

The method of capture of the food by the herring is described. It seems that the herring undoubtedly use their eyesight in feeding and the size of the food is a determining factor. The fact that the particles of food used in the above experiments were dead shows that the herring are not necessarily attracted to certain forms of food by the latter's movements and suggests that certain forms are chosen as food in nature due to either their coloration of some other factor.

(b) Capture of the food under different directions of illumination.

The direction of approach by the herring to their food is described. Alteration in the direction of the rays from the source of illumination, whether horizontal, vertical, or oblique, did not prevent the herring from feeding, the feeding only taking place, however, in the regions where the food particles were illuminated.

(c) The effect of temperature on the feeding of the herring.

The results show

The results now available are those concerned with rapid temperature changes, and show that the herring ate less at the lower temperatures, eating to full capacity at 13°C., while devouring no f od at all at 3°C., at which temperature they remained relatively inactive on the bottom of the tank. Such inactivity agrees with statements made by fishermen concerning the behaviour of the herring in winter.

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		6:15 p.m. July 4/34	10:00 a.m. July 9/34	1:50 p.m. June 30/34	9:30 p.m. July 8/34	11:40 p.m. July 11/34	1:00 a.m. June 30/34	1:00 a.m. July 1/34
		Bright sun.	Bright sun.	Faint sun.	Dusk	Starlight	Moonlight (½ full)	Weak Moonlight
Calanus finmarchicus	Male						400	
	Female							216
	Young	40			500	200	1000	
	Nauplius							
Pseudocalanus minutus	Male				600	400	200	[illegible]16
	Female	20	60	100	1000	400	2600	1728
	Young		40		100	200	2600	324
	Nauplius							
Temora longicornis	Male			20	300			
	Female						200	216
	Young							
	Nauplius							
Eurytemora herdmani	Male		220	900	3100	3000	21,600	8964
	Female			280	1900	1000	7,800	1620
	Young		40		200	400	14,200	3348
	Nauplius							
Acartia clausii	Male	120	40	600	5700	21,200	14,800	14,364
	Female	40	380	740	9100	20,000	14,600	11,988
	Young		20	1120	3500	6,400	4,800	4,752
	Nauplius							
Tortanus discaudatus	Male		60	60	1400	1600	3600	1188
	Female			60	500	200	800	
	Young		40	1000	2500	5800	2800	2052
	Nauplius							
Unknown	Male							
	Female							
	Young	200		3200	4200	5000	3000	3564
	Nauplius			60				

		July 19/34. 12:09 p.m.				Aug. 8/34. 7:50 p.m.				Aug. 16/34 12:35 am.				July 31/34. 1:50 a.m.			
		666 Bright sunlight				Dusk				Starlight				Moonlight (1/4 full)			
		o.m.	2 m.	7.5 m.	15m.	0 m.	2 m.	7.5 m.	15 m.	0 m.	2 m.	7.5 m.	15 m.	0 m.	2 m.	7.5 m.	15 m.
Calanus fin.	M																
	F									10			10			20	50
	Y					1	30	130	70	170	50	10	70		20	20	
	N																
Pseudocalanus Minutus	M	1		20						10		10		90	20	30	20
	F	27	40	100	400	2	50	30	80	110		110	120	270	340	380	80
	Y	4					100				50	20		20	40		
	N																
Temora longi.	M																
	F									30		10				30	30
	Y																
	N																
Eurytemora herdmani	M							30		190	800	10	20		40	70	
	F				400		10	50	590	660	350	240	200		30	1060	150
	Y						50		10	170	400	10			30		10
	N																
Acartia clausi	M			40			140	90	10	970	8300	160	30	10	90	100	70
	F		240	60	300		120	620	40	1140	3150	160	20	10	90	400	100
	Y		100				200			190	2400		20		10	40	10
	N																
Tortanus dis.	M				300		10	40	100	40		10	30				10
	F	3		100	1700		20	340	900	300		170	630	10	20	80	80
	Y				100			80	30	70	50	10	40				20
	N																
Unknown	M																
	F																
	Y														10		
	N						20		10		550						

