MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No. 137

Changes in the vertical distribution of the common free-swimming copepods of Passamaquoddy Bay, New Brunswick.

by

W. H. Johnson

FISHERIES RESEARCH BOARD OF CANADA

MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No. 137.

Title

Changes in the vertical distribution of the common free-swimming copepods of Passamaquoddy Bay, New Brunswick.

Author

W. H. Johnson.

CHANGES IN THE VERTICAL DISTRIBUTION

of the

COMMON FREE-SWIMMING COPEPODS

of

PASSAMAQUODDY BAY, NEW BRUNSWICK

by

W. H. Johnson

More Pertinent Literature

The behaviour of Calanus finmarchicus occupies the bulk of literature concerned with the six species dealt with in the present contribution. Other observations however, have been recorded.

H. B. Bigelow (1924) presents records on the behaviour of the six species in question from the gulf of Maine, which region includes Passamaquoddy bay. His observations can be summarized as follows:

(a) Acartia clausi: Usually constituted a larger element of the copepod community at the surface. On two occasions entirely limited to surface. However more often repeatedly proved more abundant at some deeper level.

(b) Calanus finmarchicus: In the daytime the stock at say, 10 to 30 metres, becomes enriched by its tendency to sink when the sun is high; at night it is correspondingly impoverished. The vertical distribution, however, varies with the season of the year. In the spring (1920) it was taken in all but one of the surface hauls, irrespective of the time of the day, suggesting no diurnal migration such as it carries out in summer, when it shows a tendency for diurnal migration upward toward the surface at the approach of sunset which it deserts after sunrise in the morning. However, it is not solely induced to carry out an extensive migration by the time of the day, as many rich catches have been made at midnight as at sunset, suggesting that it is as likely to swim up at one hour of night as another, and hence it appears that the direction of vertical swimming (or sinking) is governed by geotropism which changes with physiological changes in the animal itself.

In its downward descent it tends to avoid the deepest waters in summer (as well as in winter) and to congregate at mid-depths, and since physical factors offer no apparent explanation for this, the cause probably lies in the distribution of the food supply.

The fact that it is usually found deeper down during the summer he ascribes as being due to the warming of the surface layer by the sun, producing a less favourable temperature, i.e. it may sink in warm brightly illuminated water, but rise in pale illumination irrespective of its temperature.

(c) Pseudocalanus minutus: Has been taken by the Canadian Fisheries Expedition regularly and abundantly at the surface as well as in deep tows down to 150 m. In the gulf of Maine it tends to desert the upper stratum as the season advances.

(d) Temora longicornis: McMurrich (1917) at St. Andrews only found it abundant in winter, the records being all from within seven metres of the surface, and many immediately at the surface.

INTRODUCTION

The present paper deals with a study of the changes in the vertical distribution of the common free swimming copepods of Passamaquoddy bay, New Brunswick. The six species dealt with are Calanus finmarchicus, Pseudocalanus minutus, Acartia clausi, Tortanus discaudatus, Eurytemora herdmani and Temora longicornis.

The foregoing historical account gives, it is believed, a clear picture of the present status of the problem of changes in the vertical distribution of marine copepods, being especially concerned with those species dealt with in this paper. It is seen that Calanus finmarchicus has been largely dealt with, very little having been done on the remaining species. Further contributions on the behaviour of even this species however, are worth while as it is evident that the apparent underlying causes in one region may not necessarily apply in another. It is believed by the author that a detailed study of the vertical distribution on the remaining five species is lacking; hence the results are believed to be a definite contribution.

LABORATORY EXPERIMENTS

Light is generally acknowledged as being an important factor in controlling the vertical distribution of marine copepods, although Esterly (1919) brought in the factor of "physiological rhythm". With these facts in mind, experiments were carried out at the Atlantic Biological Station during the summer of 1935.

