Copepods Collected by the Nuclear Submarine SEADRAGON *on a Cruise to and from the North Pole, with Remarks on their Geographic Distribution*[1]

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ABSTRACT

A brief, non-detailed description is given of an automatic, multiple net plankton sampler used on a submarine cruise between the North Atlantic and Pacific oceans by way of the North Pole. The copepods contained in 90 samples from the Arctic have been identified and their relative abundance determined. The most frequently and widely occurring of the 18 species were *Metridia longa*, *Calanus hyperboreus* and *C. glacialis*. *Pseudocalanus minutus*, found mostly in the Chukchi Sea region, was the most abundant. From their known geographic distribution, six species are recognized as cosmopolites and 12 as Arctic or cold water species. Of the latter group, one is endemic to the Arctic and five are not known from the Pacific.

Introduction. In 1907 the famed polar explorer Fridtjof Nansen (30) briefly discussed the submarine as a tool for exploring northern waters but expressed reservations as to its practicality because of the difficulty of submerging deep enough to avoid the lower surfaces of large ice masses. Twenty-four years later a group of scientists aboard the submarine NAUTILUS made a series of observations, some biological, in the waters north of Spitsbergen to the edge of the ice at approximately 82°N (37). Although the loss of a diving rudder precluded extensive observation and cruising beneath the ice, as planned, presumably this was the first attempt to employ a submarine for oceanographic studies in the Arctic.

In the past, plankton collecting beneath the ice has been done through holes drilled in the ice, or in open areas between floes, where only vertical

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collections are generally possible. Prior to the colonization of ice islands by scientists from Russia (16) and the United States (27), most collections were obtained by ships such as the FRAM (34) and SEDOV (3) which drifted in the ice pack. Russian scientists have also landed at the North Pole in an airplane and established a station on the ice from which they collected plankton and various data (31, 36).

The series of plankton collections obtained by the nuclear submarine SEADRAGON in August and early September 1960, analyzed and reported in part below, represents the first quasi-synoptic series of horizontal plankton collections made in waters beneath the Arctic ice.

The Sampler. The sampler was specifically designed and built for use aboard a submarine. The housing, made of stainless steel, was capable of withstanding pressures up to 500 psi. The sampler measures 10″ × 10″ on a side and 38″ high. It weighs 320 pounds in air. Fig. 1 shows its place of attachment within the "sail" of the submarine. The water intake end of the hose was directed forward and fastened beneath the ice caps which partially enclose the top of the sail.

The sampler has 24 net receptacles arranged on a revolving circular plate which is geared to a battery-operated motor that is activated by a clock, the timing mechanism of which can be set so that each net is exposed to the flow of water for a period of 1/2, 1, 6, or 12 hours. The nets, 3/4″ in diameter and 12″ long, were made of nitex mesh (aperture size 0. 223 mm). Approximately two seconds are required to expose adjacent receptacles to the inflow of water into the sampler (beneath the elbow in Fig. 1). The timing mechanism was

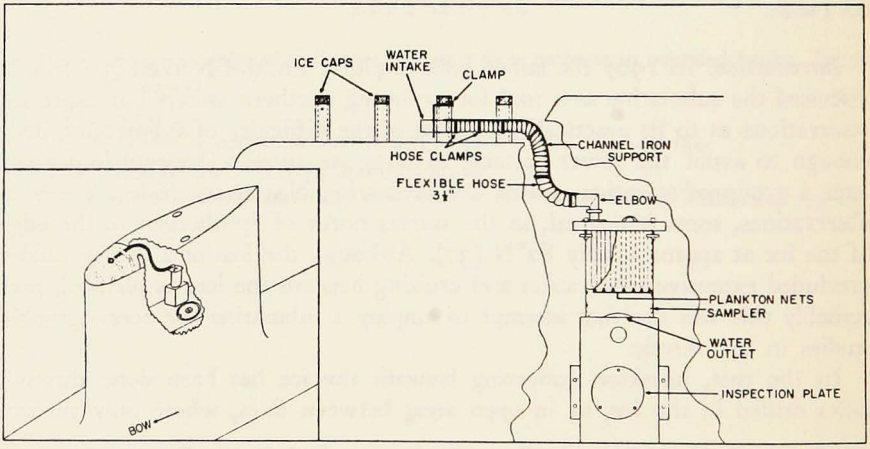

Figure 1. Sketch of sampler showing its location in the sail of the submarine (inset); from an original sketch by Charles S. Yentsch.

