SECTION 1.—GENERAL SURVEY OF THE ANIMAL PLANKTON (ZOÖPLANKTON)

Few living zoologists have been as fortunately placed as were we on setting sail on the *Grampus* from Gloucester on our first oceanographic cruise in the Gulf of Maine on July 9, 1912, for a veritable *mare incognitum* lay before us, so far as its floating life was concerned, though the bottom fauna can be described as comparatively well known. Not but what an extensive list of pelagic crustaceans, cœlenterates, and other planktonic animals had been recorded thence, but everything was yet to be learned as to what groups or species would prove predominant in the pelagic fauna; their relative importance in the natural economy of the Gulf; their geographic and bathymetric variations; their seasonal successions, migrations, and annual fluctuations; their temperature affinities, whether arctic, boreal, or tropic; and whether they were oceanic or creatures of the coastal zone. We even had no idea (incredible though it may seem at this place and day) what we should probably catch when we first lowered our tow nets into deeper strata of Massachusetts Bay, for, so far as we could learn, tows had never previously been tried more than a few fathoms below its surface. Nor did we at first realize, when the catch was examined in our floating laboratory, that the little reddish copepods (Calanus) darting to and fro in the glass dish, with a few large Sagittæ (*S. elegans*) and young euphausiids among them, would prove the backbone of the local planktonic fauna. Such, however, has proved to be the case; for station after station, cruise after cruise, year after year, have yielded cumulative evidence that (taken by and large) the calanoid copepods are its predominant members at all seasons, except where deposed from the leading rôle by the local or temporary swarming of some other and usually larger animal. Our first summer's cruise was enough to show that *Calanus finmarchicus* (large among copepods but small if judged by more familiar standards) is the most important member of the plankton of the Gulf of Maine, if bulk and numbers both be taken into account, and that it plays much the same rôle there that it does in North European waters (Bigelow, 1914, p. 99).

Calanus, as "red feed" or "cayenne," is well known to the local fishermen, who are quite aware of its importance as food for fishes.[4] Side by side with Calanus we have everywhere found its relative, *Pseudocalanus elongatus* (p. 275); but even where the latter outnumbers the former, as sometimes happens, it adds but little to the bulk of the catch, so tiny is it. We have so constantly found the copepod *Metridia lucens* (p. 253), the chætognath, or "glassworm," *Sagitta elegans* (p. 308), the amphipod genus Euthemisto (p. 156), the euphausiid genera Thysanoessa (several species, p. 133) and Meganyctiphanes (p. 147), the pteropod *Limacina retroversa* (p. 116), the ctenophore *Pleurobrachia pileus* (p. 365), and (in deep water) the larger copepod Euchæta (p. 230), associated with Calanus, that all these together may be spoken of as the "Calanus community" (figs. 10 and 11), a community that dominates the animal plankton from the Grand Banks on the north to Cape Cod (in winter even to Chesapeake Bay) on the south, and from the coast line, on the one hand, out to the continental slope, on the other.

[4] See page 188 for a further account of this copepod.

Although copepods usually dominate, the other boreal animals just mentioned are so nearly universal in the Gulf in summer that the planktonic community is then surprisingly uniform qualitatively, with the list of prevalent species varying hardly at all from station to station over its inner parts, as is illustrated by the two following tables of catches made north of the Cape Cod-Cape Sable line during the summers of 1913 and 1914, seasons that may serve as representative because the plankton of the upper water layers was of the same general type during the summers of 1912, 1915, and 1916, as I have pointed out eleswhere (Bigelow, 1917 and 1922).

Occurrence of representative species in the Gulf of Maine, August, 1913

Species	Stations																			Per cent of stations for each species
	10086	10087	10088	10089	10090	10091	10092	10093	10095	10096	10097	10098	10099	10100	10101	10102	10103	10104	10105	
Calanus finmarchicus	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	100
Pseudocalanus elongatus	(?)	×	×	×	×	----	×	----	×	×	×	×	×	×	×	×	×	----	×	80
Metridia lucens	×	×	×	×	×	----	×	×	----	×	×	×	×	×	×	×	×	×	×	80
Anomalocera pattersoni	----	----	×	×	×	×	×	×	×	×	×	×	----	×	×	×	×	×	×	80
Euchæta norvegica	----	×	×	×	×	×	×	×	----	×	×	----	----	×	×	×	----	×	----	70
Meganyctiphanes norvegica	----	----	×	----	----	----	×	×	----	----	×	----	----	×	×	×	×	----	----	40
Thysanoessa inermis [1]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Euthemisto compressa	×	×	×	×	×	×	×	×	×	×	×	----	----	×	×	×	×	×	×	90
Euthemisto bispinosa	----	----	----	×	×	×	×	×	×	×	×	----	----	----	----	×	----	----	----	50
Hyperoche kroyeri	×	×	×	----	----	----	----	----	----	----	×	×	----	×	----	----	----	×	----	40
Limacina retroversa	×	×	×	----	×	×	×	×	×	×	×	----	×	×	×	×	×	×	----	80
Tomopteris catharina	----	×	×	×	----	×	----	×	×	×	×	----	×	×	×	----	×	----	----	60
Sagitta elegans	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	100
Phialidium languidum	----	----	×	×	×	×	----	----	×	×	×	×	×	×	×	×	×	----	×	80
Pleurobrachia pileus	×	×	----	×	----	----	----	----	×	×	×	×	×	×	----	----	×	----	----	50

[1] Data for *Th. inermis* are not available for 1913; it can, however, be assumed to occur in at least 80 per cent of the cases, since it was taken at 14 of our 18 midsummer stations in 1914.

Occurrence of representative species north of Georges and Browns Banks, July and August, 1914

Species	July							August									
	10213	10214	10225	10227	10228	10229	10230	10245	10246	10247	10248	10249	10250	10253	10254	10255	10256
Calanus finmarchicus	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Pseudocalanus elongatus	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Metridia lucens	×	----	×	×	×	×	×	×	×	×	×	×	×	×	----	×	×
Anomalocera pattersoni	----	----	----	----	----	----	----	×	×	×	----	----	×	----	×	----	----
Euchæta norvegica	×	×	×	----	----	----	----	×	×	×	×	×	----	----	×	----	×
Meganyctiphanes norvegica	×	×	×	----	×	----	----	----	×	----	×	×	----	×	×	----	×
Thysanoessa inermis	×	×	×	----	×	×	×	----	×	×	×	×	×	×	×	----	×
Thysanoessa longicaudata	----	----	×	×	×	×	----	----	×	----	×	×	×	×	×	×	×
Euthemisto compressa	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Euthemisto bispinosa	----	×	×	×	×	×	×	×	×	×	----	×	×	----	----	×	×
Limacina retroversa	×	----	×	----	----	×	×	×	×	×	×	×	×	----	----	×	----
Tomopteris catharina	×	×	×	----	----	----	----	×	×	×	×	×	×	----	----	×	----
Sagitta elegans	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Sagitta serratodentata	----	----	×	×	×	×	×	×	×	×	×	×	×	----	×	----	----

Notwithstanding the qualitative uniformity of the animal plankton of the waters of the Gulf of Maine in summer, the actual aspect of the catches of the tow nets often differs markedly from station to station, according to the relative abundance of their several components and especially of the copepods. As a rule these (chiefly Calanus, Pseudocalanus, and Metridia, with Euchæta in the deepest layers of

water) are the dominant factor, and it occasionally happens that they practically monopolize the water locally. Such, for instance, was the case in the Eastern Basin on August 13, 1914 (station 10249), when the net from 50 meters captured only 3 or 4 Sagittæ, 2 pteropods (Limacina), 3 or 4 larval rosefish (Sebastes), a few small medusæ (Phialidium), 51 euphausiid shrimps, and an odd Euchæta, among millions of Calanus (3 to 4 liters, by measure; no other copepods were detected in sample examined by Doctor Esterly). Near Mount Desert Rock, too, on the same day (station 10248), a cursory examination of about 3 quarts of copepods, among which Calanus, Metridia, and Euchæta were represented in the proportion of about 30, 5, and 2, revealed only a few Pseudocalanus, 21 *Thysanoessa longicaudata*, odd amphipods (Euthemisto), 24 Meganyctiphanes, 7 *Thysanœssa inermis*, 6 or 8 pteropods (Limacina), 1 worm (Tomopteris), a few Sagittæ, 1 Pleurobrachia, and fragments of the ctenophore Beroë.

Similarly, the only other animals detected in a preliminary examination of the 2 to 3 quarts of copepods [5] captured in the 60–0 meter haul on the eastern part of Georges Bank, on July 23 of that same year (station 10224), were 89 euphausiid shrimps (*Thysanœssa inermis*), a few amphipods (Euthemisto), half a dozen young fish, and one caprellid, the latter being an accidental straggler from the bottom.

The most notable shoal of Calanus we have encountered was off Cape Cod on July 22, 1916 (station 10344), where a 15-minute haul with a net 1 meter in diameter captured 6 quarts at 40–0 meters, together with many thousands of silver-hake larvæ (Merluccius), but nothing else except a few small *Sagitta elegans*, an odd pteropod (Limacina), and an occasional larval crab and euphausiid, though the deeper waters, as exemplified by a haul at 90–0 meters, supported comparatively few copepods but many Sagittæ. We have found Calanus (with its relatives, Pseudocalanus and Metridia) hardly less dominant at enough other localities [6] to prove that it is a common event for these copepods to monopolize the plankton of any part of the Gulf in summer. As a rule, however, the animal plankton is more diversified at all levels by the hyperiid amphipods, euphausiids of several species, pteropods (Limacina), Sagittæ, etc., mentioned above, even though copepods may dominate the planktonic community as a whole (figs. 10, 11, and 12). Some of these other groups may be a major element in the plankton locally. For instance, the chætognaths (*Sagitta elegans*) often rival the copepods in bulk (if not in actual numbers) at the mouth of Massachusetts Bay and in the Isles of Shoals regions; indeed, our second towing station, 12 miles or so off Cape Ann (10002), yielded a swarm of these arrow worms on July 10, 1912 (Bigelow, 1914, p. 100), and we have encountered similar swarms of Sagittæ at other localities since then (fig. 13).

An abundance of the large pelagic shrimps Meganyctiphanes (fig. 14) and Thysanœssa is regularly characteristic of the deep northeastern corner of the Gulf throughout the year and of the Eastport–St. Andrews region in summer (p. 134), while various larval forms (crustaceans, especially) are extremely numerous locally near shore in their appropriate seasons, as noted elsewhere (p. 31). As other instances of the swarming of one characteristic boreal animal or another we may add that the

[5] Sample examined by Doctor Esterly was nearly pure *Calanus finmarchicus*.

[6] Notably off Gloucester on Aug. 9, 1913 (station 10087); in the Western Basin on July 15, 1912 (station 10007); near Platts Bank on Aug. 10, 1913 (station 10089); off the slope of German Bank on Aug, 12, 1913 (station 10095); northeast of Mount Desert Rock on Aug. 13, 1913 (station 10100); and off Cape Elizabeth on Aug. 15, 1913 (station 10104).

surface waters were alive "with young amphipods (Euthemisto) as well as with young stages of *Calanus finmarchicus*, in the proportion of about one of the former to four of the latter" (fig. 15), off Penobscot Bay and off Mount Desert Island on August 11, 1913 (Bigelow, 1915, p. 274, stations 10091 and 10092); that older Euthemisto (fig. 16) were plentiful (though not rivaling the copepods) off Cape Ann and in the western basin on August 31, 1915 (stations 10306 and 10307), and at several stations along the outer edge of the offshore banks (p. 156); that the pteropod *Limacina retroversa* (fig. 17), which, as a rule, is but sparsely represented in our tow nettings, swarmed off Penobscot Bay on August 11 and 14, 1913 (stations 10091 and 10101); that fragments of a siphonophore (Stephanomia) formed fully half the catch of the 40-meter haul off Cape Cod on July 8 of that same year (station 10058); and that the ctenophore *Pleurobrachia pileus* often fills the water to the exclusion of almost everything else in the neighborhood of German Bank (fig. 18).

In summer and early autumn the large medusæ Cyanea, Aurelia, and Staurophora often gather in vast numbers in narrow lanes or windrows, though usually for brief periods (p. 362), and at this same season the hydroid medusa *Phialidium languidum* is often so abundant on the surface that it fills the tow net to the brim (p. 350). Young fish, too, sometimes occur in numbers sufficient to loom large in the total catch, notable instances of which have been the swarming of young silver hake off Cape Cod, mentioned above (p. 18); likewise of young rosefish (Sebastes) near Cape Elizabeth on July 19, 1912 (station 10019), when several hundreds were taken (Bigelow, 1914, p. 101), off Massachusetts Bay on August 9, 1913 (station 10087), and near Cashes Ledge, September 1, 1915 (station 10308). Occasionally we have encountered notable quantities of fish eggs, particularly of squirrel hake (*Urophycis chuss*), in Ipswich Bay, July 16, 1912 (station 10008); of silver hake (Merluccius) near Monhegan Island and off Mount Desert, on August 4 and 18, 1915 (stations 10303 and 10305); of cunners (Tautogolabrus) at many localities along shore in summer, especially in Massachusetts Bay[7] (station 10340–10343); and of haddock over their spawning grounds on Georges Bank during the early spring (fig. 19).