VERTICAL DISTRIBUTION UNDER NATURALLY CHANGING LIGHT CONDITIONS

For this experiment a waterproof and lightproof rectangular wooden box was constructed with the following dimensions: length 125 cms.; width 10 cms.; depth 28 cms. The box contained running sea water. Standing upright inside the box were placed ten glass cylindrical jars, 30 cms. tall, and 4 cms. in internal diameter. The glass jars were blackened on the outside except for a strip through which the contained copepods could be seen on removing the jars. Each jar was almost filled with sea water. About 25 copepods were placed inside each jar. Each two jars contained the same species, the copepods having been secured by a No. 5 net, fishing from 2 to 5 metres below the surface at the Biological Station wharf; in the case of Acartia, Tortanus and Eurytemora the individuals being swept into the net by the outgoing tide. Calanus and Pseudocalanus were obtained from a depth of 50 metres farther out in the bay. When the jars were placed upright in the wooden box, the top of the box, containing holes which just allowed the top of each jar to pass through, was laid down. The whole arrangement was put outdoors; in this way the temperature of the water in the jars was maintained at 14°C., the light was always from above and any jar could be quickly removed and the distribution of the contained copepods noted. For the purpose of recording the vertical distribution, the jar divided into four equal parts by painting three white circles around the jar, and numbering the divisions 1, 2, 3, and 4, from bottom to top. During weak light, a flashlight suddenly snapped on enabled the distribution of the individuals to be seen. As they do not immediately respond to sudden light, this procedure did not upset their distribution. The copepods remained twenty-four hours in the jars before observations were started. Some fresh sea water was added to the jars every other day and it was found possible to keep the copepods alive by this method for two weeks. As a control similar jars were kept in complete darkness in the laboratory. The tables on pages 9 and 10 give the number of the section of the jar in which the majority of the individuals were congregated under (A) the naturally changing light conditions, and (B) in complete darkness.

Calanus shows definite negative phototropism to all intensities of light except the weaker. It is negatively phototropic to sunlight, daylight whether cloudy or clear, and to strong moonlight. It is positively phototropic to the very weak light intensity of dusk and dawn. It showed no geotropism being uniformly distributed in the jars during starlight and complete darkness. It should be mentioned here that these results are in contrast with those of Esterly (1919) who found a strong positive geotropism in diffused light and darkness, the behaviour not changing with changes in temperatures (and salinity).

Pseudocalanus. It acted in all respects as did Calanus.

Eurytemora: The individuals used in connection with the present experiments were obtained in shallower water (2-5 metres). These individuals did show a geotropism, i.e. negative geotropism in complete darkness, starlight, and very weak moonlight. During all stronger conditions of light the dominant reaction was that of phototropism, being negative to the strong intensity of sunlight, and tending to become progressively more positively phototropic as the light weakened, occupying the middle of the jar during dawn, dusk, sunrise and moonlight. These facts tend to explain their upward migration after dark in nature in that the weak light at sunset causes their upward movement to commence, while negative geotropism after sunset keeps them moving upward.

Acartia. Experiments were also carried out to determine its reaction to horizontal light and to light from below, the sources of light being (1) sunlight (2) a 50 watt bulb. In all cases Acartia proved to be strongly positively phototropic. No evidence of geotropism was found. They were strongly positively phototropic to all intensities of light, except that of starlight and weaker when they were uniformly distributed, and showing no evidence of geotropism. These results differ from those obtained by Esterly (1919) who found surface animals to be only positive to light of any intensity in water above 16°C., while at lower temperatures there was a tendency to become negatively phototropic. Furthermore, he found them to be negatively geotropic in diffuse light and positively geotropic in darkness. In the experiments in hand, the individuals were not tested to diffused light from below. In darkness they gave no evidence of positive geotropism. The sharp difference in behaviour between the individuals used in our experiments and those used by Esterly in his excellent work, show the danger of generalizing from laboratory experiments, possibly also showing that the apparent underlying causes in one region may not apply to the same species in another.