Figure 2. Areas along the submarine's cruise track where collection series I–XVII were obtained. Approximate location of 200 m contour shown with dotted line. Stippled areas are ice boundaries at points of entry and departure of the submarine.

set to move the receptacle plate at hourly intervals, and one net was placed in every other receptacle. Thus 12 collections were made during each 24-hour period, after which the sampler automatically turned itself off. Since the present sampler has no flow meter, the quantity of water passing through the individual nets could not be measured.

The Collections. When the submarine surfaced after the completion of a sampling series, the nets and their contents were frozen *in toto.* New nets were placed in the receptacles in preparation for the next submergence. During the entire cruise, 204 collections (17 series of 12 each) were made (Fig. 2).

The eight series (I–VIII) obtained prior to the submarine's entry into the Beaufort Sea are not considered in this paper. Of the 108 collections obtained in the nine Arctic series (IX–XVII), 18 were retained by Dr. John Mohr, University of California, for chemical and other analyses of the zooplankton; the remaining 90 collections form the basis for this study.

The samples were thawed in 5–10% formalin solution. The lower end of the net was cut open and the organisms were removed with the aid of a fine jet of water and forceps. The zooplankton was then sorted into the major groups represented, and all but the copepod fraction (by far the largest) was sent to Dr. Mohr. Most of the animals, particularly those obtained in the early part of a given series, were flattened, or had undergone decomposition or autolysis, presumably between the time of collecting and freezing. Since the chitinous parts of the crustaceans were generally intact, all but the most mutilated specimens could be identified. The copepods in each collection were identified and counted.

Occurrence and Geographic Distribution of the Species. Data concerning the collections and numbers of copepods and species are shown in Table I. In 79 of the 90 collections there was a total of 10,546 specimens; in the other 11 samples there were none.

Assuming that approximately the same volume of water passed through each net, one of the most obvious features of the copepod distribution was their paucity in collections from the Arctic basin (series IX–XIII) compared to their abundance in collections where bottom depths approached 200 m (series XIV–XVII). In the former, the maximum number in any single net from the five series (52 collections) varied between only 19 and 25; the mean number per collection likewise showed but little variation (6–15/sample).

TABLE I. DATA CONCERNING THE COLLECTIONS MADE BY THE SUBMARINE SEADRAGON IN THE ARCTIC.

Series	Av. depth of coll. (m)	Bottom depth (m)	No. coll. exam.* positive	No. coll. exam.* negative	Total no. copepods in all coll.	Mean no./coll.	Range	No. species
IX	122	500+	10	2	85	7	0– 25	6
X	122	500+	8	2†	59	6	0– 23	4
XI	122	500+	6	0†	89	15	2– 19	4
XII	110	500+	9	3	101	8	0– 20	9
XIII	110	500+	12	0	108	9	1– 19	11
XIV	46	*ca.* 200	10	0†	411	41	6– 93	9
XV	46	200+	8	2†	159	16	0– 39	4
XVI	91	200+	11	1	7,883	657	0–3,365	9
XVII	37	200—	5	1†	1,651	275	0– 801	6

* Each series contained 12 collections, but Dr. John Mohr retained several collections from each of five series as noted by †.

TABLE II. FREQUENCY OF OCCURRENCE AND ABUNDANCE OF THE SPECIES IN THE 90 COLLECTIONS.

Species	Series	Frequency	No. specimens found
Metridia longa (Lubbock)	IX–XVI	58	661
Calanus hyperboreus Krøyer	IX–XVII	56	868
C. glacialis Jaschnov	IX–XVII	45	273
Pseudocalanus minutus Krøyer	XIV, XVI, XVII	18	8,537
Scaphocalanus magnus (Scott)	IX, XII, XIII	15	21
Chiridius obtusifrons Sars	IX–XV	13	17
Ectinosoma finmarchicum Scott*	XII, XVI, XVII	12	43
Calanus finmarchicus (Gunnerus)	XII–XIV	9	18
Oithona similis Claus	XVI, XVII	9	36
Acartia longiremis (Lilljeborg)	XVI, XVII	6	17
Paraeuchaeta glacialis (Hansen)	IX, XIV	5	12
Oncaea borealis Sars	XIV, XVI	3	3
Microcalanus pygmaeus (Sars)	XIV, XVI	2	2
Spinocalanus magnus Wolfenden	XII, XIII	2	2
S. abyssalis Giesbr. var. pygmaeus Farran	XII, XIII	2	3
Heterorhabdus norvegicus (Boeck)	XIII	1	1
Temorites brevis Sars	XII	1	1
Lubbockia glacialis Sars	XIII	1	1
Unidentified and mutilated specimens	IX, XI–XV, XVII	15	30

* Identified by Dr. H. C. Yeatman.