In summer, generally speaking, copepods are relatively most abundant in the western side of the gulf, less so in the eastern, the result being that, in spite of the qualitative uniformity of the tow nettings from station to station, their general aspect is usually most monotonous off the coasts of Massachusetts and southern Maine and out thence to the western basin, and most diversified in the central parts of the gulf and in its deep eastern trough. The only notable exception to the midsummer dominance of calanoids anywhere in the open gulf north of its offshore banks (local swarmings of other animals, such as those just mentioned, seldom rival the copepods in actual abundance, whether measured by bulk or by numbers) is the Pleurobrachia swarm of the German Bank region, which I have already described in the several preliminary reports on our cruises (Bigelow, 1914, 1915, and 1917). Since we have found this ctenophore in abundance at that same general locality during the successive Augusts of 1912, 1913, and 1914, and again on September 2, 1915, this is evidently a regular phenomenon of summer. Having occasion to recur to it in a later chapter (p. 365), I need add here only that Pleurobrachia, large and small,

[7] The ledges off Cohasset are a very productive nursery for this fish, judging from the quantities of its eggs that are to be found there.

were so abundant on these occasions that every haul yielded quarts of them, and that they fish through the water so thoroughly with their trailing tentacles that a great scarcity of all smaller pelagic animals regularly characterizes this part of the gulf in summer. In fact, a more striking contrast would be far to seek than between the masses of these glassy sea marbles, which have filled our nets there, and the abundant crustacean plankton of the deeper basin a few miles to the westward.

Although spring, not midsummer, is the chief season of reproduction in the Gulf of Maine (p. 41), certain of the planktonic groups of animals breed in sufficient numbers there in July or August for their larvæ to loom large in the summer plankton. This is true of the euphausiids, for we have found their larval stages common in Provincetown Harbor on July 20, 1916 (station 10343); on the surface off northern Cape Cod, August 28, 1914, in company with large Calanus (station 10264; Bigelow, 1917, p. 283). Young euphausiids were also abundantly represented in the horizontal haul at 40–0 meters on August 31, 1915 (station 10306), but so closely restricted to the upper stratum that a haul from 110–0 meters brought back very few among a half liter or so of calanoid copepods. Euthemisto is likewise produced in great numbers well within the gulf in August—witness rich hauls of the newly-hatched larvæ off Penobscot Bay on August 11, 1913 (station 10092), and in the western basin two summers later (p. 160). Copepods, too, breed throughout the summer, as noted below (p. 46), and in sufficient numbers for their young stages to characterize the plankton locally. Most of the medusæ spawn during the late summer or early autumn (pp. 358, 364). We may also point out, what is discussed at some length below, that larvæ of coastwise origin and of the most diverse natures are likewise produced during the warm season, though few of them color the aspect of the plankton more than a few miles out from the land (p. 32).

In a later section the seasonal plankton cycle is discussed in some detail (p. 37); however, it may clarify the account to note here that very little change takes place in the general composition of the Calanus community during the period (July to August) covered by our midsummer cruises, except for the disappearance of the earlier and the appearance of the later maturing species of medusæ (p. 46). For example, the only notable change during the interval between hauls made at the same location off Cape Cod on July 8 (station 10057) and again on August 5 (station 10086) in 1913 was that Staurophora, Stephanomia, and Beroë, which were prominent in the tow on the first occasion, were no longer to be found on the second, the lists being practically identical otherwise.[8] Three years later we found Calanus and its companion copepods as overwhelmingly predominant in the upper 40 meters or so off Cape Cod on August 29 (station 10398), among such boreal animals as Pleurobrachia, Aglantha, *Sagitta elegans*, *Euthemisto compressa*, and larval euphausiids, as we had five weeks previous (station 10344, July 22) in the corresponding stratum of water a few miles to the south. One very notable event does take place during the summer, however; that is, the entrance of *Sagitta serratodentata* into the gulf and its westward dispersal there, which are described in a later chapter (p. 322).

The foregoing remarks have reference chiefly to the inner waters of the gulf—that is, north of the offshore banks that form its southern rim—but the same elements unite to form the general planktonic assemblage over all but the outermost

[8] A typical Calanus community with *Sagitta elegans*, Euthemisto, a few euphausiids, and Limacina.

slope of the latter. Thus, a typical Calanus community, with Clione, Limacina, and the other boreal forms characteristic of the inner parts of the Gulf, occupied the waters over Nantucket Shoals on July 14, 1908 (Bigelow, 1909, p. 201), and at the same time of year in 1913, when we found no decided change in the boreal character of the plankton (Calanus predominating) until we had sailed westward nearly to New York (Bigelow, 1915, p. 269). During the summer of 1914 we again found Calanus, with its usual companions, predominant over the greater part of Georges Bank in July, and across the mid-zone of the continental shelf abreast of Marthas Vineyard in August; also in August, 1915; and from Cape Cod out to the continental slope in July, 1916. But although Calanus is as universal over the offshore banks as within the gulf, it does not dominate the plankton so constantly there. Thus we found *Sagitta elegans* as important, faunally, as were the copepods over the central part of Georges Bank during our summer cruise of 1914, and swarming both over the northeast corner of the bank on July 23 (station 10224 [9]) and in the Northern Channel on July 25 (station 10229), practically to the exclusion of everything else, except for an abundance of adult Euthemisto, which (we may suppose) are sufficiently large and active to protect themselves from the glassworms, voracious though the latter are (p. 107).

Even when copepods, as a group, are the chief factor in the summer plankton over Georges Bank, it is sometimes the little brown *Temora longicornis* (fig. 20), not Calanus, that is the dominant species there. This was the case at a station on the northwestern part of the bank in July, 1913 (station 10059), while the frequency with which Kendall, in his field notes for August, 1896, describes "small brown copepods" (which could only be Temora) as abundant, side by side with "red feed" (Calanus) and "green copepods" (Anomalocera), or even as constituting the bulk of the surface tow, suggests that such dominance on its part is a common event on the northern part of the bank (lat. 41° 45′ to 42°, long. 66° 30′ to 68° 30′). His records suggest that Temora increases in number there with the advance of the summer,[10] which parallels its seasonal history in the Massachusetts Bay region (p. 289).

Hyperiid amphipods (two species of the genus Euthemisto, p. 156) have often been reported as plentiful over the outer part of the continental shelf off Marthas Vineyard. We found them in abundance over the corresponding zone off Nantucket Shoals and over the western end of Georges Bank, side by side with the copepods, in July of 1913 and 1916 and August of 1913 and 1914. They are equally characteristic of the outer parts of the banks eastward across the mouth of the Gulf of Maine and off the Nova Scotian coast, where they breed in abundance (p. 160) and grow larger than within the gulf to the north.

The outer part of the continental shelf is the offshore limit to the occurrence of copepods in abundance abreast of the Gulf of Maine; but the pelagic amphipod genus just mentioned is perhaps most plentiful along the upper part of the continental slope, where it mingles with the oceanic planktonic community of the warmer waters of the Atlantic basin. It has likewise been our experience (though fresh observations may give cause to alter conclusions drawn from a single summer's cruise) that in mid-

[9] The catch of one-half hour's haul of the Helgoland net at 40–0 meters was about 5 liters of *Sagitta elegans*, and very little else except a few Calanus, Temora, Pseudocalanus, 3 or 4 Euthemisto, 2 Limacina, young crabs and other decapods, and some floating hydroid fragments described below (p. 380).

[10] Kendall's tows were taken during the last week in August.

summer Euthemisto is to be expected in abundance over Browns Bank, largely replacing the copepods there, for on July 24, 1914 (station 10228), the surface waters were alive with them, while on June 24, 1915 (station 10296), the tows on the bank yielded large numbers of these amphipods among the still more abundant Calanus (more abundant in bulk as well as in numbers). Euthemisto is also an important factor in the plankton close in to the land off Cape Sable, where they increased in relative abundance in 1914 from July 25 (station 10230), when they were overshadowed by Calanus, until August 11 (station 10243), when they were dominant in the plankton. A seasonal change of the same sort took place in the shoal coastal waters off Shelburne, Nova Scotia, during the summer of 1915; for Euthemisto dominated a very scanty plankton there on September 6 (station 10313), where it had been outbulked both by copepods and by Sagittæ on June 23 (station 10291), though dominating the plankton farther out over the shelf on that day (10293).

Although euphausiid shrimps of one species or another (p. 133) are practically universal within the gulf—may, indeed, be constantly plentiful locally, as off the Eastport-Grand Manan region, and temporarily so elsewhere (p. 133)—we have never found them dominating the water of the gulf at any level except over Browns Bank, where the tow net working at 60 meters depth yielded a quart or more of these pelagic shrimps [11] on July 24, 1914 (station 10228), diversified only by an occasional Sagitta, three *Beroë cucumis*, a few copepods, and no amphipods at all, notwithstanding the abundance of the latter at the surface at this same station. Though not strictly within the limits of the gulf, I may add that four days later euphausiids occurred in great numbers over the slope abreast of Cape Sable [12] (station 10233), and in this same general region on March 19, 1920 (station 20076, fig. 21). It is not safe to assume, however, that these shrimps are constantly abundant over Browns Bank in summer, for we found none at all there on our only other visit during the warm half of the year (June 24, 1915, station 10296), but in their stead made a very rich haul of calanoids (3 to 4 liters bulk), with a few Euchæta, many large Euthemisto, small Sagittæ, and occasional tropical organisms, such as Phronima and *Salpa zonaria*.

To close this brief survey of the chief planktonic communities of midsummer, I must remark that a sprinkling of Gulf Stream animals—sometimes, indeed, a typically tropical plankton—is to be expected all along the upper part of the continental slope at that season, corresponding to the high temperature of the Gulf Stream, the inner edge of which lies but a few miles farther offshore. This tropical plankton and such members of the general bathypelagic community of the Atlantic basin as approach the slope are the subject of a later section (p. 53).

The accompanying photographs (figs. 10 to 21), illustrate certain of the more characteristic communities as they occur in nature, and the distribution of the more characteristic communities, for July-August, 1914, is outlined on the chart (fig. 22).

The great majority of the species of pelagic animals that unite to form the bulk of the zooplankton of the gulf are endemic in origin, breeding sufficiently regularly and abundantly within its limits to maintain the local stock by local production. This generalization, which the reader will find discussed in more detail under the accounts of several of the species concerned, applies to most of the com-

[11] Chiefly *Meganyctiphanes norvegica*, *Thysanœssa inermis*, *Th. longicaudata*, with fewer *Th. gregaria* and *Nematoscelis megalops*.
[12] Chiefly Euphausia and Nematoscelis and fewer *Th. longicaudata* at 100 meters; Nematoscelis at 400 meters.

mon copepods, notably to *Calanus finmarchicus*, *Pseudocalanus elongatus*, *Metridia lucens*, Euchæta, and to sundry others (see the chapter on copepods, p. 167); likewise to *Sagitta elegans* (p. 308), both the local species of Euthemisto (*E. compressa*

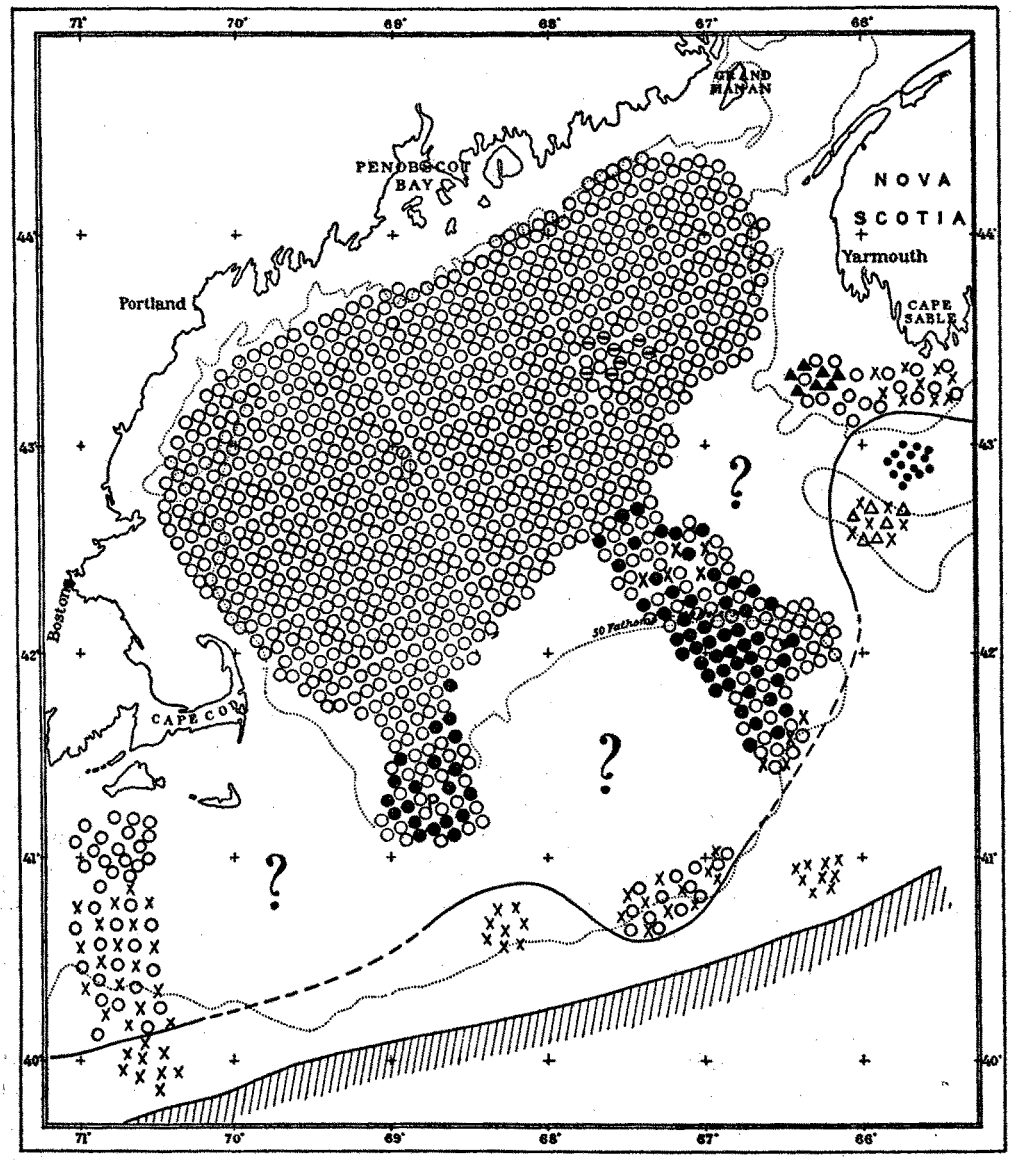

FIG. 22.—Distribution of the more characteristic types of animal plankton in the offshore waters of the Gulf of Maine, July and August, 1914. ○, calanoid copepods dominant; ●, glass worms (Sagittæ) dominant; X, amphipods (Euthemisto) dominant; △, euphausiid shrimps dominant; ▲, ctenophores (Pleurobrachia) dominant; ⊖, hydromedusæ (Phialidium) dominant; P, swarm of pteropods (*Limacina retroversa*)

and *E. bispinosa*, p. 156), the euphausiid shrimps Meganyctiphanes and probably *Thysanæssa inermis* (p. 139), and the pteropod *Limacina retroversa* (p. 124), to mention only a few. It also applies to a whole category of animals of coastwise nativity

It does not follow from this, however, that all parts of the gulf are equally favorable as marine nurseries. On the contrary, few if any animals breed indifferently or equally plentifully over its whole area, and different parts of the gulf may run the whole gamut from extreme productivity to almost complete sterility for one species or another. Our work has not progressed far enough to give more than a glimpse of such local differences; enough, however, has been done to show that the southwestern corner of the gulf generally, and the Massachusetts Bay region in particular, stand at one extreme, with innumerable copepods and a great abundance of pelagic fish eggs produced there (not to mention other planktonic animals), while certain small areas in the Bay of Fundy exemplify the other, where few if any animals with floating eggs breed successfully. Broadly speaking, our hauls have demonstrated that the coastal belt, out to the 100 or 150 meter contour, is more prolific than the deep trough in the production of planktonic animals.

