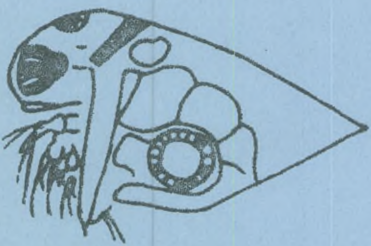

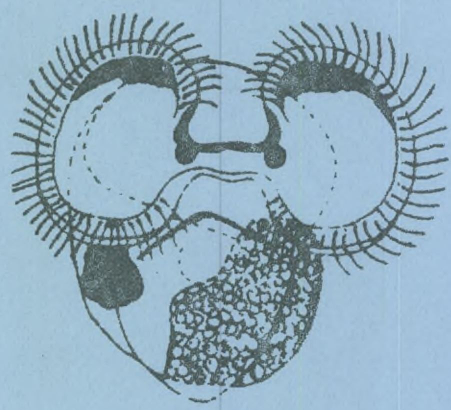

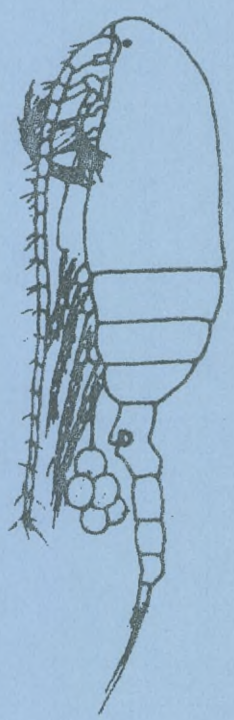

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Preliminary report on the biology of *Undinula vulgaris* (Dana) and *Calanus minor* (Dana) in the area Florida Current - Caribbean Sea

by

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This preliminary report is intended for only limited distribution. Therefore, in citing material in this report the reference should be followed by the phrase "UNPUBLISHED MANUSCRIPT", in accordance with bibliographic practice.

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INTRODUCTION

Undinula vulgaris (Dana) is often abundant in tropical and subtropical waters and is probably a very important food organism in these areas. It is a rather large copepod (adults 2.2-2.6 mm) and Vervoort (1949), working with samples collected in the eastern part of the area now comprising the Republic of Indonesia, has considered it, together with Euchaeta marina and Labidocera acuta, comparable in ecological importance to Calanus finmarchicus in northern waters.

The biology of U. vulgaris, however, has been investigated surprisingly little. Most papers concerning U. vulgaris deal mainly with its distribution. A few papers have described the development of U. vulgaris. Sewell (1929) described copepodite stages 3-6 and Björnberg (1966) described all nauplius and copepodite stages. Rather recently, Koga (1968 a,b) described the egg and nauplius I,III and V.

Recently Zillioux (1973) described a method to study the feeding rate of copepods with radioactive isotopes and compared experiment chambers operated by divers with remote-controlled chambers fixed on a hydrographic wire. An improved chamber operated by hydrographic messengers now has been developed and is suitable for operations at unlimited depths.

In April, 1973, the R/V COLUMBUS ISELIN made a cruise from Miami to the northern Caribbean Sea (see fig. 1). During this cruise feeding experiments were carried out with U. vulgaris both in situ from surface down to 200 m depth and in the laboratory. Simultaneously, samples were taken with plankton nets 4 times a day for analysing the occurrence of Undinula vulgaris.

This paper deals with the distribution of U. vulgaris and its developmental stages as well as another important copepod in the samples, Calanus minor (Dana). As the two copepods are morphologically similar, especially the younger copepodite stages, we have included a section in this paper about the length of the various stages.

MATERIAL AND METHODS

The biology of U. vulgaris and C. minor was investigated by taking samples with a 1/2 meter net with 64 µm mesh size. A flow-through cod end was used, containing a collecting bag of 44 µm mesh size. The small mesh size was used to collect all stages including nauplius stage 1. According to Björnberg (1966) N1 is about 0.16 mm long and the width is about 0.092 mm. A flow-meter (General Oceanics) was attached to the opening of the net. All the values of the analysis were afterwards recalculated to relative unit volume. As the total volume of water filtered per unit of time in the Florida Current was very different from the volume filtered per comparable time in the Caribbean Sea, it was obvious that such calculations were necessary in order to compare the hauls.

The samples were preserved in Polyspec[1)] with 5 % formalin according to a new procedure for preservation of zooplankton samples described by Zillioux and Ackefors (in preparation).

The samples were taken at noon, sunset, midnight and sunrise. During the first half of the cruise, horizontal surface tows of 10-15 min duration and vertical tows from 30-0 m, 60-0 m and 90-0 m were taken. During the second part of the cruise tows were made only at 0 m, 100 m and 200 m. After each 15 min tow, the net was hauled vertically to the surface. No closing mechanism was available.

Special attention was given to light conditions when sampling. The light was measured above surface with a Gossen Luna-Pro light meter. Measurement of light intensity from 350 000 lux to about 0.2 lux is possible with this meter.

Horizontal surface samples were taken at various light conditions just before sunset and just after sunset. Corresponding samples were also taken around sunrise. Results from these samples were the most significant of the investigation.

The occurrence and developmental stages of Undinula vulgaris and Calanus minor in the samples were determined. Certain specimens of the analysed individuals were measured and the mean and the standard deviation were calculated (table 2).

Some samples were subsampled in 4 equal parts with a subsampler. In samples with very large numbers of U. vulgaris, the first aliquots were subsampled once more and two 1/16 parts of the original sample were analysed.

The cruise of the R/V COLUMBUS ISELIN in April, 1973, surveyed the area described in fig. 1.

Samples were taken at 9 stations on route to Mayagüez, Puerto Rico. The vessel was on station near the southern shore of Mona Island, Puerto Rico, for 5 days. Each evening the vessel moved into deep water to take plankton samples both for analysis and for laboratory experiments (stations 10-13). On its return to Miami another 6 stations (14-19) were sampled south of Hispaniola in the Caribbean. Due to lack of time, no further stations were sampled until station 20 (pos.23°53'N, 79°27'W) between Cuba and Florida. Another two stations were sampled (21-22) before the end of the cruise. The remainder were sampled after the cruise with the R/V ORCA from Miami in April 1973 and in January and February 1974 (see table 1).

1) Polyspec is sold by Spectrum-Marine Research Laboratories Inc. P.O. Box 7219, Ludlum Branch, Miami, Florida 33 155.