Tortanus was always strongly positively phototropic when first brought into the laboratory but this condition soon reversed to negative phototropism in strong light which latter condition prevailed as long as the individuals lived. Such a reversal of phototropism was also observed in the case of Calanus, and sometimes with Eurytemora. The lasting behaviours are the ones always referred to. No such change was noticed in the case of Acartia and Pseudocalanus. Tortanus was repelled by strong light and attracted by weak. Hence during sunlight they were all down in the jars. During weaker conditions of light the positive phototropism became stronger and they rose, extending upward during cloudy days, sunrise, dawn, dusk and moonlight. During complete darkness and starlight they showed no evidence of geotropism.

A still further important experiment is brought out by these experiments. All the species studied, when kept in complete darkness, showed no evidence of "physiological rhythm" such as was clearly observed by Easterly (1919) in the case of Acartia, and to some extent in the case of Calanus.

(A) Changing Conditions.

ate	Time	Weather	Solarimeter Reading	Calanus	Pseudo-calanus	Eury-temora	Acartia	Tortanus
g. 9	11:30 A.M.	Sunlight	57.5	1	1	1	4	1
9	2:30 P.M.	"	58.0	1	1	1	4	1
9	5:30PM	"	28.0	1	1	1	4	1
9	8:30P.M.	Weak Moon	0.0	Uniform	Uniform	3.4	Uniform	Uniform
9	11:30 P.M.	Starlight	0.0	Uniform	Uniform	3.4	Uniform	Uniform
10	2:30 A.M.	Starlight	0.0	Uniform	Uniform	3.4	Uniform	Uniform
10	5:30 A.M.	Dawn	0.0	4	4	4	4	4
10	8:30 A.M.	Sunlight	28.0	1	1	1	4	1
10	11:30 A.M.	Sunlight	56.5	1	1	1	4	1
30	1:45 P.M.	Cloudy	16.5	1	1	2	4	2
30	3:45 P.M.	Cloudy	6.0	1	1	2.3	4	2
30	5:45 P.M.	Cloudy	4.0	1	1	2.3	4	2.3
30	7:45 P.M.	Dusk	0.0	3	3	4	4	4
30	9:45 P.M.	Rain	0.0	Uniform	Uniform	3.4	Uniform	Uniform
30	Midnight	Rain	0.0	Uniform	Uniform	3.4	Uniform	Uniform
31	2:45 A.M.	Rain	0.0	Uniform	Uniform	3.4	Uniform	Uniform
31	5:15 A.M.	Dawn and Rain	0.0	Uniform	Uniform	4	4	4
31	7:45 A.M.	Rain	3.0	1	1	2.3	4	2.3
31	9:45 A.M.	Cloudy	5.0	1	1	2.3	4	1.2
13	12:30 A.M.	Full Moon	0.0	1.2	1.2	3.4	4	Uneven
13	4:00 A.M.	Full Moon	0.0	1.2	1.2	3.4	4	Uneven
13	6:30 A.M.	Sunrise	2.0	?	?	3.4	3.4	2.3

(B) Complete darkness.

Date		Time	Calanus	Pseudocalanus	Eurytemora	Acartia	Tortanus
Aug.	9	11:45 A.M.	Uniform	Uniform	2.3	Uniform	Uniform
"	9	2:45 P.M.	"	"	2.3	"	"
"	9	5:45 P.M.	"	"	?	"	"
"	9	8:45 P.M.	"	"	4	"	"
"	9	11:45 P.M.	"	"	3.4	"	"
"	10	2:45 A.M.	"	"	3.4	"	"
"	10	5:45 A.M.	"	"	3.4	"	"
"	10	8:45 A.M.	"	"	3.4	"	"
"	10	11:45 A.M.	"	"	3.4	"	"
"	30	1:30 P.M.	"	"	3.4	"	"
"	30	3:30 P.M.	"	"	3.4	"	"
"	30	5:30 P.M.	"	"	3.4	"	"
"	30	7:30 P.M.	"	"	3	"	"
"	30	9:30 P.M.	"	"	3	"	"
"	30	Midnight	"	"	3.4	"	"
"	31	2:30 A.M.	"	"	3.4	"	"
"	31	5:00 A.M.	"	"	3.4	"	"
"	31	7:30 A.M.	"	"	3.4	"	"
"	31	9:30 A.M.	"	"	3.4	"	"
Sept.	13	12.45 A.M.	"	"	3.4	"	"
"	13	4:15 A.M.	"	"	3.4	"	"
"	13	6:45	"	"	3.4	"	"

CHANGES IN THE VERTICAL DISTRIBUTION IN NATURE.