VERTICAL DISTRIBUTION OF THE ZOÖPLANKTON

In the foregoing lines the various planktonic communities are treated as though their several component groups or species were indifferently distributed from the surface downward, independent of depth; the various lists, that is, are such as would be yielded by vertical hauls from surface to bottom at the respective stations. Such is by no means a true picture, however, for it often happens that, although the species from any given locality occur side by side geographically, they may be far apart bathymetrically, and especially so in the deeper parts of the gulf. Nor is it astonishing, with a pelagic fauna as varied as that of the Gulf of Maine, and with its sundry members responding variously in their vertical occurrence to the physical conditions under which they live, that we have usually found the plankton of midsummer more or less stratified even in the upper 100 meters or so, either by the concentration of one group of animals at one level, another group at another, or by a comparatively barren state of the immediate surface contrasted with great productivity in the underlying strata of water. The stratification between depths less than 100 meters, on the one hand, and the bottom waters of the gulf, on the other, is still more significant, being one of kind as well as of degree, as I shall endeavor to make clear later (p. 26). Indeed, it would not be too much to say that the local zooplankton is never quite uniform from the surface downward to any considerable depth, unless it be in very shallow water or in localities where vertical circulation keeps the whole column effectively stirred from top to bottom.

With so many subjects involved, stratification, whether quantitative or qualitative, may occur in infinite variety, and many instances of the sort have forced themselves on our notice, though our hauls have not been particularly directed toward the detection of such. Perhaps the most interesting phase of the subject, as it is certainly the most widespread, is the scarcity of adult pelagic animals of the Calanus community, including most of the species which together make up the preceding plankton lists (p. 17), at the surface during the daylight hours of summer. No matter what nets we have used on the surface between sunrise and sunset in the offshore waters of the gulf at this season, they have usually yielded very little zoöplankton of any kind, and often practically nothing except larval

forms and the smallest Crustacea and phytoplankton. In fact, had we relied on surface hauls by daylight alone, we would hardly have suspected the existence of the abundant and varied planktonic fauna which peoples its deeper water layers. True, we have occasionally made rich catches of Calanus, with its companion animals, right on the surface in the middle of the day, as, for example, near Gloucester on July 22, 1912 (station 10012), near Lurcher Shoal on August 12, and off Penobscot Bay and Cape Elizabeth on August 14, 1914 (stations 10245, 10250, and 10251), and near Seguin Island on August 4, 1915 (station 10303) [13]; while the extraordinary abundance of Calanus that characterized the 40–100 meter stratum in the western side of the gulf during late July, 1916 (p. 18), was reflected in the presence of considerable numbers of these little crustaceans on the surface at the time, by day as well as by night. However, such occurrences have been exceptional. Huntsman, similarly, has characterized "the presence of Calanus en masse at the surface between 3 and 4 p. m., under a bright sun," in the Bay of Fundy in September as an unusual event (Willey, 1919, p. 181). On the other hand, surface tows made in the gulf during the hours of darkness, especially if near midnight, have usually yielded an abundance of the calanoid copepods (even including the deep-water genus Euchæta). And the geographic locations of the stations where we have made rich surface catches by night point to a general diurnal migration of the Calanus community—upward after dark, downward about daylight—in the inner parts of the Gulf of Maine in summer, such as Esterly (1911 and 1912) and Michael (1911) describe for the San Diego region,[14] and with all the major planktonic groups sharing in it more or less, though perhaps none so regularly as the copepods. The data bearing on this point are not extensive, no particular attention having been paid to it in arranging the stations. We have occasionally found the surface practically barren some hours after sunset and before the first sign of sunrise, even at localities where the deeper waters supported a rich and varied plankton, as was the case in the western basin on August 9, 1913 (station 10088), and again on the 22d of that month a year later (station 10254).

Of course, there is nothing novel in a vertical migration of this kind, similar phenomena having long been known and widely heralded in other seas; nor is it necessary to seek far afield to find a parallel in New England waters, for Peck (1896) long ago described the copepods as deserting the surface of Buzzards Bay almost completely during the daytime, to reappear there after dusk.

It is unfortunate that our hauls have not been arranged to show at what precise time after sunset the copepods rise to the surface in largest number or how soon after midnight they sink again, a question of great interest from the physiological standpoint (p. 204). Few data have been gathered as to the actual vertical range through which this migration takes place in the Gulf of Maine; that is, how far up and down any individual animal may swim, or how universally or regularly the members of any group of animals indulge in it. It must be very widespread occasionally, at least among the copepods, for at times we have towed them in great numbers right

[13] In an earlier report (Bigelow, 1914a) it was stated by error that a large haul of Calanus was obtained on the surface by day at station 10027; actually this station was occupied at about midnight.

[14] Data on the euphausiids, amphipods, pteropods, etc., will be found summarized in the accounts of these several groups.

on top of the water after dark, notably near Mount Desert Rock on August 16, 1912 (station 10032), where the 4-foot net, towed for half an hour, yielded nearly 3 liters of plankton, chiefly copepods, with *Calanus finmarchicus* dominating, besides Euchæta, *Centropages typicus*, Metridia, Anomalocera, and Pseudocalanus; also the shrimps Meganyctiphanes, *Thysanœssa inermis*, *Th. longicaudata*, *Th. gregaria*, and Nematoscelis; the pteropods Limacina and Clione; Euthemisto of both species; the two common chætognaths *Sagitta elegans* and *S. serratodentata;* Tomopteris; Stephanomia; and larval redfish in lesser number; in short, a typical Calanus community. A second instance of this sort came to our notice off southern Cape Cod on July 22, 1916 (station 10346), when the surface net yielded about as much Calanus (nearly a liter), with a sprinkling of Pseudocalanus and Metridia, an odd Euthemisto, *Sagitta elegans*, and Clione, as did the 30-meter net, although the mouth area of the latter was four times the greater, and it was towed for an equal period. As a rule, however, this vertical migration does not bring nearly so large a proportion of the zoöplankton to the top of the water at any time during the night, for our catches have almost always been far richer (more varied, as well) at some little depth than immediately on the surface. This is illustrated by a station off Cape Cod on August 23, 1914 (station 10256), where the catch of Calanus, Euchæta, Meganyctiphanes, Euthemisto, *S. elegans*, and Stephanomia was several times larger in the 130–0 meter haul than in the surface haul, even after allowing for the use of nets of different diameters.

Whatever the precise physiological stimulus may be which causes so many of the copepods and other pelagic animals to rise at sunset and to sink again soon after midnight—and this is still an open question (p. 204)—its results are certainly confined to a far shoaler stratum in the Gulf of Maine, where it is never necessary to lower the net deeper than 40–100 meters to find the Calanus community at full strength at any time of day, than in the San Diego region off southern California, where Calanus in particular congregates as deep as 200 fathoms by day, to swim upward nearly or quite to the surface in the darkening hours (Esterly, 1911). Nor is it probable that the daily vertical migration in the Gulf of Maine often covers more than 100 fathoms even for Euchæta, which sinks considerably deeper in the daytime than does Calanus but less often reaches the surface at night. Until more extensive data are available it is idle to do more than touch on this interesting question.

Apart from these vertical diurnal migrations our hauls have afforded glimpses of vertical stratifications of three other sorts (sometimes all three of them are exemplified at a given station): (1) As between young and adult communities as a whole; (2) between the adults of the several groups, genera, or species, even within the rather narrow depth limits (say, 10 to 100 meters) where the Calanus community as a whole attains its most abundant development; and (3) between the planktonic communities of the upper 100 meters or so, on the one hand, and of the deepest water of the gulf, on the other. Perhaps as illustrative a case as any that has come under our notice, and one typical of the western side of the gulf as a whole in early summer, is afforded by a station off Cape Cod on July 8, 1913 (station 10057), where it was the surface hauls alone that yielded any considerable number of copepod nauplii and eggs; the haul at 15–0 fathoms (27–0 meters) caught swarms of Calanus and many

euphausiids and hyperiids, but only a few Sagittæ; the haul from 60-odd meters contained almost no euphausiids, hyperiids, or pteropods, but yielded large numbers of Sagittæ, and Euchæta was taken in it alone. Thus, the Calanus, euphausiids, and pteropods were mostly above 30–50 meters, the Euchæta and Sagittæ below that depth, with Beroë, Pleurobrachia, and Stephanomia more evenly distributed (Bigelow, 1915, p. 267).

A similar bathymetric segregation as between the copepods and the large adult Sagittæ prevailed in Massachusetts Bay on July 19, 1916 (station 10341; figs. 12 and 13), when the haul at 30 meters yielded a practically pure Calanus plankton with many larval fishes and some young euphausiids but very few Sagittæ, whereas the net working at 80 meters captured a swarm of large *S. elegans* but not nearly so many Calanus as the shoaler haul. This condition must have been general over a considerable area at the time, for we had much the same experience two days later off Cape Cod (station 10344), where Calanus and young silver hake were extraordinarily abundant at 40 meters (the largest catch of young fishes we have ever made—Bigelow and Welsh, 1925, p. 394), but evidently concentrated in a narrow depth zone centering at about that level, for both were practically absent on the surface, on the one hand, and very much less numerous in the 90-0 meter catch, on the other, whereas Sagittæ, equally absent from the surface, were scarce in the 40-meter hauls but abundant in the catch from 90 meters.

A depth relationship of the same sort (between copepods and euphausiids) obtained on August 9, 1913, off Cape Ann (station 10087), where the 30-0 meter haul brought back a rich gathering of the former (chiefly Calanus, with many Pseudocalanus) and many larval rosefish, but only an occasional euphausiid, whereas we captured a considerable number of the latter (small Thysanœssa) at 80–0 meters, but only a fraction as many copepods as at 30 meters, and an occasional Sebastes. On the other hand, lest the reader conclude that the Sagittæ and the euphausiids invariably congregate below the densest shoals of copepods when stratification occurs between these groups, I may point out that we found the 40-0 meter haul on the northwest slope of Georges Bank, July 20, 1914 (station 10215), practically monopolized by *S. elegans* and *Limacina retroversa*, with very few copepods, whereas a rather rich haul from 70–0 meters brought in about as great a bulk of copepods (about equal numbers of Calanus and Pseudocalanus) as Sagittæ, but no Limacina at all. Similarly, there were about six times as many Calanus and Pseudocalanus at 110–0 meters as at 40–0 meters off Cape Ann on August 31, 1915 (station 10306), with just the reverse holding in these same hauls for Euthemisto and for young euphausiids. The latter, indeed, were almost wholly confined to the shoaler level, where they about equaled the copepods in bulk if not in numbers. The copepod plankton of the western basin must also have been much denser below than above 100 meters on May 5, 1915 (station 10267), when the vertical haul from 250–0 meters yielded great numbers, whereas the catch of the horizontal net working at 85 meters and up to the surface was scanty (total catch less than ¼ liter).

As still another instance of vertical stratification in summer, I may mention our station of August 12, 1914, on German Bank (10244), where the surface water contained an abundance of small Euthemisto but only a few Calanus (besides the Pleuro-

brachia so common there, p. 19), whereas the haul from 40 meters yielded copepods chiefly, with only occasional Euthemisto.

No doubt a more intensive examination of the zoöplankton of the Gulf of Maine will multiply such instances indefinitely, but enough have been mentioned to show that a definite vertical segregation may occur at certain times and places between animals having the same faunal status. On other occasions the contents of hauls at different depth levels, between, say, 10 and 100 meters, are often almost precisely alike, as was the case near Lurcher Shoal on August 15, 1912 (station 10031), when copepods, euphausiids, Sagittæ, Staurophora, Euthemisto, and even Salpæ (p. 56) occurred in proportions so similar in hauls from 50–0 and from 100–0 meters that it would have been difficult to distinguish samples of the one catch from the other had it not been for the presence of the large copepod Euchæta in the deeper one. Many other instances of this same sort might be mentioned also.