EFFECTS OF HYDROGRAPHIC CONDITIONS

We have included the following discussion of hydrographic conditions for two purposes. First is the obvious need to relate samples from different locations with some knowledge of the transport conditions affecting distribution. Secondly, we have attempted to offer a possible explanation for the observed variability in populations of U. vulgaris sampled in the Florida Current off Miami. It must be emphasized that placing values on current effects upon distribution requires a good deal of extrapolation and assumptions based upon a very limited knowledge of the total system of hydrographic conditions. We will, nevertheless, attempt such an interpretation of distribution in the hope that if our values prove not realistic in a broad sence, they will be relative at least to the main volume of flow of the primary water masses affecting U. vulgaris distribution.

The horizontal distribution of U. vulgaris in the Caribbean is dependent upon transport by currents which are primarily wind-driven and, therefore, seasonally variable (Wüst, 1964 and others). Although vertical migration of the stage V copepodite and adult forms is a distinct character, it is of relatively shallow range and individuals of the main population are consistently under the transport influence of the wind-driven water masses. The vertical range of U. vulgaris extends through the Caribbean Surface Water and into Caribbean Subtropical Underwater. Wüst (1964) reports the core position of the Subtropical Underwater to be between 100-200 m except in the southern Caribbean where it rises as shallow as 50 m. Measurements of current velocity in the Subtropical Underwater are limited but its direction is generally the same as the Surface Current and the main axis of flow of Caribbean Subtropical Underwater coincides with the high speed axis of the Caribbean Surface Current. Direct current measurements by Pillsbury (1887) show little variation in speed at depths of 6.3, 27 and 57 m and significantly lower speeds at 117 m only within the high speed axis. The descriptive results of Wüst (1964) compared with the geostrophic velocities and transports given by Gordon (1967) illustrate the similarities between these closely associated water masses which represent the main sources of the Gulf Stream System. From these data and because the vertical range of U. vulgaris is primarily within the upper 100 meters, we feel that it is reasonable to approximate the horizontal transport of the total population of U. vulgaris from the more abundant surface current measurements.

It is difficult to determine a mean velocity for horizontal movement of water masses based upon integration of individual current measurements due to wide variations in velocity, direction and seasonal influence. For our purposes, the most useful integrations of current speeds have been prepared by Fuglister (1951) for large segments of the Caribbean and Florida Currents. These data were assembled from many thousands of observations of ship drift. Only averages of a very large number of observations would be reliable because short-term (less than two weeks) variability in both velocity and hydrographic structure has been shown to be as large as seasonal changes in the Florida Current (Niiler & Richardson, 1973). The much lower values of speed which Fuglister obtained by averaging the resultant drifts for all one degree quadrangles in each segment for each month are considered more useful to the distribution analysis than measurements of main current flow. We have accepted, therefore, the mean of the values given for Fuglister's Caribbean Current and Florida Current segments as the best available estimate of mean surface current velocity for the Gulf Stream System from the beginning of the Caribbean Current through the Florida Current.

The mean transport velocity of the Caribbean - Florida Current System varies from a low of 49.8 km day^{-1} in November to a high of 68.6 km day^{-1} in July. Following the direction of main current flow and assuming 100 % transport efficiency we have calculated 85.7 days in November or 84.8 days in July for a segment of the U. vulgaris population to travel from the eastern Caribbean at the Antillian arc to the Florida Current off Miami. The total distance traveled is corrected for seasonal changes in path length of the Gulf of Mexico Loop Current (Maul, 1974) which varied from 605 km in Oct-Nov 1972 to 2 153 km in July 1973. Although not all monthly calculations of total transport time are this similar, it appears, in general, that the seasonal fluctuations in Loop Current path length approximately compensate for seasonal variations in current velocity. A chart of path lengths of the Gulf Loop Current as determined by Maul (1974) is reproduced here (fig. 2).

Although the Loop Current may not significantly vary the length of transport time through the Caribbean - Florida Current System, its path through the Gulf of Mexico is in part responsible for the occurrence of mixed plankton populations off Miami. The flora and fauna of the Gulf of Mexico are seeded by organisms indiginous to the Caribbean Current that, in turn, may establish resident populations in the Gulf for indefinite periods. During the cruises from which Maul obtained his data on Loop Current path lengths, Michael Ednoff (personal communication) obtained evidence from continous plankton sampling through the edge zone that exchange of plankton organisms between Loop Current water and shelf water occurs commonly in either direction. Evidence also exists (Maul, 1974 and others) that following the period of deepest intrusion of the Loop Current into the Gulf a large anticyclonic eddy of Caribbean Current Water separates and is retained in the northern Gulf as the main current drops back to a position of minimum panetration. Populations of copepods thus separated from the Caribbean Current may obtain a production advantage by spending more time at higher temperatures which could extend the period of productivity for a single life cycle. Also, offspring produced in the Gulf may reach reproductive age in that system whereas, if they had not been retained in the Gulf, they would have been carried north-ward and probably beyond optimal maturation temperatures before completing development. The optimum temperature for Undinula vulgaris is apparently above 25°C (Björnberg, 1963). If production does occur in displaced populations, entrainment of the resultant offspring by the Gulf Loop Current would confuse samples taken from the Florida Current east of the Gulf of Mexico.

An additional source of confusion in plankton samples from the Florida Current east of Miami comes from a secondary input from the east. In several charts of current measurements taken throughout the year, Wüst (1964) shows a consistent shunt of eastern Caribbean Surface Water which passes northward through Mona Passage (probably mixing with North Equatorial Current Water passing to the north of Puerto Rico) and thence westward following the Hispañola Basin and Old Bahama Channel to join with the Florida Current. Calculating transport time from the median values of current velocity arrows on the charts prepared by Wüst, organisms from the eastern Caribbean should reach the Florida Current in about 112 days or about 27 days later than the calculated total transport time of the main current system. The importance of this input is unknown but probably is less than the effect of prolonged periods of productivity by Caribbean populations retained in the Gulf of Mexico.

Based upon the above analysis of the Caribbean - Florida Current System, it is probably unwise to assume continuity of samples or to infer maturation times or production cycles from sample data if a portion of the collections were taken downstream from the Yucatan Straits.

RESULTS

The temperature in the surface waters was around 25°C from Florida Current off Miami to the area north of Cuba. It was 26°C at station 9 north of Dominican Republic and between 25.5-27.0°C at stations 10-19 in the Caribbean Sea.

At 100 m the temperature increased from about 24°C off Miami to 27°C on some stations south of Republic of Haiti (stations 17-18). At 200 m level the temperature increased from 17°C off Miami to 22-23°C at stations 17-18.

The salinity at surface varied irregularly between 37.2 to 38.7 ‰ at the various stations showing no correlation that the salinity increased from north to south. The salinity was rather homogenous from surface down to 200 m. At some stations there was, however, a slight increase from surface to the 200 m level. In one case, there was an increase of 1.8 ‰ at the deep level reflecting the presence of Subtropical Underwater, but on certain stations the intermediate or surface layer had slightly higher salinity than the deeper layers.