The vertical distribution was determined under different conditions of light. This was done by collecting samples at four different depths simultaneously (surface, 2 metres, 10 metres, and bottom), with identical nets (20 inch No. 5), and for the same length of time (10 minutes).

By a special arrangement, it was possible to collect the organisms only at the specific depths, no such arrangement being necessary for the surface tow. The 2 metre net was only closed while being raised, as it could quickly be lowered so as not to strain an appreciable amount of water on the way down. The arrangement used on the two deeper nets can be explained by the two following diagrams:

1. Lowering the net:

The net is shown descending in figure I. Two persons were used for lowering the net, one to keep the line (a) taut, and the other to pay out the line (b) freely. In this way the net descends vertically due to the weight (w).

2. Straining the water:

On reaching the desired depth a messenger is let down the line (b) releasing the attached mechanism. The net thus takes up the position shown in figure II, and the line (b) is drawn up to the boat. The boat moves slowly forward during this process. The net is now straining the water and the speed of the boat is increased to the set speed, as judged by the number of revolutions of the engine's fly-wheel.

3. Raising the net:

At the end of ten minutes a messenger is let down the line (a), causing the net to be closed and the whole arrangement withdrawn to the boat as shown in figure III.

The contents of the pint sealer (s) were immediately preserved in 5% formalin and carefully labelled.

While the nets were being towed the light intensity incident at the surface was measured by means of a solarimeter. This instrument is made by Kipp and Zonen, Delft, Holland. The light receiving unit is a Moll surface thermopile covered with a hemispherical quartz window. The current produced is measured by a microammeter. On a clear day this instrument will measure the intensity of sunlight from sunrise to sunset. After the tows were completed, the transparency of the water was measured by means of a Secchi Disk, and the temperatures at the surface, 10 metres, and bottom by a reversing thermometer. Water samples were also obtained at the same three depths and their salinities later determined by titrating with silver nitrate.

The contents of the pint sealers were treated in the laboratory 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. At least two counts were made, except when there was so little plankton present that the whole tow was counted without making use of the Stempel pipette. The results of the two counts were averaged. If the counts were within 10% of their average no further counts were made. Numerous specimens always showed close agreement. It was, however, often found necessary to make as many as five counts of the scarcer forms.

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-[2]"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 as not to be confused with other species but is not, however, fully developed. The six species of copepods investigated were the only free-swimming copepods usually encountered in this Bay, 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 (1) *Tortanus discaudatus* by M. W. Johnson - 1934. (2) *Pseudocalanus minutus* (or *Pseudocalanus elongatus* Boeck) by Oberg-1906. (3) *Calanus finmarchicus* by M. V. Lebour-1916. (4) *Temora Longicornis* by Oberg-1906. The above literature was made use of for the identification of the young copepods. Such identification was not difficult as no very young forms were present in the tows so that the young were sufficiently alike 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 lay on their sides thus exposing the fifth leg. A drop of a dilute aqueous solution of Methylene Blue added to the contents of the counting cell greatly facilitated the counting of the segments and the recognition of the shape of the fifth legs.

All the tows were made at the same Station, namely in the middle of Bocabec Bay, which is at the head of Passamaquoddy Bay, New Brunswick. This station was chosen due to the lack of currents which would complicate the results. Furthermore, the tows were taken at times when there was practically no wind. Salinity is usually quite uniform from top to bottom. Such conditions offered a good chance to study the effect of light on the vertical distribution of the copepods.