Our experience has been that young and larval forms of all sorts, from fish eggs to copepod nauplii, are usually most plentiful at or very near the surface. For example, in May, 1920, which is the season of their greatest abundance, nauplii were far more abundant in the surface catch and in closing-net hauls from 10–15 meters in Massachusetts Bay (stations 20120, 20121, and 20124) and off the Merrimac River (station 20122) than in the deeper catches. It is safe to say that the great majority of the copepods breeding in the Gulf of Maine pass through their early stages in the upper 40 meters of water. Similarly, the nauplius and cyprid larvæ of the common barnacle, so prominent in the plankton for a brief period in spring (p. 43), are usually condensed at and near the surface, rarely at some lower level (station 20105, figs. 23 and 24). Larval and even half-grown euphausiids are also far more plentiful above than below 50 meters; and this is even more true of larval amphipods (Euthemisto), which live close to the surface at first (p. 163), to sink to deeper levels with advancing age; likewise of young *S. elegans*, as described elsewhere (p. 316). Since most of the fish produced in the gulf live in this same zone during their first weeks, it may, not inaptly, be named the nursery of the gulf.

Certain conspicuous adult animals are also as typically characteristic of the surface of the gulf as are the innumerable larval forms. Such, for instance, is the large blue copepod Anomalocera which may often be seen darting to and fro in the sunlight immediately in the surface film and which seldom sinks more than a few fathoms. The small brown copepod *Temora longicornis* likewise occurs in greatest numbers near the surface; for instance, a surface tow near Nantucket Lightship, on July 9, 1913 (station 10060), "yielded thousands, while the haul from 20 fathoms caught only 25 specimens, and it was not taken at all in hauls from depths greater than 23 fathoms" during that summer (Bigelow, 1915, p. 294). Much the same rule holds for the little copepod *Centropages typicus*, of which "the surface haul at station 10088 yielded ten times as many specimens as the haul from 80 fathoms, though made with a net of only one-sixth the mouth area" (Bigelow, 1915, p. 293), and which we twice found common at the surface during August, 1914, but not at all in the catches at 25 meters and deeper (Bigelow, 1917, p. 291). It is our surface hauls, too, that most often yield Evadne and appendicularians; indeed, we question whether the latter ever sinks to any great depth in the Gulf of Maine. One of the

most striking instances of vertically stratified plankton we have ever encountered resulted from a swarming of large appendicularians (fig. 25) on the surface and down perhaps to 40 or 50 meters over the southern edge of Georges Bank on May 17, 1920 (station 20129), overlying a moderately abundant Calanus and young euphausiid community in the deeper strata down to about 100 meters (fig. 26).

Various medusæ, among them the largest (Aurelia and Cyanea), likewise seek the surface even in bright sunlight, while smaller species, notably the common hydroid medusa *Phialidium languidum*, sometimes swarm there in such numbers as to fill our tow nets to the brim. In fact, the latter seldom, if ever, sinks more than a few meters deep. Ctenophores, too, of several species, come up to the top on smooth days, where they can be seen drifting along like crystal balls (p. 372), and on occasion even the large euphausiid shrimps may swarm on top of the water, day as well as night, probably to avail themselves of a particularly succulent food supply; in the Eastport region, for instance, in summer (p. 147), and in the Isles of Shoals-Boon Island region in spring (p. 145), though they are no more characteristic of the superficial layers elsewhere and at other seasons than are the adult Sagittæ. Since most of the deep-water members of the plankton (e. g., Euchæta, the largest of local copepods, and the chætognath *Eukrohnia hamata*) have occasionally been taken on the surface in the Gulf of Maine (pp. 235, 328), any number of this faunal group may be expected to appear at that level occasionally.

It needed very few hauls from the deep trough of the gulf to show that there is a decided cleavage in composition between the zooplankton of the upper and of the lower water layers, with the 100 to 150 meter level roughly delimiting the two. No hard and fast line can be drawn between these communities, for the gap is bridged, on the one hand, by such occasional excursions of the deep-water dwellers upward even to the surface as have just been mentioned and, on the other, by the presence of Calanus, Metridia, *Thysanoessa inermis*, Tomopteris, *Sagitta elegans*, Euthemisto, Limacina, etc., in decreasing numbers right down to the bottom, even in the deepest parts of the gulf, a fact demonstrated by the closing-net hauls listed below (p. 50). Nevertheless, the two communities are so characteristic in general aspect that it is usually possible to tell at a glance whether any particular sample came from much above or far below 100 meters. The features making this possible are the abundance and regular occurrence of *Euchæta norvegica* in the deep basin of the gulf. This copepod is so much larger than any of its relatives and is made so conspicuous by the blue egg clusters of the female that it gives a distinctive appearance to the entire catch. It is regularly accompanied by the chætognath genus Eukrohnia (p. 328); more rarely by the larger glass worm *S. lyra* (p. 327); frequently by the large pelagic decapodous shrimp Pasiphæa; and locally by large numbers of the euphausiid shrimp *Meganyctiphanes norvegica* (the latter, however, occurring in shallow water also). On the other hand, this "Euchæta" community includes only a sparse representation of Euthemisto, Calanus, or Pseudocalanus, and practically no Pleurobrachia or pteropods.

Unfortunately we have made only one successful closing-net haul deeper than 100 meters during all our summer cruises, for it was not until the spring of 1920 that our closing apparatus for horizontal hauls was developed to a dependable state;

hence, except for that one instance, the catches in the deep summer hauls have all been contaminated by the Calanus community captured by the open nets on their journeys up and down. For this reason I can not claim that the Euchæta, Eukrohnia, etc., taken at any given station necessarily came from the deepest levels. But the Euchæta community has been consistently represented in our midsummer hauls below 100 meters, no matter in what part of the basin of the gulf these have been made (see the following tables, pp. 40 and 50), and as we have never found it in any abundance in hauls shoaler than 100 meters it would be merely academic to dispute the general thesis that it is actually characteristic of the deepest stratum of the Gulf of Maine.

Whether the occasional excursions of Eukrohnia and Euchæta to the surface, such as I have just mentioned (p. 29) and discuss at greater length elsewhere (pp. 235, 328), are sporadic events induced by some temporarily or locally active vertical circulation, or whether they are more regular concomitants of regularly recurrent physical states than now appears probable, the fact remains that it is only below 100 meters—that is, in the saltest water of the trough of the gulf, which is never very cold—that the Euchæta community occurs regularly.[15] The Euchæta community similarly characterizes the corresponding level along the continental slope abreast of the gulf.

The use of the closing net is requisite to show in what relative amounts these deep-water animals are mingled with Calanus and its companions in the deeper strata of the inner parts of the gulf. In one such haul just mentioned (off Cape Cod, August 29, 1912, station 10043) at a station where Calanus outnumbered Euchæta at least 2,000 to 1 in the 20–0 meter haul (Bigelow, 1914, p. 116), these two copepods were about equally numerous at 125 to 120 meters, with Euchæta bulking the larger, thanks to its great size. The total volume of the catch was small, however (less than one-half liter), and we have never found the deep-water Euchæta community even approaching the swarms of Calanus of the upper 100 meters, or so, in volume of plankton present in the water. Unfortunately we lack precise data on this point.

To recapitulate, three chief bathymetric pelagic communities of animals can be distinguished in the Gulf of Maine in summer, not, of course, sharply outlined, but still sufficiently so to be recognizable. First is that of the surface, with its juveniles, small copepods, etc., which receives accessions of large copepods, Sagittæ, euphausiids, etc., by night and rarely by day; second, the general boreal community of the upper and mid depths, with Calanus, Metridia, and Pseudocalanus, Euthemisto, Thysanoessa, and *Sagitta elegans* as its index species; third, the Euchæta community of the deepest waters of the gulf. The distinctions between these communities, and especially between the last two, are greatest when and where the water is most stratified in density and temperature—that is, in the southwestern part of the gulf in midsummer—least when and where the water is most uniform vertically. This is the case in all parts of the gulf during late winter and early spring; and throughout the year in regions of very active vertical circulation, such as the neighborhood of Eastport, the St. Andrews region at the mouth of the Bay of Fundy, and locally on the offshore banks.

[15] See p. 236 for precise temperatures and salinities.

To answer a question that has often been asked me by zoologists as well as laymen, I may remark that there is no level in the Gulf of Maine but supports a varied pelagic fauna.

NERITIC AND OCEANIC PLANKTON

None of the criteria by which the plankton can be subdivided ecologically (e. g., relation to temperature, season of reproduction, depth of habitat, etc.) is more fundamental than whether its members do or do not depend on the coast line with its shallows and great supply of foodstuffs; that is, whether they are neritic or oceanic. This distinction is as interesting to the oceanographer as to the biologist, a knowledge of the mutual distribution of the two groups on the high seas often going far to reveal the mutual relationships and fluctuations of waters of coastal and of offshore origin.

The pelagic larvæ of various familiar bottom-dwelling animals (a host in themselves), including most of the worms, bivalve and gastropod mollusks, decapod crustaceans, barnacles, starfishes, and sea-urchins, so abundant in the bays and shallow waters along the coasts of the Gulf of Maine, belong to the neritic category. The adults of many medusæ, including the largest and most conspicuous species as well as others minute, are equally neritic, for they pass through a fixed stage in shallow waters during early life. Here, also, fall certain small phyllopod crustaceans (e. g., Evadne), which, though pelagic for most of their lives, survive unfavorable seasons in the form of resting spores on the bottom, a life history analogous to that of many diatoms, which consequently fall in the neritic category also, as do various other pelagic plants less prominent in the plankton. There is also a whole series of planktonic animals, particularly among the copepods, bound to the neighborhood of the coast by some unknown bond (perhaps by dependence on a particular food supply), and hence to be classed as neritic, although they are pelagic throughout life both as larvæ and as adults. Here, too, must be classed the pelagic eggs of all the species of fish that spawn in shallow water, such as cod, haddock, pollock, silver hake, cunners, and flounders of sundry species.

Contrasted with this coastwise population of the open sea are all the oceanic animals and plants, which are not only free floating or swimming throughout life but show no apparent relation to the coast line in their distribution—to borrow a nautical term, they form its "blue water" population.

It is, of course, impossible to draw a hard and fast distinction between the neritic and oceanic categories, the border line being bridged in too many instances by the many pelagic forms occurring indifferently both near shore and out at sea, and also by animals that are dependent on the bottom in deep water at some stage of existence but not in shallow water; for example, by the hydromedusan genus Calycopsis, which probably passes through a fixed stage but has never been found nearer shore than the continental slope. However, the division holds fairly well for the Gulf of Maine.

In northern seas, generally, neritic elements form a large part, if not practically the whole, of the plankton of sheltered bays and estuaries and off river mouths—

indeed, in all locations where conditions may be described as estuarine—and dominate for a mile or two out from the coast line generally. No detailed study of the plankton of any such situation tributary to the Gulf of Maine has yet appeared, but Willey's (1913 and 1915) and McMurrich's (1917) observations at St. Andrews, with the lists contributed by Doctor McMurrich (p. 12) and the record that might be collected from many sources of the abundance of various medusæ and of larval forms of many kinds inshore, show that the gulf is no exception to the general rule.

The complexion of the plankton at Woods Hole recently described by Fish (1925) may serve as an indication of the preponderance of neritic forms that may be expected in the Gulf of Maine bays and harbors and close along its coast line generally. Thus, Fish classifies 42 of the characteristic diatoms as neritic and only 16 as oceanic, while at least 13 out of 15 hydromedusæ described by him as "occurring commonly in surface towings" (Fish, 1925, fig. 26) are characteristic of the neritic group and only one oceanic. Two neritic scyphomedusæ occur in abundance. Only two of the many annelids listed from his tows (Sagitta and Tomopteris) are truly pelagic when adult, for the others swim only during the breeding season or as larvæ.

Molluscan larvæ are at times abundant in the Woods Hole plankton. The neritic phyllopods Evadne and Podon are characteristic of the local tows, as are the larvæ and sometimes the adults of neritic mysids. Fish found barnacle larvæ abundant in their season, bottom-dwelling amphipods were taken in large numbers in the tow during their breeding season, and the larvæ of decapod Crustacea—shrimps, prawns, crabs, and hermit crabs—are dominant. On the other hand, no euphausiid is a permanent member of the local plankton, though several species have been recorded at Woods Hole. Thus, aside from the copepods, the oceanic element of the Woods Hole plankton is wholly overshadowed by the neritic.

If one were to turn to the Gulf of Maine *de novo*, one might naturally expect the plankton of its central portion to be so largely recruited from the coastal zone that neritic elements would loom large there also, judging from the form, length, and complexity of the shore line with the abundant and varied bottom fauna which it supports; from the confinement of the gulf by the extensive and shallow offshore banks on the ocean side; from the great volume of river water that pours into it; and from the fact that the tides are strong enough in places to stir the water thoroughly. Our first summer's cruise (in 1912) was enough to show that this is not the case but that the pelagic communities of the gulf a few miles out to sea are predominantly oceanic, except over the offshore banks.

Our subsequent cruises have corroborated this for summer, autumn, and winter for all the years of record, and for the whole offshore basin of the gulf, where we have never found neritic forms, plant or animal, playing a rôle of any importance in the plankton except for a brief period in spring, as pointed out below.

The rarity of animals of coastwise origin or affinity in the open gulf in summer (except within a trivial distance of land and over the shallow banks) will appear from the following facts of distribution, already summarized in an earlier report (Bigelow, 1917, p. 251).