Undinula vulgaris

Sewell (1914, 1929) and Vervoort (1949) have described and discussed varieties or formae. Moreover Sewell (1929) reported about two growth classes in adult females, viz. forma *major* and forma *minor*. Var. *giesbrechti* and var. *zeylanica* (Sewell 1914, 1929) seem to belong to the forma *major* according to Vervoort (1949). Both varieties have *double* spines on the left side of the thoracic margin. In forma *giesbrechti* the upper spine projects straightly backwards, the lower curves downwards. The right spine is as in the forma *zeylanica* single and curved downwards.

Forma *zeylanica's* posterior thoracic margin is considerably thickened; the spine on the right side is straight and points backwards.Var. *typica* Sewell belongs to the forma *minor* according to Vervoort (1949). Forma *typica* has its left and right lateral thoracic margins symmetrical, produced into a *single* spine, which at first points backwards but later curves ventrally and becomes distinctly claw-shaped.

The forma we got in our investigation was forma *typica* (or *minor*) if taking into consideration the single spine on the thoracic margin as the main character to distinguish between forma *typica* from the two other formae. The size range of our specimens is, however, nearly exactly the same as Sewell (1929) reported for forma *major*. The total length of forma *major* ranges from 2.208 to 2.623 mm (Sewell, 1929). In our material the size range is 2.04-2.64 mm (see below). We got the following size ranges for different stages in comparison with Sewell(1929):

	Ackefors & Zillioux	Sewell (1929)
C3	1.00-1.20 mm	1.075 mm
C4	1.44-1.64 mm	1.547-1.887 mm
C5	1.72-2.14 mm	1.717-1.924 mm (forma *major*) 1.547-1.698 mm (forma *minor*)
C6 ♂	2.04-2.54 mm	
C6 ♀	2.20-2.64 mm	2.208-2.623 mm (forma *major*) 1.868-2.189 mm (forma *minor*)

Hence, it is evident, that the size of our specimens is more like forma *major* (var. *giesbrechti* or *zeylanica*).

The mean size of Undinula was different at station 1 off Miami in comparison with the mean from all stations together. The mean ± 2 SD is given below

	off Miami	all stations
C6 ♀	2.53 ± 0.18 mm	2.44 ± 0.18 mm
C6 ♂	2.33 ± 0.28 mm	2.23 ± 0.24 mm
C5	2.02 ± 0.10 mm	1.94 ± 0.16 mm
C4	1.54 ± 0.08 mm	1.53 ± 0.10 mm
C3	1.16 mm	1.15 ± 0.11 mm

In fig. 2 the total body lengths of representative specimens of U. vulgaris and C. minor are reproduced.

Calanus minor (syn. Nannocalanus minor)

Sewell (1929) distinguished between two very similar forms, differing mainly in size. Forma major (♀); total length varies from 1.55 to 1.64 mm and the length of forma minor varies from 1.32 to 1.49 mm. In our material the adult females were in the size range 1.54-2.00 mm and the males in the size range 1.50-1.80 mm. Copepodite stage 5 ranged from 1.40 to 1.60 mm. Our specimens are thus more like forma major but are bigger than Sewell (1929) found. Vervoort (1949), however, reported about 3 ♀♀ in the size range 1.65-2.09 mm and the mean 1.86 mm.

The abundance of copepods

The calanoid copepods dominated in the samples and among them the small copepods as Paracalanus spp. and Clausocalanus spp. Among the bigger copepods Undinula vulgaris and Calanus minor were par préference the most abundant species and other big copepods as Euchaeta marina, Eucalanus mucronatus, Labidocera acutifrons, Pontellopsis regalis were not abundant.

The cyclopoid copepods as Farranula spp. and Corycaeus spp. were also abundant but not as abundant as the small calanoid copepods. Less abundant but never the less rather common were the harpacticoid copepods Miracia spp. and Microsetella spp.

U. vulgaris was 3-4 times more frequent in the surface samples than C. minor (table 2). U. vulgaris occurred in all samples but C. minor was missing at 8 stations. They did not occur at all at most of the stations in the Caribbean Sea and at stations 9, 10 and 14 (cf. fig. 1). They were much less frequent than U. vulgaris. As the length of

C. minor is about 70 % of the length of U. vulgaris, the relation between the volume or biomass of the specimens of the two species is in the order 1:3. Supposing that our samples reflect the time relative frequency of the two species, the mean biomass of U. vulgaris was 10 times greater than the biomass of C. minor. Such calculations also indicate that U. vulgaris was the most important copepod although the small copepods were more numerous as mentioned above.

The efficiency with which our net captured large copepods was limited, however, due to the selected mesh size. As the compression wave in front of a net increases with decrease in mesh size, succesful avoidences by the stronger swimming of larger animals will naturally increase. Comparisons of abundances between small and large copepods in our samples, therefore, should be considered with caution. This restraint should not, however, effect comparisons of relative differences between hauls of the individual species and stages under investigation.

Age distribution and sex ratio

In April, 1973, the age distribution in the samples of U. vulgaris from the waters north of Hispaniola and Cuba was very different in comparison with those from the Caribbean Sea. From Miami to Puerto Rico (cf. fig. 1) the samples consisted of only copepodite stages 3-6 (table 1). In the Caribbean Sea, however, the nauplii were abundant as well. They made 37-99 % of the population at four stations (15-18).

One week after the cruise we also got nauplii off Miami in the Gulf Stream (sample 68). Later in 1974 we got great amounts of nauplii in January and February (samples 71, 73 and 76). On the same occasions copepodite stage 2 occurred in the samples. Unfortunately no samples were taken at night and,consequently, no adult could be expected in the surface samples.

Hence the spawning of U. vulgaris occurs both in the Caribbean Sea and in the Loop Current/Florida Current System. It can also be concluded that spawning of U. vulgaris takes place at least during the period January through April.

The relation between the abundance of males and females were calculated (table 3). In the waters between Cuba and Florida (stations 1-5) the ratio was 0.60 as compared with 1.11 in the Caribbean Sea (stations 10-19). The spawning population in the Caribbean Sea had obviously a different sex ratio with more males than females in comparison with the non spawning population between Cuba and Florida. If the life span of males is shorter than the life span of females, the analyses indicate that the spawning population was younger than the non-spawning population.

The same calculations were also made for C. minor at the stations where both males and females occurred, mainly at the northern stations. The mean sex ratio was even lower as compared with the calculated one for U. vulgaris at stations 1-5 (table 4). This indicates that the population was relatively old, assuming that the life span of males is shorter than the female life span.