In the latter series (from comparatively shallow waters), particularly in the two series near Alaska (XVI, XVII) in the Chukchi Sea, the mean numbers, with the exception of series XV, greatly exceeded those in the Arctic basin. These large numbers were due to the presence of a single species found rarely elsewhere.

Eighteen species of copepods were found in the collections (Table II). Following is a brief discussion of the more common of the 18 species. In compiling the distribution of the species I have not, except where noted, used Wilson's (45, 46) records, since many of his determinations have been found to be incorrect.

Metridia longa was the most frequently encountered and the third most abundant species (Table II), being represented in all except series XVII, which was obtained from the relatively shallow Chukchi Sea. Only seven males were observed among the 353 adults. The number of immature specimens (308) indicates that the species thrives in Arctic waters.

This species has been reported from the Arctic by numerous authors (4, 5, 15, 17, 24, 34, 36 *et al.*). It also occurs in the North Atlantic (25, 35). Although it has been reported as not occurring in the Pacific Ocean (6, 8), there have been reports of it from both the eastern (9, 12) and western (38) parts of this ocean; Dr. T. E. Bowman has re-examined the specimens from the

Pacific Ocean reported by Wilson (46) as *M. longa* and has found that only those collected off the Alaskan coast are this species.

Calanus hyperboreus, also a markedly Arctic species, ranked second in abundance and in frequency of occurrence (Table II). It was observed in all series, but only juvenile specimens were detected in the Chukchi Sea series XVII. Of the 868 specimens collected, most of the 715 immature specimens were stage IV and V copepodids, indicating that the peak of reproduction in these waters occurred sometime before the collections were made.

This species has frequently been reported from the Arctic and neighboring waters (5, 8, 14, 15, 17, 22, 24, 27, 29, 34, 36). Its presence in one deep collection (0–1500 m) from the Sargasso Sea (30°04'N, 42°29'W) constitutes the southernmost record of it in the Atlantic Ocean (35). There are also many other reports of it from the North Atlantic (*e.g.*, 1, 2, 25). Although it has been reported from the Pacific Ocean by Marukawa (26) and Wilson (45, 46), the former is probably based on erroneous determinations (39) and the latter is definitely based on incorrect identifications (*in litt.* Dr. T. E. Bowman to Dr. R. J. Conover).

Calanus glacialis, occurring in 45 collections, was third in frequency and the fourth most abundant (Table II). It was present in all series but was more abundant in the last four than elsewhere. Of the 273 specimens, 184 were juveniles, mostly stage V copepodids.

This decidedly Arctic species occurs in the polar basin and marginal seas (19), but according to Brodsky (7), Jaschnov's (19) report of it from "far eastern seas" is in need of confirmation. There is, however, a recent report of it from Aniva Bay, Sea of Okhotsk (33). Grainger (18) has found it in many localities in Canadian Arctic-subarctic waters. He showed that its distribution coincides with the known extent of either unmixed polar waters (if found without *Calanus finmarchicus*) or mixed polar and Atlantic waters (if found with *C. finmarchicus*). The southernmost record for *C. glacialis* is the Gulf of Maine (18); I, too, have examined specimens from there collected by Dr. R. J. Conover.

Pseudocalanus minutus was represented by two size groups (*P. minutus* f. *elongatus* and f. *gracilis*) but they were not routinely discriminated. In terms of numbers, this was the most abundant species (8,537 individuals) but it occurred in only 18 collections from series XIV, XVI and XVII. Only five specimens were found in series XIV, the remainder being recorded in collections from the other two series.

This species is well known from the Arctic (15, 17, 21, 22) and occurs as far south in the northern hemisphere as Japan (40) in the Pacific and North Carolina in the western Atlantic (32) and south of the Azores in the eastern Atlantic (25). Within this extensive range it is likely that the two forms noted have a more restricted distribution.

Calanus finmarchicus was first encountered in the last two collections of series XII (about 87°N), and the remaining specimens were found in series XIII and XIV. No adult males and only 18 adult females were counted, these varying in total length between 3.1 and 3.7 mm. On one specimen (3.6 mm) the teeth on the first basipodal segments of the fifth feet totalled 27 and 31 on either side and the rows formed nearly a straight line. These length and teeth data are in fair agreement with Jaschnov's (19) restricted definition of this species. In the same series of samples containing *C. finmarchicus* there were specimens of *C. glacialis* measuring over 4.5 mm in length.