Observations on the vertical distribution of the free-swimming copepods were taken under the following conditions of light; (a) A 24-hour series covering bright sunlight, weak moonlight, starlight, and back to sunlight again. (b) Diffuse light as a result of rain clouds. (c) Full moonlight. (d) Half moonlight. (e) Extreme darkness at night as the result of a dense fog. (f) Sunrise. (g) Sunset.

The four depths sampled simultaneously were surface, 2 metres, 10 metres, and bottom. The depth of the bottom tow varied, of course, with the tide. This must be borne in mind when interpreting the results. Organisms were always found in the bottom tows and hence the depth can be readily seen from the diagrams at the end.

RESULTS AND DISCUSSION

The diagrams at the end of this paper show the changes in the vertical distribution of the five most common copepods, over a period of 24 hours.

Examination of the table showing the physical factors recorded shows light to be the only factor which markedly changed throughout the 24 hours. Salinity showed no appreciable change either from time to time or with depth. Temperature remained not only the same but constant at 10 metres and the bottom. Surface temperature showed a slight increase as day advanced, the difference only being 1.4°C., from the lowest at 6:25 A.M. to the highest at 5:40 P.M.: the difference between the surface and 10 metres averaged 5.78°C.

CALANUS FINMARCHICUS

All the Calanus obtained were immature of copepodite Stages IV and V. They were limited to the water extending from 10 metres to the bottom from 8:20 A.M. to 5:40 P.M., always with the maximum at the bottom. At night time they had extended upward to the surface, being found at all depths. There is a tendency for the maximum to move upward during the night. One-half hour after sunrise they had all moved back down to the deep water again, taking up much the same distribution as they had occupied during the previous day.

Their phototropic behaviour in nature is in line with experiments. They are strongly negatively phototropic to all intensities of light except the weaker. In all intensities of sunlight they were limited to the deeper water with their maximum at the bottom, while the weak intensity prevailing after sunset caused them to move up being positively phototropic to this weak light, and possibly also to weak moonlight. No evidence, however, explains why they keep moving up during starlight, as in the laboratory they showed no tendency to become either positively phototropic or negatively geotropic during starlight.

PSEUDOCALANUS MINUTUS

This form was never very abundant, the males and young being especially scarce. Their scarcity necessitates more general conclusions.

Males, females, and young all avoided the upper 2 metres during the bright light of the day. By nightime however, they had extended up to the surface, passing down to the depths again soon after sunrise. Laboratory experiments support these results in that their vertical distribution is dependent upon negative phototropism to the high intensity of sunlight, while being positively phototropic to the very weak light intensities such as prevails after sunset, and possibly to that of weak moonlight. There is evidence of a continued upward migration throughout the night. Its behaviour in nature as well as in the laboratory closely parallels that of Calanus described above. Scarcity of material prevents one from drawing any conclusions as to the difference in behaviour between males, females and young.

ACARTIA CLAUSI

This was easily the most abundant copepod of the region, always outnumbering the other species at any depth. Furthermore, its vertical distribution differs from that of all the other species studied in that it was always to be found at any depth at all times of the day and night. It, however, did show changes in vertical distribution from time to time.

The males showed a maximum, during the daytime, between 2 and 10 metres from 8:20 A.M. to 2:40 P.M., being very scarce at the surface. By 5:40 P.M., however, the number at the surface had considerably increased indicating the commencement of an upward migration which continued until midnight, when the maximum distribution was at the surface. By 3:20 A.M. the surface numbers had still further increased but the maximum had dropped down to 2 metres. Shortly after sunrise the maximum had dropped still further down and the vertical distribution had reached a similar state to that which occurred during the previous day from 8:20 A.M. to 2:40 P.M.