The occurrence of U. vulgaris and C. minor in surface waters in relation to light

The possibility to catch great amounts of adult U. vulgaris and partly copepodite stage 5 was closely correlated to light (figs. 4-7). At sunset the greatest amounts of specimens were caught (fig. 4). But even then it was of utmost importance that the tow took place at surface when the light intensity was very low. Repeated hauls at the same station (no. 1) showed that no U. vulgaris was available until the sun just disappeared below the horizon when the light intensity was very low (table 1). Samples 5 and 27 contained most adult U. vulgaris. During haul no. 5 the light intensity decreased from 44 lux to 3 lux and during haul no. 27 from 700 lux to 5.5 lux. At night (fig. 5) many adults were found except when the moon was full or nearly full. At dawn (fig. 6), most adults were found just before sunrise when no light could be registered by the light meter or, as in sample 9, when the light intensity was as low as 1.4 - 28 lux. At noon (fig. 7) not a single adult was caught.

Hauls at 100 m and 200 m levels at various light intensities were never very successful. Although some individuals were captured in the 100 m tow, we cannot be certain that these were not taken at shallower depths during the retrieval haul. Many vertical tows 30-0 m, 60-0 m, 90-0 m, 0-50-0 m, 0-100-0 m, 0-150-0 m, 0-200-0 m were not successful either. Very few specimens were caught.

The diurnal migration or relation to light was less obvious the younger the specimens of U. vulgaris were. Copepodite stage 5 seemed to be partly sensitive to light in the same way as adults. But C3 and C4 can be abundant at noon at surface (fig. 7). The vertical distribution in the water mass can thus probably not be related to light as regard to younger stages than C5-C6. Nor do nauplius stages seem to be sensitive to light (cf. table 1). Great amounts of nauplius stages were found at noon at surface.

The conclusion of our investigations was that the best catches of adults always were taken at sunset when the sun just had disappeared. It seems to be in light intensities less than 100 lux. Hence, it is also obvious that only adults have a very conspicuous diurnal migration.

The vertical distribution in the water column at various times day and night can not be found out by the method used in this investigation. At the next cruise closing nets and a modified sampling program will be performed. On single sample at noon (100 000 lux) from 50 m depth off Miami showed great amounts of adults and copepodite stage 5. This indicate that the older part of the population in contrast to the younger one may be concentrated at two different levels in two very narrow layers day and night.

The distribution of C. minor seemed to be similar to the one of U. vulgaris. Very few specimens younger than stage 5 were found, however, and no comparisons with younger stages can, therefore, be carried out.

DISCUSSION

U. vulgaris has a cosmopolitical distribution. It occurs in the Atlantic, Pacific and Indian Oceans and is abundant mainly in the tropical and subtropical areas. It occurs between 25°N and 38°S in the Indian Ocean and the Pacific. In the Atlantic it has an even larger distribution from 47°N to 37°S (Vervoort, 1949). There are, however, great differences in abundance in the open ocean between the Pacific where it is very scarce (cf. Grice, 1962) and the Atlantic where it is rather abundant (cf. Evans, 1961). It is considered to be one of the most common species in Indian waters (Sewell, 1929) and in Japanese waters (Koga, 1968 b).

In the Atlantic off Brazil it is one of the most numerous copepods (Björnberg, 1963). Owre & Foyo (1964) reported about high abundance in the eastern Caribbean and later Owre (Michel) & Foyo (1972) found it very frequent in oceanic waters from South America outside the Amazon River through the Caribbean Sea to the Gulf of Mexico. In the West Indies near Barbados it is the most abundant copepod in the plankton (Fish, 1962). In the western part of the northern Atlantic (27°N-35°N) Bowman (1971) said that it was among the most abundant and widespread of the oceanic calanoids.

It also appear abundantly in shelf waters or shallow waters, e.g. at the Great Barrier Reef (Farran, 1949) and at the Bikini Atolls (Johnson, 1954). Farran (1936) characterizes U. vulgaris as a coastal plankton, which was abundant inside the reef but scarce outside. In contrast to the cited authors, others have called it an oceanic species (Björnberg, 1963; Yamaxi, 1958; Bowman, 1971; Owre (Michel) & Foyo, 1972). In the Atlantic it may occur in as different waters as coastal waters off Montauk Point, New York, in the Gulf Stream or in the Sargasso Sea (Grice & Heart, 1962).

The cited examples of U. vulgaris distribution imply, that this copepod cannot be called a coastal, neritic or oceanic form. Instead it might be more correct to talk about neritic distribution or oceanic distribution, when it is characterized in different areas. For example, in the Atlantic U. vulgaris has an oceanic distribution in contrast to the more neritic distribution in the Pacific.

According to Björnberg (1963), the optimum temperature for U. vulgaris is above 25°C and the optimum salinity higher than 36 ‰; the species was not present in her samples from deep waters where temperatures were lower than 20°C. This is in accordance with our results of great abundance from Florida to the Caribbean in temperatures above 25°C and salinities above 36 ‰. The lower temperature (less than 20°C) off South America in the Humboldt Current probably explains why Björnberg (1973) did not find Undinula vulgaris in her samples. This temperature limit might also explain why no records are published from the eastern Pacific (e.g., outside the North-American coast except from the Panama region (Giesbrecht,1888 in Vervoort, 1949)). The relatively narrow area in the eastern Pacific (outside Mexico and Middle America) with higher surface temperatures than 25°C, therefore, may be the only area where it could be expected.

U. vulgaris has been considered to be a surface water species. Owre & Foyo (1964) reported about a range 0-1316 m, but 97 % of the specimens occurred in the upper 50 m. In general, this copepod is common in surface waters (e.g. Owre & Foyo, 1967; Koga, 1968 b; Björnberg, 1963). The diurnal migration of this copepod has been studied by some authors. For example, Roehr & Moore (1965) found that 30 per cent of the population was above 134 m in day-time and above 85 m at night. On the other hand, the extent of diurnal migration was very little in the shallow Bikini Lagoon with the main concentration at 12 fathoms in the daytime and above that level at night (Johnson, 1954). A more comprehensive discussion will follow in a coming paper about the vertical distribution.

The size of the developmental stages seem to be slightly different in different areas. Even inside the authors' studied area the size of the specimens off Miami at station 1 were bigger than the mean for the whole area although the sizes are overlapping within the 95 % confidence interval (cf. p. 8). This implies that the population at station 1 and the other stations could be of different origin and from completely separate areas with various nutrient supply. Jespersen (1923) found that the macroplankton was about twice as abundant in the Gulf of Mexico as in the Caribbean Sea.

Our specimens of U. vulgaris were about the size reported by Sewell (1929)(cf. p. 7). Our nauplius stages had the same size as reported by Björnberg (1963). Copepodite stage 2 varied from 0.90-0.94 mm but no specimen of stage 1 was found. Our fig. 2 can be completed with values published by Björnberg (1963):

N1	0.16 mm	N4	0.32 mm	C1	0.65-0.70 mm
N2	0.20 mm	N5	0.38-0.42 mm	C2	0.81-1.19 mm
N3	0.28-0.33 mm	N6	0.47-0.48 mm		

The egg size is 0.16 mm according to Koga (1968 a).