C. finmarchicus has been reported from the southern half of the Barents Sea, coasts of Norway, and the North Sea (19). In the Atlantic it occurs as far south as at least Cape Hatteras (2), excluding Lysholm's and Nordgaard's (25) records of this species, which possibly also include *C. helgolandicus* and *C. glacialis*. The occurrence of *C. finmarchicus* with *C. glacialis* may indicate the presence of mixed Atlantic and polar waters as Grainger (18) has shown in his study of the distribution of these species in Canadian Arctic-subarctic waters. *C. finmarchicus* is apparently absent from the Pacific.

The remaining 13 species (Table II) did not occur in sufficient abundance or frequency to warrant individual discussion. Although all have been previously reported from polar or adjacent seas, seven (and also the above five) have a fairly restricted geographic distribution and six are widely distributed or bathypelagic.

The seven species with restricted distribution listed in the order of frequency of occurrence together with the southernmost report of each for the Atlantic and Pacific oceans are: *C. obtusifrons*, Atlantic (1), Pacific (absent); *E. finmarchicum*, Atlantic (14, ?20), Pacific (10); *A. longiremis*, Atlantic (32, omitting 44 [see p. 106]), Pacific (28); *P. glacialis*, Atlantic (47), Pacific (absent); *O. borealis*, Atlantic (23), Pacific (9); *H. norvegicus*, Atlantic (35), Pacific (absent); *L. glacialis*, Atlantic (endemic to Arctic region), Pacific (absent). The latitudinal distribution of each and of the five species discussed earlier is shown in Fig. 3.

The remaining six widely distributed species occur in both northern and southern hemispheres. In the Arctic region the oceanic species are sometimes found in the epiplankton, but in intermediate latitudes and especially in the Antarctic region some of these species, such as *Scaphocalanus magnus*, *Spinocalanus magnus*, *S. abyssalis* and *T. brevis*, usually occur in considerably deeper water. *O. similis* and *M. pygmaeus* also have exceedingly wide geographic range in the Atlantic and Pacific oceans. Vervoort (41, 42, 43) has summarized the geographic and bathymetric range of all these species.

Using species of endemic Pacific copepods as indicators, Brodsky (cited in 8 and 16) was able to trace a layer of Pacific water which penetrated the Bering Straits and spread northward over much of the Arctic Basin. This water oc-