The females were always most abundant from 10 metres to the bottom during the daytime, never being present in very large numbers at the surface or at 2 metres. At 5;40 P.M. there was an increase in the numbers at the surface. During the night the numbers at the surface showed no large change, but at 8:55 P.M. there is a large increase in the numbers at 2 metres indicating that an extensive upward migration had taken place during the continually weakening light intensity between 5:40 P.M. and 8:55 P.M. When starlight conditions prevailed large numbers were forced right from the surface to the bottom with the maximum always below 10 metres. Soon after sunrise their distribution had returned to that shown the previous day during bright sunlight. Although no length measurements were made, it was a definite impression that females present at 0,2, and 10 metres at any time were larger than those existing at 10 metres. Both smaller and larger females were often found carrying eggs and hence probably mature. This impression suggests that the large females at the bottom never carried out an extensive migration, such as is carried out by the smaller females.

The young Acartia were always most abundant above 10 metres, being found in largest numbers in the upper 2 metres from 8:20 A.M. to 2:40 P.M.; with the figures suggesting that a still larger number would be found between 2 and 10 metres. At 5:40 P.M. the numbers in the upper 2 metres had tremendously increased, at which stratum the largest number was always found throughout the night, while they had decreased greatly in numbers soon after sunrise.

Experiments showed that this species is strongly positively phototropic to all intensities of daylight. No evidence of geotropism was found. Field observations bear out these conclusions but show remarkable differences in the degree in which they are carried out depending on whether they be males, females, or young. Furthermore a difference in behaviour among females is suggested. This difference apparently correlated with size. Males, females and young all showed a degree of positive phototropism, then came the males, and finally the females. The females, however, could be divided into two groups: the smaller, which showed a vertical migration, and the large, probably showed no migration. Hence, during sunlight, we can expect, on descending, the young nearest the surface, then largely males, followed mostly by females, and finally almost entirely by still larger females at the bottom. At 5:40 P.M. they had all considerably increased in numbers at the surface, it may be that they are all more positively phototropic to this decreased sunlight intensity - the fact that just after sunrise there is a decrease in numbers at the surface does not support this, however. Another explanation may be in the fact that Klugh (1929) found ultra violet light to be somewhat lethal to this form; it being a well known fact that this radiation is absorbed in the first 2 metres of sea water. When sunlight begins to weaken at 5:40 P.M. they all extend up towards the surface indicating them to be still more positively phototropic to the weaker intensities of sunlight. The number in the upper 2 metres fluctuates somewhat throughout the night. No reason for this can be seen. In the case of the males there appears to be a downward migration starting at midnight. On comparing the distribution of males, females, and young at 5:40 P.M. and 6:25 A.M., no reason can be given for the lack of individuals in the upper 2 metres after sunrise, as, on the basis of phototropism, they should be very abundant here. It is seen, however, that the numbers are very low both for all other depths and all other species. It may be that the tows were not effectively carried out at 6:25 A.M.

EURYTEMORA HERMANI

The males were all limited to the deeper water during sunlight, extending almost uniformly from 10 metres to the bottom. By night-time they showed an intensive concentration right at the surface, showing that the majority had undertaken an extensive migration from the deeper water right up to the surface, at which place they remained throughout the night. Just after sunrise they returned to the deeper water again occupying the same position as on the previous day.

The females were comparatively scarce. In general they behaved as did the males. Their scarcity, however, prevents any other conclusion.

The young were the most abundant of all. In general they behaved as did the males, with their maximum in the deeper water during sunlight and largely concentrating at the surface at night-time. There is, however, some evidence to show that they extended nearer to the surface during the day-time than did the males.

Laboratory experiments bear out their distribution in nature. During the day-time they are negatively phototropic to sunlight living in the deeper water. Due to their positive phototropism to weak light they extend up toward the surface as the day drew to a close, so that by 8:55 P.M. they had largely accumulated at the surface. Furthermore the experiments indicate why they remain in large numbers at the surface throughout the starlight night, in that they are negatively geotropic during starlight and darkness. Experiments on individuals taken near the surface show this negative geotropism

Furthermore, individuals from a depth of 18 to 20 metres showed no geotropism and it is possible that these are the froms which do not reach the surface during starlight.

TORTANUS DISCAUDATUS

This is the second most abundant copepod in this locality. The males were all limited to the lower depths during the day extending more or less uniformly from 10 metres to the bottom. By night-time they had carried out an extensive migration upwards, so that during the night large numbers were found in the upper layers. A considerable fluctuation occurred in the numbers at the surface during the night. Soon after sunrise they had passed back down into the deep water again, occupying a position similar to that of the previous day.