During the cruise in April, 1973, U. vulgaris had spawned in the Caribbean but not in the other areas investigated. Owre & Foyo (1964) suggested that the eastern Caribbean and probably other parts of the Sea as well, may be a nursery area for many copepods found in the Florida Current. The slow rate of water movement in the Caribbean relative to the rate both in Yucatan Channel and any other part of the Gulf Stream (cf. Leipper, 1954) would promote reproduction of bisexual, holoplanktonic forms. A year-around spawning in tropical waters seems to take place (Owre, 1960). The Caribbean Sea could thus be a source of the huge stocks of adult species which are carried northwards both in the Gulf of Mexico and through the Straits of Florida. During the cruise in April, 1973, this theory seemed to be verified for U. vulgaris when great amounts of nauplii were found in the Caribbean Sea but nowhere else. Later, however, we found that spawning also takes place in the Florida Current. This fact does not indicate that Owre & Foyo (1964) were wrong. The Caribbean Sea might be the most important nursery area for other copepods as well as U. vulgaris but an additional spawning for warm water species such as U. vulgaris may take place in the Florida Current, in the Gulf of Mexico Loop Current, or as a consequence of separation from the Loop Current which effectively extends the period spent within the optimum temperature range.

C. minor also occurs in three oceans. In the Indian and Pacific Ocean it occurs from 34°N to 54°S and in the Atlantic between 44°N and 37°S (Vervoort, 1949). The distribution is thus wider in the Pacific and Indian Ocean than that of U. vulgaris. It is common over the whole Pacific from the east to the west coast although the abundance seems to be rather low in some areas (Grice, 1962). Outside South America it is the most numerous and frequent species of Calanidae (Björnberg, 1973). It appeared in 77 % of the samples between surface and 140 m in the daytime and in 80.5 % at night. It is also widely distributed throughout Indian waters (Sewell, 1929).

In the Atlantic it has about the same general distribution (44°N - 37°S) as U. vulgaris. C. minor is abundant in surface layers although the range was 0-877 m in the eastern Caribbean Sea. 96 % was found in the upper 100 m and 75 % above 25 m (Owre & Foyo, 1964). In contrast to U. vulgaris it was not common inside the reef at the Great Barrier Reef but regular outside the reef in the open sea (Farran, 1936, 1949).

Brodsky (1967) reported occurrence of C. minor in temperatures between 10° and 29°C. Björnberg (1963) said it was most common outside Brazil, where it was abundant above 35 ‰ and 21°C. She considered the species to be euryhaline and eurythermic.

The difference in distribution and abundance between U. vulgaris and C. minor might be explained by the optimum temperatures. Björnberg (1963) indicated that U. vulgaris is stenothermic (abundant above 25°C and does not occur below 21°C) and stenohaline (abundant above 36 ‰) and that C. minor is eurythermic (abundant above 21°C, occurring between 10° and 29°C) and euryhaline (abundant above 35 ‰)(see also Brodsky, 1967). As the temperature was 25-27°C in the studied area and the salinity above 36 ‰ the conditions might have promoted the occurrence of U. vulgaris. On the other hand the frequency of the two species can be masked by biotic competition which is hard to detect in normal field samples without experimental studies.

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SUMMARY AND CONCLUSIONS

1. U. vulgaris in the western Atlantic from Florida to the Caribbean Sea has a morphological shape like forma minor or var. typica. The size of the specimens is, however, in accordance with the size range reported for forma major or var. giesbrechti or zeylanica (Sewell, 1929; Vervoort, 1949).

2. U. vulgaris was 3-4 times more frequent in the surface samples than C. minor and the biomass of the former copepod was about 10 times the biomass of the latter. Although small calanoid copepods were more numerous, the biomass of U. vulgaris was greater than the biomass of the small calanoid copepods. U. vulgaris was thus the most important copepod and species sampled within the studied area.

3. All copepodite stages except C1 and all stages of nauplii were found in the samples for U. vulgaris. Only copepodite stages 5 and 6 were found of C. minor.

4. The sex ratio males:females was much higher for the population of U. vulgaris in the Caribbean Sea than for the non-spawning population north of Cuba and in the Florida Current.

5. Spawning of U. vulgaris occurred also in the Florida Current during a later investigation. This indicates that spawning might take place from the Caribbean Sea to the Florida Current. Nauplii were found in January, February and April. No spawning of C. minor was seen during the period of study.

6. Adult males and females of both species (and partly stage 5) make diurnal migrations which are closely related to the light intensity. In light intensities less than 100 lux just at the sunset, the adults were concentrated in a dense layer just below surface. Copepodite stage 4 and younger stages including the nauplii were not sensitive to high light intensities and occurred in surface waters at noon.

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LEGENDS

Fig. 1. The cruise of R/V COLUMBUS ISELIN, April 2-17, 1973. Stations 1-22 were sampled during the cruise. Station 23 on April 25, 1973; station 24 on January 27; station 25 on January 31 and station 26 on February 14, 1974. The results of the analyses are evident from table 1-4.

Fig. 2. Total body lengths of representative specimens of U. vulgaris and C. minor. Shown are the mean (horizontal line), standard error (shaded rectangle), 99 % confidence interval (open rectangle), range (vertical line) and sample size.

Fig. 3. Seasonal variability of the Gulf of Mexico Loop Current as indicated by the position of the 22^{o}C isotherm at 100 meters depth (after Maul, 1974).

Fig. 4. The number of copepodite stages 3-6 of Undinula vulgaris at various stations at sunset in surface samples. The light intensity above surface and the time of the sampling is given below each sample (cf. fig. 1 and table 1).

Fig. 5. The number of copepodite stages 3-6 of Undinula vulgaris at various stations at midnight in surface samples. The phase of the moon is reproduced.

Fig. 6. The number of copepodite stages 3-6 of Undinula vulgaris at various stations at dawn. The light intensity above surface is given below.

Fig. 7. The number of copepodite stages 3-6 of Undinula vulgaris at various stations at noon. The light intensity above surface is given below.