The most conspicuous planktonic inhabitants of the gulf, of neritic nature, are the two large scyphomedusan genera Aurelia (p. 362) and Cyanea (p. 357). Their value as indices of coast water has long been appreciated in north European seas, and they are both so large that they are usually visible as they float on or near the surface, if present in any numbers; consequently, notes on their local presence or absence, as seen from the vessel, afford a closer record of their distribution than do the actual captures of specimens at the tow-net stations. Both of these medusæ are abundant along the shores of the gulf in summer, but Aurelia is so closely confined to the immediate vicinity of the land that we have seldom seen it more than a mile or two outside the 100-meter contour (or more than 15 miles from land), while the zone within which it occurs regularly, if not abundantly, extends hardly 10 miles seaward beyond the outer headlands and islands (p. 363); nor have we found it on Georges Bank, though the shallowness of the water there suggests this as a possible breeding ground for it. Cyanea, the common "red jellyfish," which often grows to a breadth of 3 feet across the disk and sometimes to a tremendous size (A. Agassiz, 1865), is not so closely confined to the immediate vicinity of the land as is Aurelia, for it occurs regularly in the coastal zone, on Nantucket Shoals, and on Georges Bank, which must be important centers of production for it, judging from the abundance of the young medusæ there in spring and summer (p. 359). However, it is a rare occurrence to find a Cyanea outside the 100-meter contour in the Gulf of Maine (on July 15, 1912, we captured a very large Cyanea in a haul from 120–0 meters in the western basin). The hydromedusa *Melicertum campanula*,[16] so abundant all along the coasts of the Gulf of Maine (p. 341), is an even more precise neritic indicator than Aurelia, for it is still more closely confined to the coastal zone, not because the waters of the open sea are fatal to it (its abundance in Massachusetts Bay proves the contrary), but because it passes through its fixed stage only in sheltered localities, estuaries, etc., and because its free-floating (medusa) stage is of shorter duration. Although Melicertum often swarms in localities as open to the ocean as Massachusetts Bay and the outer parts of Penobscot Bay, as well as in more inclosed waters, a single example from the western basin (August, 1913, station 10088) is our only record of it more than 15 miles from land.

The medusæ of the genus Sarsia, which are plentiful in season (p. 43) in bays and estuarine situations all along the shallow coastal zone of the gulf, where they are detached from their hydroids in great numbers in spring, are similarly restricted to the coast line, for we have never taken them in the offshore parts of the gulf and rarely more than 4 or 5 miles from land. This is equally true of many other small hydroid medusæ, most of which appear in the gulf for a brief period only, and then far more numerously close to shore than outside the outer islands.

As I have pointed out elsewhere (Bigelow, 1917, p. 252), an interesting example of neritic occurrence among Cœlenterates is afforded by the hydroid colonies we have found floating in considerable numbers over Nantucket Shoals and Georges Bank in July of 1913, 1914, and 1916, and in February, 1920, as well (p. 379). These are so closely confined to the immediate vicinity of the localities where they are torn from the bottom that we have never found them or their free medusæ (which sometimes swarm on the banks) anywhere in the deeps of the gulf to the north.

[16] Large catches of Melicertum 38 miles off Cape Cod and near Browns Bank on August 12 and 19, 1926, prove that it drift farther offshore.

There are other species of hydroid medusæ that are not so closely confined to shoal water, probably because they are able to pass through their fixed stage at greater depths and consequently at a greater distance from land. Staurophora and Phialidium, for example, bear much the same relationship to the 100-meter contour in their distribution (p. 345) as Aurelia, Melicertum, and other forms more dependent on shoal water bear to the immediate coast line.

Other typical examples of the neritic habit are afforded by the larvæ of various decapods among the pelagic Crustacea, young crabs, in particular, being instructive because so conspicuous and so easily recognized in the tow. These (provisionally identified as the common rock crab, *Cancer amœnus*[17]) are produced in great numbers all along the coast line of the Gulf of Maine in summer, and occasionally they have occurred in swarms in our summer hauls near land, for instance, off Rye, N. H., and in Ipswich Bay, Mass., on July 23, 1915. Crab larvæ of some species are equally plentiful on Georges Bank, where we encountered hosts of them on July 23, 1916 (station 10347), and where Dr. W. C. Kendall towed them in abundance and found them providing the young mackerel with a rich food supply at various localities along the northern edge of the bank during August, 1896. They are so closely limited to the vicinity of the land and to the shallow waters of the offshore banks, however, at least so far as occurrence in any numbers is concerned, that I have usually sought them in vain in towings made in the central parts of the gulf, even during their season of abundance; nor have we found crab larvæ over Platts Bank or near Cashes Ledge, though they may be expected there, these doubtess being as good crab grounds as is Georges Bank. The presence of an abundance of crab zœæ in the surface water of the western basin on August 22, 1914 (station 10254), was an exception to the general rule and interesting because the considerable depth (268 meters) at the locality in question makes it almost certain that these young crabs were not hatched there but had drifted out from the rocky banks and ledges off Cape Ann, 25 or 30 miles to the west and northwest, which is visible evidence of the circulation in this part of the gulf at the time.[18]

Hermit crab (Pagurid) larvæ may also swarm locally over the offshore shoals, as was the case near Nantucket Lightship on July 25, 1916 (station 10355), when they were plentiful in the tow from 30 meters (the total depth of water being 36 meters), though represented by occasional examples only at 16 meters and on the surface. We have not detected them in any of our hauls in the basin of the gulf, nor are the macruran larvæ of various species (which are almost invariably present in the coastal waters of the gulf in summer) of any importance in the plankton more than a few miles from land.

The larval (naupliid and cyprid) stages of the common barnacle, which appeared in myriads along the coast north of Cape Ann in April, 1913 (Bigelow, 1914a), and again off Cape Sable during the same month of 1920 (p. 40), are strictly confined to shallow waters, for we have never detected them outside the 100-meter contour. This applies equally to many other metazoan larvæ; those, for example, of the common sea anemone (Metridium), which appear in some numbers in our coastwise catches

[17] See Connolly (1923) for account of the larval stages of this crab.

[18] Crab larvæ also were plentiful 38 miles off Cape Cod and on Georges Bank August 12 to 19, 1926.

in spring. In fact, we have never found the young stages of any bottom-dwelling animals numerically important in the plankton in the basin of the gulf. This fact is interesting because, although the fauna of these deep bottoms is neither so varied nor so rich in actual numbers of specimens as that of the coastal belt, the various mollusks, decapods, worms, and echinoderms that occur there no doubt contribute their larvæ to the waters above them, but are so overshadowed by the shoals of Calanus, etc., that only close examination of large amounts of plankton would reveal their presence.

The phyllopod crustacean genus Evadne deserves mention in this connection; not for any faunal importance in the Gulf of Maine, but because its peculiar life history makes it an infallible index of coastal water, as European students have long recognized (Gran, 1902; Apstein, 1910; Herdman and Riddell, 1911). Probably Evadne, which is seasonal in its appearance in northern coastal waters as a whole, would be found in summer in bays and sheltered waters all around the gulf, for it occurs regularly at the mouth of the St. Croix River in the Bay of Fundy (Willey, 1913), on the one hand, and at Woods Hole, on the other. So seldom does it stray seaward in any numbers, however, that the nine stations where it was detected in 1915 (the first season when special watch was kept for it, and when towing was carried on from May until October), all lay within 10 miles of land, and most of them closer in.

In this connection it is interesting that several of the pelagic shrimps (Meganyctiphanes) taken in the eastern basin on August 7, 1915 (station 10304), were carrying numbers of Evadne (among other prey) clasped between their thoracic legs (p. 108), although none of these little Cladocera were taken in the tows made at that station. From what distance could their captors have brought them?

In an earlier paper (Bigelow, 1917, p. 253) I have briefly summarized the status of neritic copepods in the Gulf of Maine in the following words:

> It is less easy to divide the copepods than other Crustacea into the neritic and oceanic categories, because they are pelagic at all stages. Hence (barring brackish water species), what is neritic in one sea may prove to be oceanic in another. Nevertheless, since they constitute the bulk of the plankton of the Gulf of Maine, I may point out that species which are generally classed as neritic in the North Sea region play only a very subordinate rôle, if they occur at all, in the central part of the gulf, our summer lists containing only five which are so classed by Farran (1910), [T.] Scott (1911), Herdman and Riddell (1911), and Gough (1905 and 1907); viz, Acartia, *Tortanus discaudatus*, *Centropages hamatus*, Eurytemora, and Temora.

We have only one or two records for each of the first four outside the outer islands; none from offshore parts of the gulf (Bigelow, 1914 and 1915). The fifth (*Temora longicornis*) is apparently less closely confined to coastal waters in the western than in the eastern side of the Atlantic, for in the summer of 1913 it was generally distributed over the gulf (p. 287), though there was no corresponding expansion of other neritic organisms. As a rule it is common only locally near land and over Nantucket Shoals and Georges Bank, a distribution roughly paralleling that of Cyanea.

Dr. C. B. Wilson's examination of the copepods of the cruises of 1915, 1920, and 1921 somewhat enlarges the neritic list at the offshore stations, but supports the general thesis that, as a rule, the more oceanic species greatly predominate outside the outer islands.

The pelagic eggs of the many species of fish that spawn on the banks or in shallow water alongshore in the gulf are as rarely found in our tow nettings outside the 100 or 150 meter contours as are other neritic organisms. Cod, haddock, and several species of flatfish may serve as examples of this; likewise the silver hake (Bigelow and Welsh, 1925, p. 488, fig. 217, and p. 244); while the eggs of the cunner are closely confined to the coast line and to the vicinity of the outer islands and shoals (Bigelow and Welsh, 1925, p. 284).

The locality records for the neritic animals just summarized, and for sundry others belonging to the same category, are concentrated in a rather narrow coastal zone paralleling the periphery of the gulf and over its shallow southern rim, with neritic forms very seldom of any importance in the planktonic community more than a few miles out at sea in summer, except for the shallow offshore banks. The fact that most of the animals of this category, if not wanting in the central basin of the gulf, are at least so scarce there as to have been overlooked, is sufficient evidence that the plankton of the coastwise belt has little tendency to disperse seaward at that season, but that the eddylike circulation parallels the coast, which is corroborated by drift bottles and by oceanographic evidence generally.

With few exceptions the scarcity of pelagic animals of neritic origin in the offshore parts of the gulf leaves the planktonic communities that people its open waters (not only in the central basin but right up to the outer headlands) composed of animals and plants not only independent of the bottom at all times but most of which are equally oceanic as opposed to neritic in European waters, as appears from the very extensive records accumulated by the International Committee for the Exploration of the Sea. However, they are not the product of the Atlantic basin outside the continental slope, as the term "oceanic" might imply, but of the banks water that washes the continental shelf on both sides of the Atlantic, and to which they are confined off the North American littoral by the high temperatures of the tropical water farther offshore.

The diatom plankton encountered over the basin in May, 1915, typified by *Chætoceras densum* and *Rhizosolenia semispina*, belongs to this category (p. 434; Gran, 1915; Ostenfeld, 1913; Herdman and Riddell, 1911), while the Ceratium community, which usually occupies the Gulf of Maine as a whole throughout the summer (p. 391), is also characterized by species (*Ceratium tripos* and *C. longipes* var. *atlantica*) usually regarded as oceanic in the North Sea region (Paulsen, 1908; Jørgensen, 1911) and in the Norwegian Sea (Gran, 1902). This is equally true of most of the pelagic animals most constantly characteristic of the plankton of the gulf; for example, of the copepods *Calanus finmarchicus*, Pseudocalanus, Euchæta, and Metridia (Damas, 1905; Gran, 1902; Farran, 1910; Herdman and Riddell, 1911); of the amphipods *Euthemisto bispinosa* and *E. compressa* (Tesch, 1911; Sars, 1895); of the pteropod *Limacina retroversa* (Paulsen, 1910); and of the euphausiid shrimp *Thysanoessa inermis* (Tattersall, 1911; Kramp, 1913a), to mention only a few of the most typical. While two of the most important of its members, faunistically (*Sagitta elegans* and *Meganyctiphanes norvegica*), are intermediate between oceanic and neritic in their biologic status in the North Sea region (Apstein, 1911; Kramp, 1913a), in the Gulf of Maine they cover practically the same range as the more typically oceanic forms just mentioned. Off the European coast most of these species—in fact, the Calanus commu-

nity as a whole—are not only charactersitic of the waters over the continental shelf, but also of the neighboring parts of the ocean basin, and spread right across the North Atlantic from the Norwegian Sea and Iceland, on the one side, to Newfoundland and Nova Scotia, on the other (Herdman and Scott, 1908; Murray and Hjort, 1912). Passing southward from the region of the Grand Banks, however, the band of cool banks water next the coast is a sort of cul-de-sac for them, with the tropical water ("Gulf Stream") limiting their spread on the offshore side as definitely as the coast line does on the inner side.

The contrast in distribution between the neritic and oceanic elements of the zooplankton of the Gulf, which I have just outlined, prevails throughout the summer, autumn, and winter; and although in spring neritic diatoms, such as Thalassiosira, appear in swarms over deep water as well as along the shore, when the rivers are in flood and the outpouring of land water is evidenced far out from the coast by lowered salinity, they are decidedly more abundant in the coastal zone than in the basin even at the time of their widest dispersal, a fact discussed below in the general account of the phytoplankton. Neither are larvæ of coastwise origin of much more importance in the plankton over the basin in spring (as exemplified by our tow nettings of March, April, and May of the years 1915 and 1920) than in summer. Probably this is because the water has hardly warmed appreciably by freshet season, so that the vernal wave of reproduction has only begun on the part of the littoral and bottom fauna.