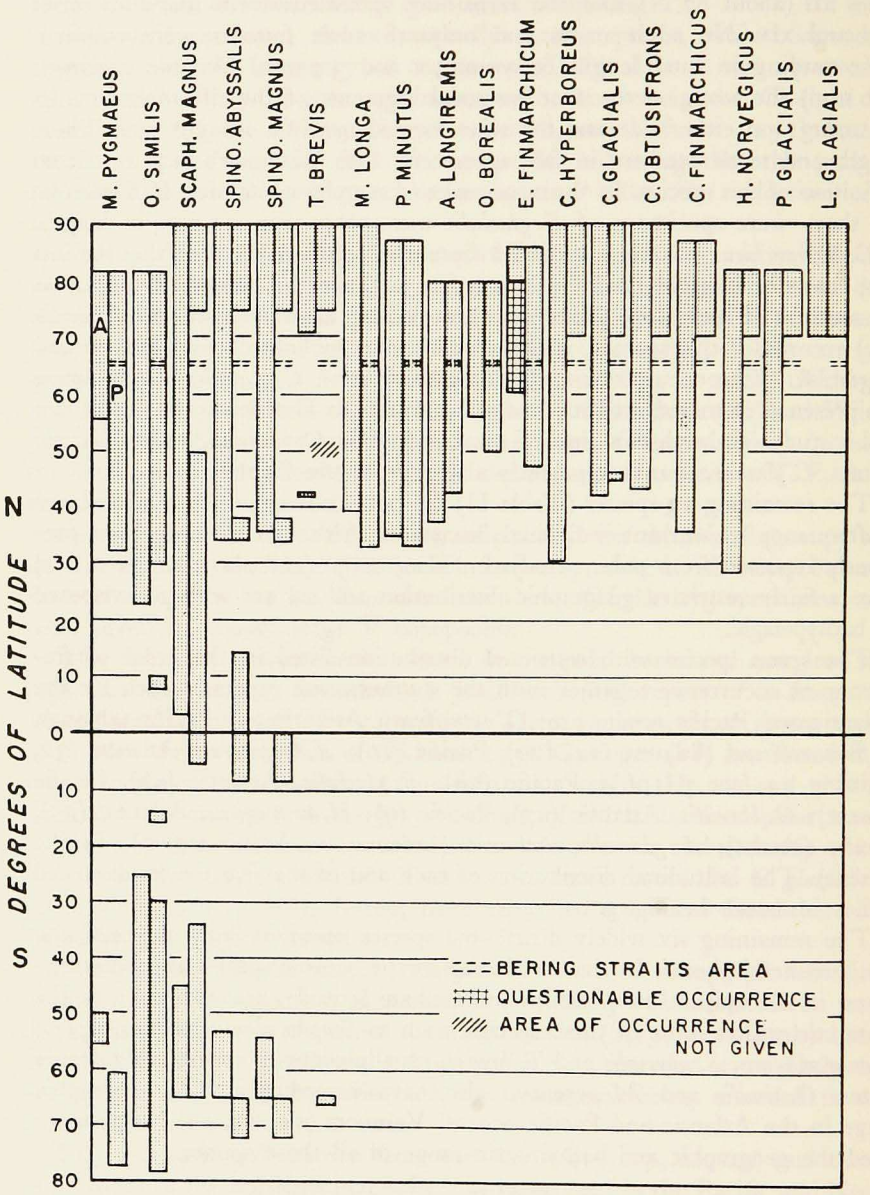

Figure 3. Latitudinal distribution of the species in the Atlantic (A) and Pacific (P) oceans.

cupied a stratum between depths of 250 and 350 feet. None of the indicator species was found in the present study. Since the indicator species are not abundant, as evidenced by the few reported, they could have been missed owing to the diminutive nets used and the small volumes of water filtered.

Discussion. The 18 species of copepods found in the epiplankton of the Arctic can be classified into two groups on the basis of their geographic distribution (Fig. 3).

Species of the first group have little value in characterizing geographic regions and are referred to by Ekman (13) as cosmopolites, of which two types are recognized—eurythermal and cold-water cosmopolites. The eurythermal species occur over a wide geographic and bathymetric range in both cold and warm water regions, as in the case of *O. similis*, which is known from the Arctic and Antarctic areas as well as from the tropical Pacific and Atlantic oceans. The cold-water cosmopolites usually live in cold deep water in the equatorial area and in the epi- or meso-plankton of the Arctic and Antarctic areas. Species of this type are *Scaphocalanus magnus*, *Spinocalanus magnus*, *S. abyssalis* and *T. brevis*, but the last two may be predominantly bathypelagic everywhere. *M. pygmaeus* may also be included among these latter species, but apparently there are no records of it from equatorial latitudes of the Atlantic or Pacific.

The second group, including the remaining 12 copepods, are cold-water species which penetrate southward from the Arctic, the oceanic ones usually in deep water, to varying degrees of north latitude (Fig. 3). Five of these, *C. finmarchicus*, *C. hyperboreus*, *C. obtusifrons*, *H. norvegicus* and *P. glacialis*, do not occur in the Pacific Ocean. The shallow neritic waters of the Chukchi Sea and Bering Straits apparently form an effective barrier to their dispersal into this ocean.

Some of the cold-water species appear to be much more confined to the Arctic and closely adjacent waters than other species. *L. glacialis* is endemic to the Arctic. *E. finmarchicum* is known from only one locality in the northern Pacific and from no certain records outside of polar seas in the Atlantic. The southernmost record for *C. glacialis* and *C. obtusifrons* is the Gulf of Maine, for *P. glacialis* the northern Atlantic off Ireland (51°N), and for *O. borealis* (in the Atlantic) the southern Labrador Sea. These six species (except possibly *O. borealis* and *E. finmarchicum*) can be considered Arctic as defined by Ekman, and it is possible that they are in an expatriated zone in their extreme ranges where they are unable to maintain themselves through reproduction.

C. hyperboreus, *M. longa* and *H. norvegicus* are Arctic-bathy-subarctic species, and apparently can breed over part of their subarctic ranges. Juveniles of *C. hyperboreus* have been reported as far south as about 41°N off Martha's Vineyard, Massachusetts (11). *M. longa* is known to breed in the southern Labrador Sea (23) and possibly in the Gulf of Maine (1), but nothing is known

of its reproductive activity in the Pacific Ocean. Ripe females of *H. norvegicus* have been found in the Labrador Sea (23).

The remaining three species (*A. longiremis*, *C. finmarchicus* and *P. minutus*) may be considered Arctic-boreal (cold temperate) and are usually found in the epiplankton throughout their range. They are able to breed in the area immediately south of Cape Cod. *A. longiremis* has recently been reported from near Barbados Island (44). This single female was collected from the surface waters. *C. finmarchicus* does not occur in the Pacific and nothing is known of the breeding of the other two species in that ocean.

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