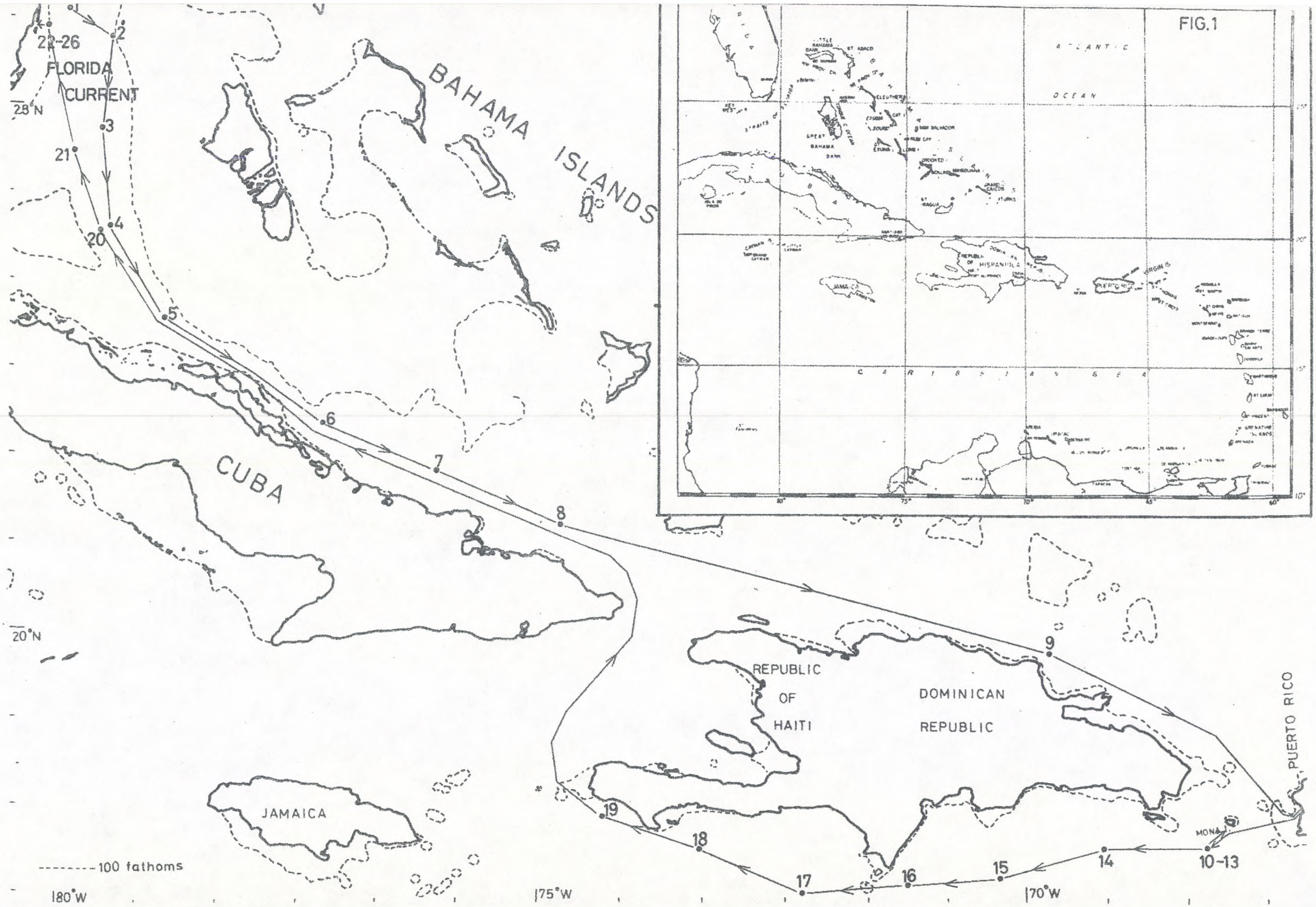
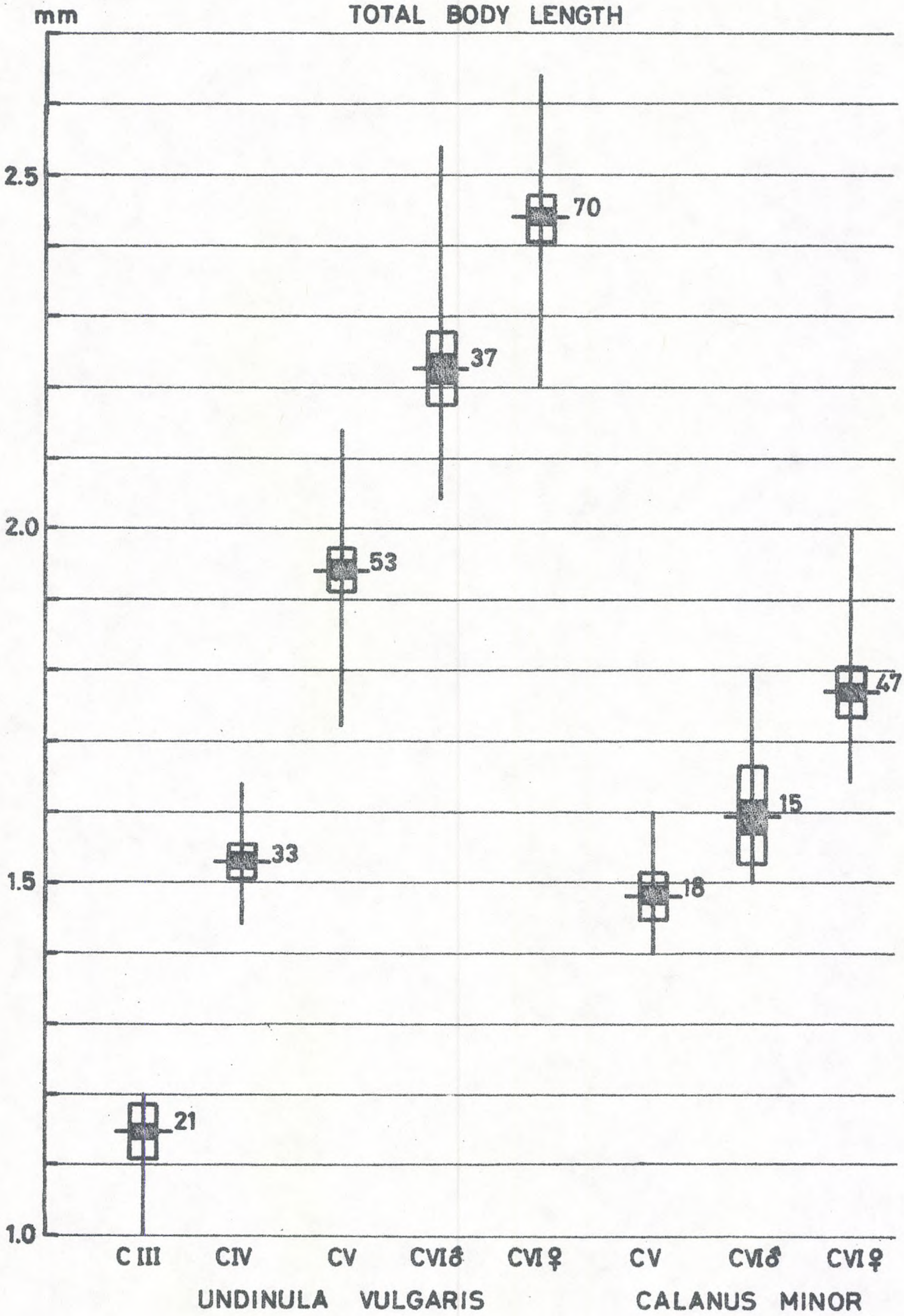