SEASONAL FLUCTUATIONS IN THE PLANKTONIC COMMUNITIES

Seasonal fluctuations in the plankton are greatest in regions where neritic larvæ, or forms dependent on the bottom at some time of year, bulk large in the pelagic community, and in seas where the pelagic fauna or flora is largely recruited from extralimital sources by ocean currents, which may vary in strength or in origin from month to month. In the Gulf of Maine the presence or absence of the various crustacean larvæ, or of fish eggs, may govern the composition of the catch for the particular season close in to the land, as examples of which I may cite the swarming of Balanus cyprids near the Isles of Shoals (p. 44) and of haddock eggs on Georges Bank (p. 44), both in spring. This applies more generally to the North Sea, the Irish Sea, and the Baltic than to the Gulf of Maine, where the communities of planktonic animals are, as a whole, more oceanic; and since few constant or even regularly seasonal members of the zooplankton of the gulf are immigrants, but nearly all of them are endemic, the seasonal cycle of the plankton is a simpler problem for us than for students of the North Sea region. It can hardly be emphasized too strongly that very few immigrants, whether from the north, the south, or from the open ocean, penetrate the Gulf of Maine in numbers sufficient to color its plankton community (*Sagitta serratodentata* is an exception, p. 58), instructive though the regular or sporadic occurrence of animals of exotic origin may be for the light they throw on the sources of its waters. This question is discussed below (p. 51).

In the case of the pelagic flora, a very pronounced alternation of the prevalent planktonic types does take place from season to season, and one characteristic of northern seas as a whole; viz, a tremendous flowering of diatoms in spring, giving

place to a rich Peridinian flora in summer, which is succeeded in turn by the limited flowering of diatoms in autumn, as described in the chapter devoted to the phytoplankton (p. 383).

No such seasonal alternation of dominance by one or other group takes place among the planktonic animals of the gulf, however, though there is a very pronounced oscillation in the total amount of zooplankton present there at different times of year and in the abundance of its several members relative to one another. Thus, we have never failed to find the Calanus community dominating the pelagic fauna generally in the southwest part of the gulf, whether our trips thither were made in the heat of summer, the cold of winter, in autumn, or in spring. Nevertheless, even in this region the varying seasons of reproduction of different animals, which determine the presence or absence of their larvæ and the abundance or scarcity of the adults, with the local irregularities of distribution that always obtain for the larger pelagic forms, added to the general ebb and flow in the abundance of the zoöplanktonic community as a whole, cause such variations from month to month as appear in the following lists of the more abundant species in tow-net catches made at the mouth of Massachusetts Bay in spring, summer, autumn, and winter. The case is made still more complex by sporadic fluctuations in the abundance of one species or another, for which we are not yet able to account.

Tow-net catches at the mouth of Massachusetts Bay

[D, dominating the plankton; X, occurred]

	Mar. 1, 1920, station 20050, 75–0 meters	Apr. 9, 1920, station 20090, 60–0 meters	May 4, 1920, station 20120, 40–0 meters	July 9, 1916, station 10341, 0 and 80–0 meters	Oct. 31, 1916, station 10399, 60–0 meters	Feb. 13, 1913, station 10053, 20–0 meters
Cod eggs						X
Haddock eggs			X			
Cod or haddock eggs	X	X				
Silver hake (Merluccious) eggs				X		
Silver hake (Merluccius) larvæ				X		
Butterfish (Poronotus) eggs				X		
Plaice (Hippoglossoides) eggs		X	X			
Plaice (Hippoglossoides) larvæ			X	X		
Dab (Limanda) larvæ				X		
Witch (Glyptocephalus) larvæ				X		
Olkopleura					X	X
Decapod larvæ			X			
Thysanoessa inermis				X		
Thysanoessa raschii				X		
Meganyctiphanes norvegica				X		
Euphausiid larvæ			X			
Euthemisto compressa	X					X
Euthemisto bispinosa					X	X
Calanus finmarchicus	D	D	D	D	D	D
Calanus hyperboreus		X				
Pseudocalanus elongatus			X	X	X	X
Metridia lucens				X	X	X
Anomalocera pattersoni				X		
Euchæta norvegica				X		X
Temora longicornis					D	
Centropages hamatus					X	
Tortanus discaudatus						X
Copepods, juvenile	X	X	D		X	
Copepod nauplii			D	X		
Sagitta elegans	D	X	X	D	X	X
Sagitta serratodentata						X
Tomopteris catherina	X					X
Limacina retroversa			X		X	X
Staurophora mertensii			X			
Tima bairdii			X			
Aglantha digitale				X	X	
Pleurobrachia pileus		X				
Beroë cucumis						X
Anemone (Metridium) larvæ			X			

The most striking event in the seasonal cycle of the zoöplankton of the Gulf of Maine (if a negative one) is that a very decided decrease, amounting on occasion almost to complete disappearance of the pelagic fauna, takes place early in spring over the whole area of the gulf, coincident with the tremendous vernal flowering of diatoms (p. 385), an event the precise date of which varies locally and from year to year. The quantitative aspect of this change is discussed elsewhere (p. 82), but it also exerts an adventitious influence on the qualitative composition of the plankton, for with all its members sharing in the impoverishment, the rare as well as the common, the less abundant forms practically disappear and the scanty catches become extremely monotonous.

We first observed this impoverishment in Massachusetts Bay during the late winter and early spring of 1913, when the zoöplankton fell to so low an ebb, quantitatively, as the water began to warm from its winter minimum, that the total volume of the catch of a net about 1.2 meters in diameter, towed for half an hour at 40–0 meters on March 4, was only about 15 cubic centimeters. In this catch an occasional *Pseudocalanus elongatus*, 12 *Sagitta elegans*, 9 *Tomopteris catharina*, an odd Euthemisto, and some haddock eggs were the only variants detected among the *Calanus finmarchicus*, of which the general mass consisted. On April 3, following, the net yielded only a few dozen copepods, one Euthemisto, and two Clione, with a few unrecognizable siphonophore bells and Balanus nauplii; while the catch of planktonic animals made on April 14 was no more varied (a few Calanus, one Tomopteris, one *S. elegans*, one Beroë, one young Staurophora, and a few Balanus nauplii), whereas the water was thick with diatoms on both these occasions.

Subsequent experience during the spring of 1920 has shown that this vernal impoverishment of the zoöplankton, which takes place to a greater or less degree in the upper strata of water over the entire area of the gulf, is especially characteristic of the coastal belt and of Georges Bank, where it culminates in March. It involves no qualitative alteration in the plankton, however, for the spring community, sparse though it be near land, is of essentially the same type as the more abundant pelagic population of midsummer, with the same groups and species (notably *Calanus finmarchicus*) predominant. Practically all the common oceanic animals of midsummer except *Sagitta serratodentata*, which is a seasonal immigrant (p. 320), may be found represented in late winter and spring, if a sufficient mass of plankton be examined from any given locality in the gulf, though many are so rare then that the net is more apt to miss than to catch them. Winter adds few extralimital visitors to the local pelagic fauna, never (in our experience) enough to give a distinctive aspect to the plankton.

The essential qualitative unity between the zoöplankton of summer and that of spring may be illustrated by the horizontal hauls off Cape Elizabeth on March 4, 1920 (station 20059), which yielded *Calanus finmarchicus* (dominant), *Sagitta elegans*, *Thysanoessa inermis*, *Th. raschii*, haddock and plaice eggs, Pleurobrachia, and *Tomopteris catharina*, although the water was then so barren that the vertical net caught nothing at all (p. 82). The typical boreal fauna was still more fully represented on the same day off Penobscot Bay (station 20057), although the plankton was hardly denser there numerically, viz, by *C. finmarchicus* (dominant), Pseudocalanus,

Euchæta, *Sagitta elegans*, Eukrohnia, Euthemisto of both species, Clione, *Limacina retroversa*, Tomopteris, Meganyctiphanes, *Thysanoessa inermis*, and *Th. longicaudata*. This is a list that might be expected in summer or autumn, and the same was true of the hauls made in Massachusetts Bay during the winter of 1912–1913, mentioned above (p. 39). The plankton is as uniform, qualitatively, from season to season in the deeper parts of the gulf as the following table shows for a location in the western basin about 30 miles off Cape Ann.

Zoöplankton in the western basin, various months

[D, dominant; ×, occurred]

	February, station 20049	March		April, station 20115	May, station 10267	June, station 10299	July, station 10007	August			December, station 10490
		Station 20087	Station 10510					Station 10088	Station 10254	Station 10307	
Calanus finmarchicus	D	D	D	D	D	D	D	D	D	D	D
Calanus hyperboreus			×	×	×						×
Pseudocalanus elongatus					×	×		×	×	×	×
Metridia lucens					×	×		×	×	×	×
Metridia longa								×			
Euchæta norvegica	×	D	×	D	×	×	×	D	D	×	×
Anomalocera pattersoni					×			×	×	×	
Centropages typicus								×			
Pasiphæa		×		×				×	×	×	
Meganyctiphanes norvegica	×	×	×	×			×	×	×	×	
Thysanoessa inermis	×	×	×				×	×	×	×	
Thysanoessa longicaudata		×	×					(?)	×		
Thysanoessa gregaria									×		
Euthemisto compressa		×				×	×	×	×	×	
Euthemisto bispinosa										×	
Limacina retroversa			×					×		×	×
Clione limacina	×	×	×	×			×				
Sagitta elegans	×	×	×	×	×	×	D	×	×	×	×
Sagitta serratodentata									×	×	
Sagitta lyra		×		×				×	×		
Eukrohnia hamata		×	×	×					×		×
Tomopteris catharina			×	×	×			×			×
Aglantha digitale	×	×	×	×			×				
Beroë cucumis		×		×			×			×	
Stephanomia			×				×	×	×		×
Phialidium languidum								×	×		

Broadly speaking, our March hauls have paralleled those made in midsummer in the relative importance of the several groups of animals in different parts of the gulf, as well as in the qualitative composition of the catches. Thus, Pleurobrachia was dominant on German Bank both on March 23 and on April 16, 1920 (stations 20085 and 20103), just as it usually is in summer and autumn, and its area of abundance extended from abreast of Yarmouth, on the north, to the shoals off Cape Sable, to the south, on both these visits. On both these spring visits there was a second center of abundance for Pleurobrachia on Browns Bank, where our June and July tows have yielded only an occasional specimen; but although the area of abundance for Pleurobrachia in this general region was more extensive in March and April, 1920, than we have found it in summer, these ctenophores were less plentiful in actual number; nor had they so thoroughly exterminated the other smaller animals, for we found the German Bank–Cape Sable swarm accompanied by copepods in fair numbers on the April visit, besides barnacle (Balanus) nauplii (in abundance), *Sagitta elegans*, euphausiids, Euthemisto, and Tomopteris.

Similarly, the spring cruise of 1920 suggests that *S. elegans* may be expected to rival the copepods in abundance over a large part of Georges Bank in February, March, and April, just as it does in July; for it was a large element in the catch at a station on the southwest part of the bank on February 22 (station 20046), on the northeast part on April 17, and had been so plentiful at a third station on the eastern part of the bank on March 11 (station 20066) that the "glass worms," with a great abundance of haddock eggs, dominated the catch (fig. 19). In short, Georges Bank is apparently a center of abundance for *S. elegans* throughout the year (p. 310), and the presence of a shoal of large *Limacina retroversa* on the northern part of the bank on March 11, 1920 (station 20065), reproduced our experience of July 20, 1914, though the exact localities in question were about 80 miles apart.

Late in the winter and early in the spring the scanty zooplankton of the gulf is chiefly composed of fully adult animals, a fact made evident by the predominantly large size of its calanoid copepods and Sagittæ, giving the catches a distinctive aspect when compared with those of July or August. The recrudescence which characterizes the advance of spring results primarily from the local propagation of its several component groups, not of replenishment by immigrants from any extralimital source. This has been proved by repeated observations.

In Massachusetts Bay this vernal augmentation is earliest apparent at stations close in to the land, in the shape of a sudden appearance of hosts of copepod nauplii (figs. 27 and 28). This event commences some time late in March off the mouth of Boston Harbor, for we found few nauplii there on the 5th of that month in 1920 (station 20062), but an abundance of them on the 5th of April (station 20089), besides many copepods in the older larval stages. As the season advances this vernal wave of reproduction on the part of the copepods spreads seaward; and the nauplii appeared in multitudes at the mouth of the bay during the last half of April, 1920, where we had found only an occasional copepod—egg, nauplius, or juvenile—on March 1 or April 9. In 1920 the swarms of larval copepods, together with the various other larvæ that appear about the same time, produced a decided increase in the volume of animal plankton present in the water of the Massachusetts Bay region by the first week in May. This was our experience in 1913, also, when W. W. Welsh found the water in Gloucester Harbor reddened for areas of about a square yard, several yards apart, with what proved to be swarms of copepod nauplii and young copepods on May 3. The peak of production of copepods, however, is so soon passed in Massachusetts Bay that our nets brought back proportionally more of the older juveniles and fewer nauplii off Gloucester on May 16, 1920, than 12 days earlier, while the hauls off Magnolia, Mass., on May 17, 1913, yielded only a few copepod nauplii but an abundance of the later stages (chiefly Calanus, with some Eurytemora), besides many crab larvæ in the zœa stage.

The vernal replenishment of the zoöplankton follows much the same course in the coastal belt immediately north of Cape Ann as in Massachusetts Bay, with a few copepod nauplii among the swarming diatoms off the mouth of the Merrimac River as early as March 4 in 1920 (station 20060). The nauplii were again noted there on April 9, and on May 7 hauls made close by with the closing net yielded

nauplii (besides copepod eggs), larval Anemones, and young Staurophora down to 30 meters, overlying a sparse adult Calanus–Sagitta–Pleurobrachia community in the deeper strata of water.