The females were comparatively scarce, behaving, however, as did the males, except that no appreciable fluctuation in the numbers at the surface occurred throughout the night.

The young extended nearer to the surface during the daytime than did the adults. By night they had extended up to the surface. Soon after sunrise they had descended again to the distribution occupied the previous day.

Laboratory experiments indicate Tortanus to be negatively phototropic and positively geotropic to light of high intensities hence explaining their abundance in deep water during the day. During weak light intensities they show a positive phototropism which is stronger than their geotropic force, and hence they ascend upwards as the day draws to a close (possibly also due to weak moonlight). Laboratory experiments indicate them to have no geotropic response during starlight and so we could expect little change throughout the night. This latter fact is not entirely followed throughout the night, due largely to the distribution at midnight, especially at 2 metres, although the other two night tows approximate each other; as all the species obtained in the 2 metre tow at midnight are quite scarce, it is possible that this tow was not effectively carried out. Soon after sunrise they had all descended to the lower depths, and as intensity of the sunlight at this time is low and the amount entering the water must be extremely small, if any at all, (Murray and Hjort - pp. 93-94) it must take a very small amount of light to evoke positive geotropism and negative phototropism. This effect is even more noticeable in the case of the male. Comparing males, females, and young, it is shown that the young are not as strongly repelled by strong light and attracted by weak light as are the adults, especially the male.

SUMMARY

A study was made of changes in the vertical distribution of the common free-swimming copepods of Passamaquoddy Bay, New Brunswick. The species studied were Calanus finmarchicus, Pseudocalanus minutus, Acartia clausi, Tortanus discaudatus, Eurytemora herdmani.

Conclusions from laboratory experiments are given on pages 5, 6, 7 and 8.

Observations on this vertical distribution in nature over a period of 24 hours with a clear sky show:

(1) Immature Calanus finmarchicus of copepodite stages IV and V, showed strong negative phototropism to all intensities of sunlight causing them to descend to the lower depths. They showed positive phototropism to weaker intensities of light extending up to the surface at night, this upward migration continuing throughout the starlight night.

(2) Pseudocalanus minutus proved to be comparatively scarce, preventing any differences to be observed between males, females and young. In general it showed negative phototropism to all intensities of sunlight, causing it to seek the lower depths while the sun was shining. It became positively phototropic to weak light, however, extending up to the surface at night. No evidence of a continued upward migration during the night, such as was observed for Calanus, was found however.

(3) Acartia clausi. Males, females and young all showed a degree of positive phototropism to sunlight. The young manifested the strongest positive phototropism, followed by the males and finally the females. The females, however, showed differences in that the smaller were to be found above the larger. As the sunlight decreases in intensity from that existing about the middle of the afternoon there is an extensive upward migration to the upper 2 metres, at which stratum the number of individuals fluctuated throughout the night. It is possible that the largest females remained in the deepest water and carried out no extensive migration at any time.

(4) Eurytemora herdmani. Males, females, and young all showed negative phototropism to all intensities of sunlight, being largely found in the deeper water during the day. Because of their positive phototropism to weaker light they had extended up to the surface by night-time, throughout which they remained largely concentrated at the surface as a result of negative geotropism in starlight. Females were quite scarce, but acted rather similar to the males. The young were not as strongly positively phototropic to sunlight as were the adults.

(5) Tortanus discaudatus. This species is to be found largely at the lower depths during sunlight extending upward when the light becomes very weak so as to be found in large numbers in the upper layers during the night. This distribution is correlated with positive geotropism and negative phototropism to strong light, while predominately positive phototropic to weak light, and showing no geotropism in starlight or darkness.

The males appear to be the most strongly repelled by strong light and attracted by weak light, the females less so, and the young still less.

(6) <u>Temora longicornis</u> was so rare that nothing definite can be concluded.