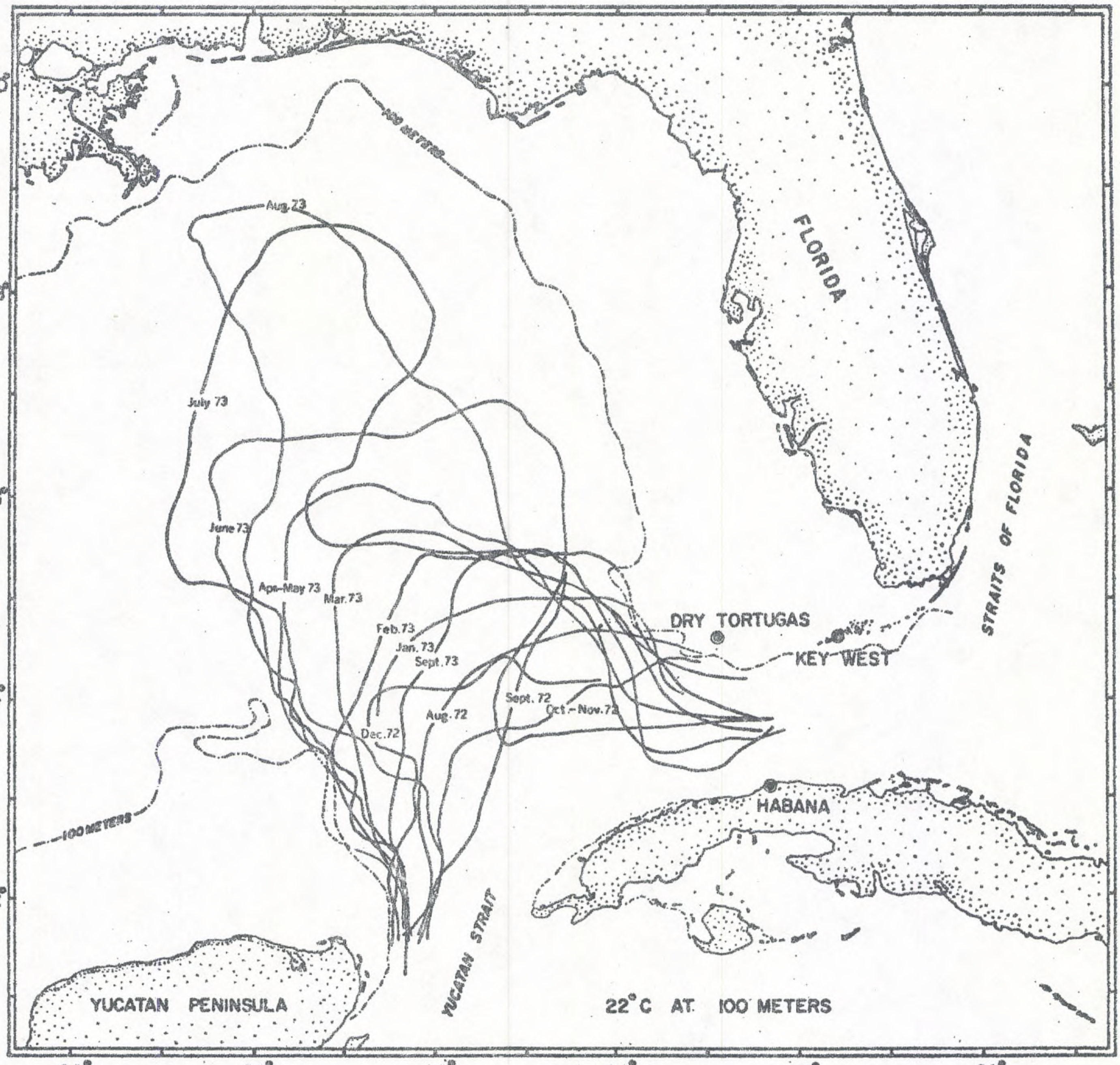