	July 19/34 11:17p.m. Bright sunlight				Aug. 16/34 8:30 p.m. Dusk				Aug.16/34 11:50 p.m. Starlight				July 31/34 1:00 a.m. Moonlight (½ full)			
	0 m.	2 m.	20 m.	40 m.	0 m.	2 m.	20 m.	40 m.	0 m.	2 m.	20 m.	40 m.	0 m.	2 m.	20 m.	40 m.
Calanus fin.											20	20				
		1		200							20				20	
Y	2				10		220	150	40		320	620	50	40	120	260
N																
Pseudo-calanus minutus												20		10		
	2	4	3	3800	70		800	80	10	100	60	520	20	100	240	1800
Y	2						10			100					60	
N																
Témora longi.			2		30			10	20		10	10	10	50		
Y																
N																
Eurytemora herdmani	1				100	4600			10	500	20		50	60	80	
		2	1	800	10	1200	220	100	100	200	150	110		70	860	80
Y					20	5400			50	2800	30		20	120	60	
N																
Acartia clausii		1	1		340	25,600	100	40	230	29,700	130		30	1760	20	
	2	21	4		240	20,200	50	40	220	21,800	70	30	70	1650	100	
Y	2	1				12,400	20	10	100	15,600	70	10	20	240	60	
N																
Tortanus dis.		2		200	220	400	40	40	80		40	10	40	40	180	40
	1	6	4	2400	230	200	770	790	210		260	480	70	140	860	1240
Y					10	200	90	160		100		10		10	240	120
N																
Unknown						400	880	100		100	350	380			40	100

	July 24/34 11:40 a.m. Bright sunlight 0 m.	2 m.	15m.	30m.	Aug.8/34 9:00 p.m. Dusk 0 m.	2 m.	15 m.	30 m.	Aug.16/34 1:40 a.m. Starlight 0 m.	2 m.	15 m.	30 m.	July 31/34 2:50 a.m. Moonlight (½ full) 0 m.	2 m.	15 m.	30 m.
Calanus fin. Y N			40	100	30		80	60	150		40			10 20	29 30 70	
Pseudo-calanus minutus Y N			20	200	10	30 450		20	400	300 500 2300	60 60	50	450 50	40	20 220	60
Temora longi. Y N				100		10	40		150	100 100	20				20	10
Eury-temora herdmani Y N		2	20 260	800	30	10 10 50	160	40	100 500 50	500 600 300	60 160	100 300 50	100	20 210	70 570	60 400
Acartia clausii Y N		2 4	40 100	300	20	490 800 440	80 200		250 900	9200 11,600 1000	180 80	500 1300 150	100	30 90	190 380 10	60 180
Tortanus Dis. Y N	4	4 73 5	420 3420 200	200 6600 100	160 360 10	360 110 120	1120 1240 280	40 1080 20	2100 5550 300	2500 900 5800	280 1780 220	1400 5500 1250	450 1050 50	40 440 70	450 890 210	200 1140 180

TABLE V. Prince Station 6.

Tows taken successively with the same net (12 inch No. 5) on Sept. 14/34 at which time immature Copepods were abundant.

		Bright sunlight 0 m.	5 m.	15 m.	30 m.
Calanus fin.					
	Y			100	50
	N				
				50	
Pseudocalanus			300	900	300
minutus.	Y		400	1000	300
	N				
				50	50
Temora longi.					
	Y				50
	N				
		100	2000	1000	1700
Eurytemora			1600	2450	3750
herdmani	Y	650	1200	200	600
	N				
		7900	22,300	3400	1450
Acartia clausii		19,150	20,800	5300	3300
	Y	4,450	9,300	1550	750
	N				
			1800	1100	7200
Tortanus dis.			400	1400	3850
	Y	50	3000	2850	1850
	N				100?