There is some evidence that the wave of reproduction of copepods continues to spread offshore with the advance of the season until it covers the southwestern part of the gulf generally; and it certainly endures later into the spring in the open gulf than in Massachusetts Bay, for the presence of nauplii showed that in 1920 these little crustaceans were breeding actively from Cape Cod to Georges Bank as late as May 16 and 17. In the spring of 1915 nauplii were abundant on the surface off the Cape, with older stages deeper down, as late as the 26th of the month (station 10279), although they had been almost entirely replaced by the older larvæ and by half-grown Calanus (fig. 29) as early as the 4th of that month off Gloucester (station 10266). Similarly, the presence of copepod nauplii in the sink off the Isles of Shoals on May 14, 1915 (station 10278), coupled with a decided increase in young copepods between April 26 and May 14 to 16, 1913 (Bigelow, 1914a, p. 407), though with diatoms still abundant there on both these occasions,[19] suggests that copepods do not begin to multiply this far offshore until well into May, although reproduction is under way more than a month earlier than this inshore off the Merrimac River.

We have no evidence that the coastal waters east of Penobscot Bay ever see a local reproduction of copepods comparable to the waves of production just described for Massachusetts Bay.

As to local production of copepods along the eastern (Nova Scotian) side of the gulf, I can only say that our hauls near Lurcher Shoal on March 23 (station 20082), and again off Yarmouth, on German Bank, and near Cape Sable on April 13 to 15, 1920 (stations 20102, 20103, and 20104), yielded nauplii and older larval copepods in some numbers, which probably marks the beginning of a period of active propagation, for in 1915 we found both nauplii and the older juvenile stages of Calanus plentiful on the surface of the eastern basin near by on May 6.

The vernal wave of production of these little crustaceans reaches its apex by the end of May or the first of June in the northern and eastern parts of the gulf, for we found a typical Calanus plankton reestablished off Boothbay (station 10280), in the Fundy Deep (station 10282), and off Mount Desert Island (station 10284) by May 31 to June 11 in 1915.

An important problem in the natural economy of the gulf is how far the vernal augmentation of the zoöplankton of the offshore parts of the gulf—say, outside the 100-meter contour—is due to local propagation there and how far to a migration of the copepods out from the coastal zone where they are produced in such enormous numbers. To answer this question definitely demands a more critical study of our towings than opportunity has yet allowed. One thing is clear, however. None of our offshore hauls at any season has ever yielded copepod nauplii or the later larval stages in numbers to compare with their abundance in Massachusetts Bay. It is equally suggestive that in May, when the coastwise copepod plankton is juvenile, large Calanus have invariably been an important element in the total copepod catches in the deep basin, just as is the case in summer, which points to the coastwise waters

[19] In 1913 they were diminishing in numbers locally by that time.

of the gulf, especially its southwestern part including the Massachusetts Bay region, as the chief source of the copepod plankton of its center. It is probable, also, that Georges Bank is an important nursery for copepods, since nauplii occurred in some numbers among the adult calanoids off its northern slope on March 11, 1920 (station 20064).

The vernal increase in the numbers of copepods present in the Massachusetts Bay region, and wherever else reproduction takes place actively, is many times greater than the bulks of the catches might suggest, the production of young coupled with the dying off of the parent stock giving the copepod plankton of the coastal waters a juvenile character in spring with relatively few large adults. Thus, there were only about 8,000 adult Calanus per square meter among some 500,000 copepods, mostly young Calanus, off Gloucester on May 4, 1915 (station 20066)—that is, a little less than 2 per cent. After the peak of production is past, however, and with the growth of its product toward maturity, the percentage of large Calanus and adults of other species once more increases, until they form about one-third of the copepod population at the mouth of Massachusetts Bay by the end of June or first week in July (Bigelow, 1922, p. 136). During the late summer, when the stock of copepods of all species and ages dwindles, adults may locally amount to as much as one-half or two-thirds of the total (fig. 30).

Coincident with the vernal propagation of copepods various young medusæ commence their period of pelagic existence, as, for example, Staurophora, which appears in swarms in Massachusetts Bay in May. Although we have never found young medusæ more than a minor factor in the zooplankton of the gulf outside the outer headlands in spring, they often dominate inclosed waters for a brief period in May. This, for instance, was the case in Gloucester outer harbor on May 3, 1913, when *Sarsia tubulosa*, *Bougainvillea superciliaris*, *Rathkea blumenbachii*, *Tiaropsis diademata*, Obelia, and Staurophora were all abundant, and Æquorea and Cyanea tolerably common—all of them, no doubt, liberated close at hand, and certainly very recently, for none was found there a month earlier. We also found young hydromedusæ swarming in the harbor of Yarmouth, Nova Scotia, in May, 1915, and this probably applies to similar situations all along the complex coast line of the gulf from Cape Cod to Cape Sable; also to the shallow waters of Georges Bank, where young Hybocodon and Staurophora are sometimes sufficiently plentiful to "color" the tow in April (Bigelow, 1914a, p. 414).

The larvæ of echinoderms, worms, and mollusks of many kinds likewise appear in the plankton along shore in spring. Most of these, in fact most of the pelagic animals of coastwise origin, are confined to estuarine situations in the Gulf of Maine, to sounds and bays among the islands, or to a coastal belt only a few miles wide at most, as noted above (p. 32), and hence may be passed over without further comment here. The early stages of the common rock barnacle (genus Balanus), however, are so abundant and so conspicuous that they deserve a word of mention. In 1913, as I have elsewhere described (Bigelow, 1914a), barnacle nauplii[20] were taken in large numbers in the Isles of Shoals-Boon Island region[21]

[20] Here let me correct an error in an earlier paper, namely, that "barnacle" eggs were taken in the tow in March and April of 1913 (Bigelow, 1914a, p. 108). Barnacle eggs are not set free to float, but are nursed by the mother until the nauplii hatch out. For accounts and figures of the early stages of Balanus see Hœck, 1909.

[21] No doubt young barnacles are as common in Massachusetts Bay as in any part of the gulf, though somehow we have chanced to miss their season there.

on April 5; the cyprid stage in abundance on the 9th, with only a few nauplii; while by the 19th cyprids alone were taken. These dominated the surface plankton during the last week of April, after which their numbers diminished, though some persisted in that region until mid-May.

The reproduction of barnacles is at its height at about the same season along the eastern shores of the gulf, for their nauplii occurred at all our stations over the shallows from Yarmouth to Browns Bank on April 13 to 15, 1920—abundantly in the North Channel (station 20105; fig. 24). At St. Andrews, in the Bay of Fundy, where because of the violent tides the surface waters warm slowly in spring, barnacle larvæ (either nauplii, cyprids, or both) are recorded by Doctor McMurrich in his plankton lists as early as the last week of January, regularly after mid-February, reaching their maximum abundance during April, occurring in diminishing numbers until June 8, and occasionally still later in that month. In 1917, according to Willey (1921), barnacle nauplii dominated the plankton at St. Andrews on April 7; nauplii and cyprids in subequal numbers formed nearly the entire catch on May 1; and cyprids alone on the 17th. The season is about the same for them in the Irish Sea.

The spring season, likewise, sees striking additions to the plankton of the coastwise and shoaler waters of the gulf generally, in the shape of buoyant fish eggs. Haddock eggs in particular are produced in such numbers locally during March and April (which is the height of the breeding season) that they may be a considerable element on the more prolific spawning grounds, such as the eastern part of Georges Bank, the neighborhood of the Boon Island ground, and locally in Massachusetts Bay. The extremely characteristic eggs of the plaice (*Hippoglossoides platessoides*) appear early in March (that is, slightly later than those of the haddock) and are taken until mid-June, with the height of the spawning season during April and May. Rusty-flounder (Limanda) eggs are first seen in the tow toward the end of April, most numerously in June and July, and rarely as late as mid-September. The spawning season of the witch flounder (Glyptocephalus) likewise follows hard on that of the haddock. Spring is the season most prolific in fish eggs in the Gulf of Maine, but they are seldom numerous except in the immediate vicinity of the spawning grounds, or anywhere over the central deeps of the gulf, outside the 100-meter contour.[22]

The most obvious effect of the very active reproduction of copepods just described, coupled with the scarcity of most other planktonic animals in the offshore waters of the gulf at the time, is that soon after its inception the zooplankton in the more productive centers of propagation becomes almost pure copepod; and, whether by local breeding or by drifting out from the coastal belt, as seems more likely, their numbers so multiply offshore as the water warms with the advance of the season that they overwhelmingly dominate the pelagic community of the whole gulf north of a line from Cape Cod to Browns Bank in May and during the first half of June. Since, furthermore, the other planktonic groups of animals that assume faunal importance later on in the year (e. g., Sagittæ, amphipods, euphausiids) do not commence multiplying actively until later in the season, it is during late spring and the first weeks of summer that the zooplankton of the upper 100 meters (empha-

[22] For the chief spawning grounds and breeding seasons of Gulf of Maine fishes see Bigelow and Welsh (1925).

sizing this depth limit for reasons which will appear presently) of the offshore parts of the gulf is the most monotonous.

Although our records for this season are not all that might be desired, it seems certain that copepods (Calanus in particular) reach their high-water mark early in June, the exact date varying locally and with the forwardness of the season. So completely did the calanoids (chiefly *C. finmarchicus*) monopolize the upper strata of water right across from Cape Cod to Cape Sable during May, 1915, that the only other animals to be found among a liter of copepods off Cape Ann on May 4 (station 10266) were a few *Sagitta elegans*, one young fish, two tiny Euthemisto, a few euphausiid larvæ, and a few fish eggs, with the zoöplankton of the western basin (station 10267), where diatoms were still swarming, so monotonous that a haul from 85 meters yielded nothing but copepods and one Tomopteris. Nor was the catch more varied in the central deep (station 10269), only one euphausiid, one Euthemisto, six or seven large Clione, and an occasional Limacina being detected among the copepods in the 85-meter tow on May 6, while we found only a few Euthemisto, euphausiids, and Sagittæ, with an arctic planktonic element to be discussed elsewhere (p. 59), among swarms of copepods in the eastern basin on that same day (station 10270).

In that year (which was apparently a typical one) the plankton of the upper 100 meters was as monotonously calanoid in June as it had been in May. In the Grand Manan Channel, for example, on the 4th (station 10281), the 50-meter catch consisted of copepods varied only by 1 Euthemisto, 2 Clione, 1 Aglantha, 1 young fish, 1 fish egg, 2 *Sagitta elegans*, and a single specimen of Tomopteris. Much the same condition prevailed in the Fundy Deep on the 10th (station 10282); likewise near Mount Desert Island on the 11th (station 10284), when a cursory examination of more than 2 liters of Calanus and other copepods in the 70–0 meter haul revealed only one Clione and a single Sagitta as the sole variants. On the 26th of June, too, the upper strata of the western basin were similarly occupied by a calanoid plankton in extraordinary abundance (about 40,000 large Calanus per square meter).

In the western and northern parts of the gulf, where copepods monopolize the water more completely at their peak season than they do the deep basin offshore, it is an unusual event for Sagittæ, amphipods, euphausiids, or pteropods, etc., to be of any importance in the plankton in spring or early summer, with the notable exceptions of the swarms of the euphausiid shrimp *Thysanoessa raschii* near the Isles of Shoals in April and May, 1913, and (with its relative, *Th. inermis*) on April 9, 1920 (station 20093), described below (p. 145); with the exception, too, of Meganyctiphanes, which is so plentiful in the northeast corner of the trough off Grand Manan that we captured no less than 1½ liters there on June 10, 1915 (station 10283), in half an hour's haul at 100–0 meters, and of Pleurobrachia, which swarms on German Bank in May and June just as it does in summer (p. 19). Even where copepods so dominate the contents of the net, however, that nothing else strikes the eye at the first glance, a more careful examination of the catch will reveal some few amphipods, euphausiids, Sagittæ, etc.

June 19 is the earliest date on which we found large Euthemisto in any abundance in 1915 (eastern basin, haul from 85–0 meters, station 10288). The interesting

hydroid medusa *Mitrocoma cruciata* reaches maturity during this same month, when it may appear near shore in numbers sufficient to give a distinctive aspect to the tow, as was the case at the mouth of Penobscot Bay on June 14, 1915 (station 10287 p. 348). For the sake of clarity I should point out, at the risk of repetition (p. 389), that diatoms still swarm along a narrow coastwise belt east of Penobscot Bay in June.

The advance of summer (from June on) sees an actual decrease in the number of copepods, owing, no doubt, to the destruction wrought among them by fishes and other enemies (p. 97). In part this decrease is made good by constant reproduction, evidence of which was afforded by an abundance of copepod nauplii near Cape Cod on July 8, 1913 (station 10057, surface), on July 7, 1915 (station 10300), and on August 29, 1916 (station 10398); likewise by the presence of large numbers of juvenile Calanus [23] between Cape Ann and the Isles of Shoals in July, 1912. The offshore banks also serve as a copepod nursery in July—at least locally—for copepod eggs, nauplii, and juveniles abounded on the surface near Nantucket Lightship on the 25th of that month in 1916 (station 10355), while the presence of young Calanus at various stages in development in most of the summer towings proves that this copepod breeds more or less regularly throughout the summer. Our experience, however, does not suggest that sufficient reproduction takes place during the warm months to maintain the local stock of calanoid copepods against depletion by the many dangers to which it is subjected.

As copepods dwindle in numbers the other groups of common boreal animals increase, lending an increasing diversity to the plankton of the offshore parts of the gulf during the summer, most noticeably in the western side, where the plankton is most monotonously calanoid in May and June, thus producing the midsummer state already described (p. 17). Events notable in this gradual alteration are a great production of Euthemisto, resulting from local centers of reproduction such as I have just mentioned (p. 20); the active propagation of euphausiids (p. 20); a general penetration toward the western and northwestern shores of the Gulf on the part of the pteropod *Limacina retroversa* (p. 119); the appearance of shoals of the white and red jellyfishes (Aurelia and Cyanea) in the coastal belt as they disperse and drift seaward from their estuarine nurseries (pp. 360, 362); the presence of large Stauro-phora, often in abundance (p. 342); and the offshore swarming of the hydroid medusa *Phialidium languidum* (p. 350). It is during the summer, too, that the large and conspicuous arrow-worm *Sagitta serratodentata* first appears in any number in the gulf as a visitor from warmer waters to the south and east outside the edge of the continent, and spreads its range northward and westward as described elsewhere (p. 322). The copepod population, also, becomes diversified as the summer advance by increasing numbers of Anomalocera and Centropages, not only within the gulf but also on Georges Bank, where the former (which we did not find in spring) is practically universal and comparatively abundant in August.[24] The ctenophore *Pleurobrachia pileus* reaches its maximum abundance on the German Bank ground

[23] Identified by Dr. C. O. Esterly.

[24] The "green copepod" of Doctor Kendall's field notes.

and may almost completely monopolize the water there during the summer. In June and July, too, the eggs or larvæ, or both, of sundry summer-breeding fishes, such as silver hake, rosefish, cunner, and witch flounder, appear in the appropriate parts of the gulf to take the place of such spring spawners as the haddock and plaice.

As summer passes into autumn *Sagitta serratodentata* continues to spread westward right into Massachusetts Bay (p. 322). The hyperiid–amphipod genus Euthemisto likewise works inshore in September and October, so that it is more numerous in the bay then than at any other time of year, and Pleurobrachia may swarm locally, notably off the coast of eastern Maine and at the mouth of the Bay of Fundy. It is during late summer or early autumn, too, that Phialidium is most plentiful and that Salpæ and other tropical forms (p. 53) are most often encountered in the gulf.

Hand in hand with the autumnal cooling of the surface, the small *Phialidium languidum* disappears first and then the larger scyphomedusæ, either dying at the close of their natural period of life or being destroyed by the fury of the autumn storms. The large, blue copepod Anomalocera likewise vanishes from the waters of the gulf (p. 184). On the other hand, ctenophores may be locally abundant until well into the autumn, witness the swarms of Pleurobrachia that appeared off Cape Cod during October, 1916 (p. 367); and the small brown copepod *Temora longicornis* becomes so plentiful locally near the land at this season that it dominated the surface catch off Cape Ann on October 31, 1916 (station 10399), when a sample of the copepods consisted of over 100 Temora with but 2 Centropages and 1 Calanus. Doctor McMurrich, likewise, found Temora most regularly and in greatest abundance in October, November, and the first half of December at St. Andrews (p. 289), but in the open Gulf no definite seasonal periodicity has been established for it (p. 289).

Centropages was the most numerous copepod on the surface off Cape Cod in November, 1916 (station 10404), but all our deeper hauls in autumn have been dominated by Calanus, Pseudocalanus, and Metridia, with Euthemisto of both species, *Sagitta elegans*, Meganyctiphanes, Thysanoessa, and Limacina. In fact, they have paralleled the community characteristic of summer. So few of the bottom dwellers of the Gulf breed in October or November that their larvæ are practically nonexistant in the plankton at that season; but the presence of juvenile Calanus in the western basin on November 1 (station 10400), of young Aglantha and young *Sagitta elegans*, of eggs probably referable to the latter, and of an abundance of small as well as large Limacina off Massachusetts Bay at that time (stations 10399 and 10403) proves that all these pelagic animals reproduce in the Gulf during October, though probably not in any great abundance.

I have already pointed out that no general alteration takes place in the zooplankton of the Massachusetts Bay region during late autumn and early winter, for our tows gave us much the same yield off Cape Ann at the end of November and in December, 1912, and in January, 1913,[25] as is to be expected there in August, September, or October—that is, Calanus dominant, with such other copepods as Pseudocalanus, *Metridia lucens*, Centropages, and Euchæta; the chætognaths, *Sagitta elegans* and occasional *S. serratodentata; Euthemisto compressa* and *E. bispinosa;* the common

[25] These hauls are described in an earlier report (Bigelow, 1914a, p. 404)

boreal pteropod *Limacina retroversa;* and the ctenophores Pleurobrachia and Beroë. This also applies to tow-net catches at 12 stations between Cape Cod and Yarmouth (Nova Scotia) for the midwinter of 1920 and 1921, listed below. These lists vary somewhat from station to station, as is always to be expected, but there is no characteristic qualitative difference between the western and the eastern stations, the Calanus community (and chiefly *C. finmarchicus*) dominating the same general assemblage of boreal animals as occurs in summer at the localities in question.

Species [1]	Location, date, and depth of hauls					
	Off Boston, Dec. 29, 1920, station 10488, 15–0 meters	Off Cape Ann, Dec. 29, 1920, station 10489, 75–0 meters	Western Basin, Dec. 29, 1920, station 10490, 240–0 meters	Off Cape Cod, Dec. 30, 1920, station 10491, 125–0 meters	Off the Merrimac, Dec. 30, 1920, station 10492, 20–0 meters	Off Isles of Shoals, Dec. 30, 1920, station 10493, 75–0 meters
Acartia clausi	×	×		×	×	×
Calanus finmarchicus	×	×	×	×	×	×
Calanus hyperboreus			×			
Pseudocalanus elongatus	×	×		×	×	×
Metridia longa	×	×		×	×	×
Metridia lucens	×	×		×	×	×
Centropages typicus	×	×				×
Euchæta norvegica			×			
Meganyctiphanes norvegica			×	×		
Thysanoessa inermis			×			
Thysanoessa longicaudata			×			
Euthemisto compressa		×		1		
Sagitta elegans	×	×	×	×	×	
Eukrohnia hamata			×			
Limacina retroversa	×		×	×	×	×
Clione limacina		1	2	3		1
Tomopteris catharina		1	×			
Aglantha digitale			×	×		
Pleurobrachia pileus			×	1		
Beroë cucumis	×	×		×		
Stephanomia	×	×	×	×		×

Species [1]	Location, date, and depth of hauls					
	Off Cape Elizabeth, Dec. 30, 1920, station 10494, 75–0 meters	Off Seguin Island, Dec. 31, 1920, station 10495, 60–0 meters	Off Matinicus Island, Jan. 1, 1921, station 10496, 100–0 meters	Off Mount Desert, Jan. 1, 1921, station 10497, 50–0 meters	Fundy Deep, Jan. 4, 1921, station 10499, 150–0 meters	Off Lurcher Shoal, Jan. 4, 1921, station 10500, 60–0 meters
Acartia clausi	×	×		×	×	
Calanus finmarchicus	×	×	×	×	×	×
Calanus hyperboreus			×	×	×	
Pseudocalanus elongatus	×	×	×	×	×	
Metridia longa	×	×	×	×	×	×
Metridia lucens	×	×	×	×		×
Centropages typicus		×	×	×		×
Euchæta norvegica			×	3	×	1
Meganyctiphanes norvegica	×			×	×	×
Thysanoessa inermis	×			×	×	×
Thysanoessa longicaudata	1					
Thysanoessa raschii	1					1
Euthemisto compressa					×	4
Euthemisto bispinosa				1		
Sagitta elegans	×	×	×	×	×	1
Eukrohnia hamata	1		1	1	×	
Limacina retroversa		×	×	×		×
Clione limacina		1	1	7		
Tomopteris catharina	12	1			4	
Aglantha digitale					×	
Pleurobrachia pileus				×		
Beroë cucumis					×	
Stephanomia				×		

[1] For complete lists of the copepods at these stations see p. 304.

The winter plankton of 1920–1921 differed from that of 1912–1913 in the rarity of the amphipod genus Euthemisto, both species of which not only occurred regularly during December, January, and February, 1912 and 1913, but usually in considerable numbers. *Sagitta elegans*, though it occurred regularly, was also far less numerous in the midwinter of 1920–1921 than at that season in 1912–1913, when it was an important factor in the tows made in Massachusetts Bay from December until February. Whether these differences were actually the result of annual fluctuation in the stock of these two animals present or whether both are normally more abundant in Massachusetts Bay and its vicinity than in other parts of the gulf in winter remains to be learned.

Other features of the winter plankton of the gulf worth mention are that the buoyant eggs of the American pollock (*Pollachius virens*) appear in great numbers from November until February over its restricted breeding grounds; that cod eggs are to be expected throughout the winter (Bigelow and Welsh, 1925, p. 424) if the nets be towed near where the fish are spawning—seldom otherwise or in large numbers; and that some few copepods (probably Calanus) continue to reproduce right through the cold season, for their nauplii were detected at most of our December–January stations of 1920 and 1921, most plentifully in Massachusetts Bay. Euthemisto, too, must breed then (though probably in small numbers) to account for very young specimens taken off Gloucester on December 29, 1920. In this connection I may also call attention to numbers of large *Calanus hyperboreus* (5 per cent of all the copepods) among a very rich catch of *C. finmarchicus* in the western basin on December 29, 1920 (station 10490, p. 304), and of Stephanomia bells in the eastern basin and in the shoal water off Yarmouth (Nova Scotia), which was nearly barren otherwise, on January 5. On the other hand, the arrow-worm *Sagitta serratodentata* vanishes from the gulf sometime during late winter, our latest seasonal record of it being for January 16, 1913 (off Gloucester).

Judging from the tow-net hauls made during 1913, the zooplankton of the Massachusetts Bay region continues decidedly uniform in composition throughout January and February, when the successive hauls reproduced one another with monotonous regularity, until early in March, when the quantity of animal plankton present in the water decreased to its annual minimum (p. 39) coincident with the vernal augmentation of vegetable plankton described elsewhere (p. 385), a change soon followed by the wave of reproduction on the part of the copepods which I have just discussed. It may safely be assumed that this is equally true of the northeastern part of the gulf, for although, unfortunately, we have no plankton records from its outer waters during the period January 9 to February 22, Doctor McMurrich found *Calanus finmarchicus* and Pseudocalanus, with *Temora longicornis* and the neritic copepod genus Acartia, the chief animal constituents of tow-net catches during this season of the year at St. Andrews.

The seasonal planktonic cycle in the deep waters of the gulf below 100 meters calls for separate discussion, because the Euchæta community is largely below the reach of the wide fluctuations of temperature to which the inhabitants of the shoaler strata of the gulf are subject. Data on this for the early winter consist of two tow-net hauls, one from 240 meters in the western basin, December 29, 1920

(station 10490), and the other from 150 meters in the eastern basin on January 5, 1921 (station 10502). On the former occasion the only members of the Euchæta community detected among a great abundance of large *Calanus finmarchicus* and *Calanus hyperboreus* (p. 304) were a few Euchæta and Eukrohnia; on the latter date the whole catch was extremely scanty (not over one-tenth liter), consisting chiefly of débris of the siphonophore genus Stephanomia, with Calanus and other copepods, among which there were a few Euchæta, Meganyctiphanes, *Thysanoessa inermis*, *Th. longicaudata*, *Sagitta elegans*, pteropods (*Limacina retroversa*), two *Euthemisto compressa*, but none of the deep-water chætognaths. These hauls suggest that a decided impoverishment of the deep-water plankton takes place during the autumn, but this may have been accidental. The Euchæta community probably persists unaltered in qualitative composition throughout the winter, as widespread over the deep trough then as it is in summer, judging from the following catches made with the closing net in the central and eastern parts of the basin on March 2 to 3, and in the Fundy Deep on March 22, 1920.

[D, dominant; M, many; ×, occurrence]

Species	Station 20052, central basin, 160 meters	Station 20053, southeast part, 175 meters	Station 20055, east basin, 180 to 140 meters	Station 20079, Fundy Deep, 180 meters
Calanus finmarchicus	D	×	D	×
Metridia lucens	×	×	×	×
Euchæta norvegica	M	×	×	M
Meganyctiphanes norvegica	11	2	2	22
Thysanoessa inermis			1	×
Pasiphæa	1		1	[1]2
Euthemisto compressa	1	1	1	1
Euthemisto bispinosa	1			1
Tomopteris catharina	×		×	1
Sagitta elegans	M	M	×	×
Sagitta lyra			1	[1]1
Eukrohnia hamata		12	×	20+
Limacina retroversa	×	×		
Clione limacina			2	[1]1
Beroë	×	1	1	[1]1
Aglantha			2	

[1] In open-net haul from 200 meters.

Occurrence of characteristic animals in the Eastern Basin, various localities and months [1]

[D, dominant; M, many; ×, occurrence]

Species	Location, date, and depth of hauls								
	Station 20081, 140–0 meters, Mar. 22, 1920	Station 20086, 150–0 meters, Mar. 23, 1920	Station 20112, 200–0 meters, Apr. 17, 1920	Station 10270, 150–0 meters, May 6, 1920	Station 10288, 200–0 meters, June 19, 1915	Station 10246, 150–0 meters, Aug. 12, 1914	Station 10093, 170–0 meters, Aug. 12, 1913	Station 10310, 175–0 meters, Sept. 2, 1915	Stations 10500 and 10502, 150–0 meters, Jan. 4 and 5, 1921
Calanus finmarchicus	D	D	D	D	D	D	D	D	D
Metridia lucens				×		×	×	×	
Euchæta norvegica	×	×	×	D	M	M	×	M	×
Meganyctiphanes norvegica	D	D	×	M	×	M	×		×
Thysanoessa, various species		×	×	×	×	×	×	×	×
Pasiphæa	×		×						×
Euthemisto compressa			×	×		×	×	×	
Euthemisto bispinosa						×	×	×	
Tomopteris catharina	×	×		×	×		×		×
Sagitta elegans	×	×	×			×	×		
Sagitta maxima	×	×	×			×	×	×	
Eukrohnia hamata	×	×	×			×	×	×	×
Limacina retroversa				×	×	×	×	×	
Clione limacina	×	×	×	×					
Beroë	×	×	×	×				×	
Aglantha	×					×			

[1] For further lists of the copepods see p 297.