FIG.1
ATLANTIC
OCEAN
CARIBBEAN SEA
BAHAMA ISLANDS
FLORIDA CURRENT
CUBA
JAMAICA
REPUBLIC OF HAITI
DOMINICAN REPUBLIC
PUERTO RICO
MONA
1
2
3
4
5
6
7
8
9
10-13
14
15
16
17
18
19
20
21
22-26
28°N
20°N
180°W
175°W
170°W
100 fathoms


mm
TOTAL BODY LENGTH
2.5
2.0
1.5
1.0
70
37
53
33
21
47
15
18
C III
CIV
CV
CVI♂
CVI♀
CV
CVI♂
CVI♀
UNDINULA VULGARIS
CALANUS MINOR


30°
28°
26°
24°
22°
FLORIDA
STRAITS OF FLORIDA
DRY TORTUGAS
KEY WEST
HABANA
YUCATAN STRAIT
YUCATAN PENINSULA
22° C AT 100 METERS
100 METERS
Aug. 73
July 73
June 73
Apr-May 73
Mar. 73
Feb. 73
Jan. 73
Sept. 73
Dec. 72
Aug. 72
Sept. 72
Oct.-Nov. 72
90°
88°
86°
84°
82°
80°

AT SUNSET

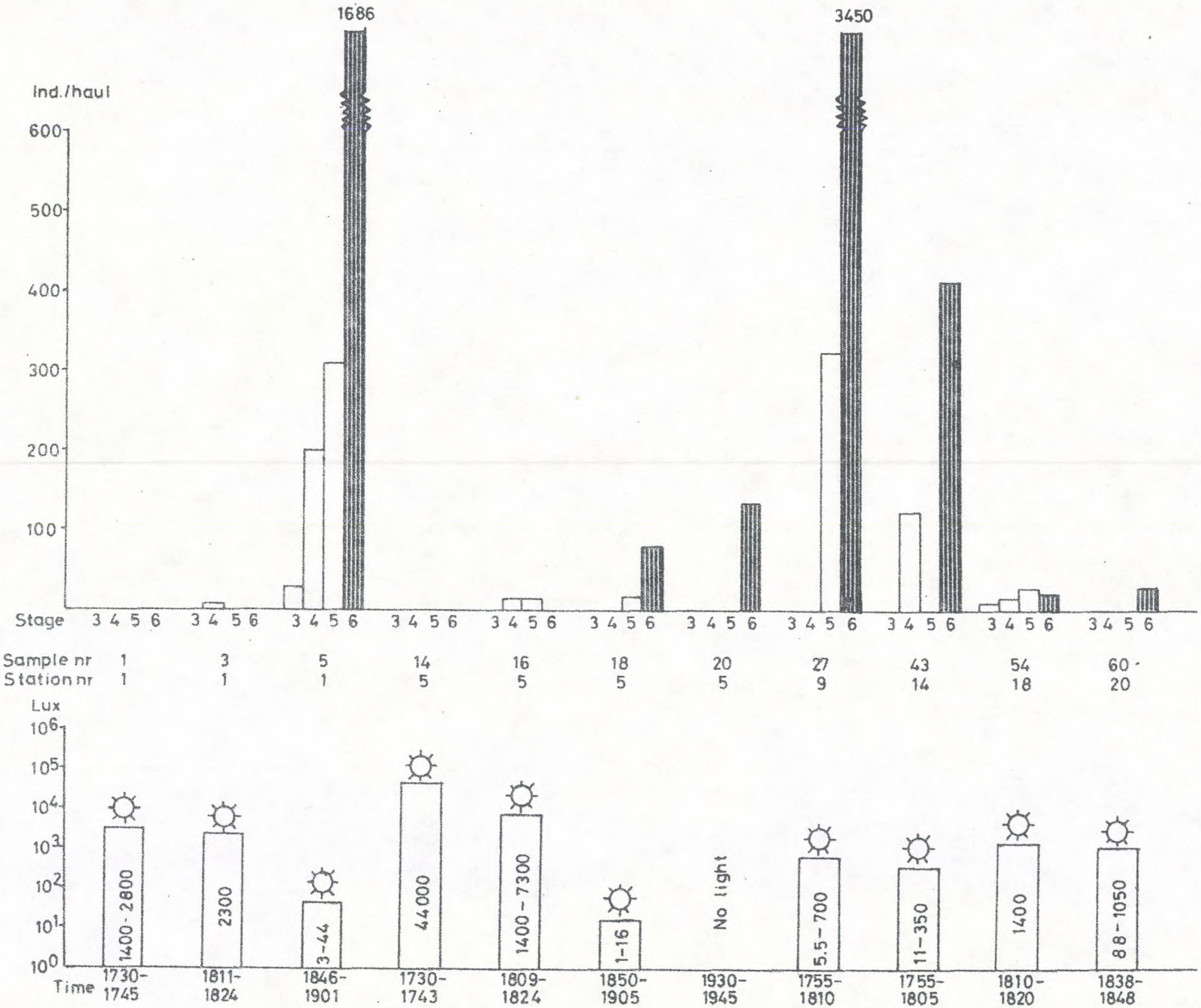
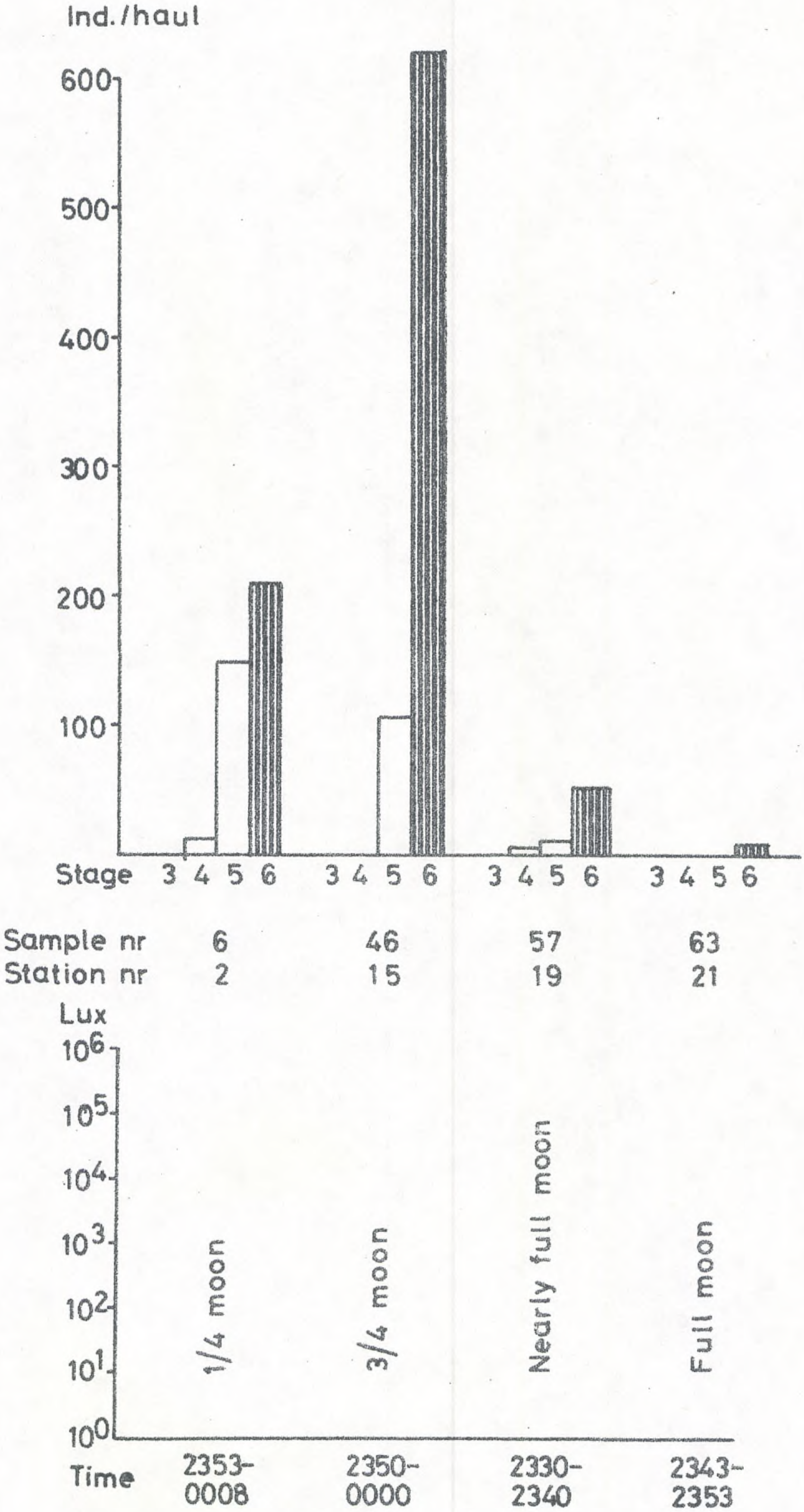
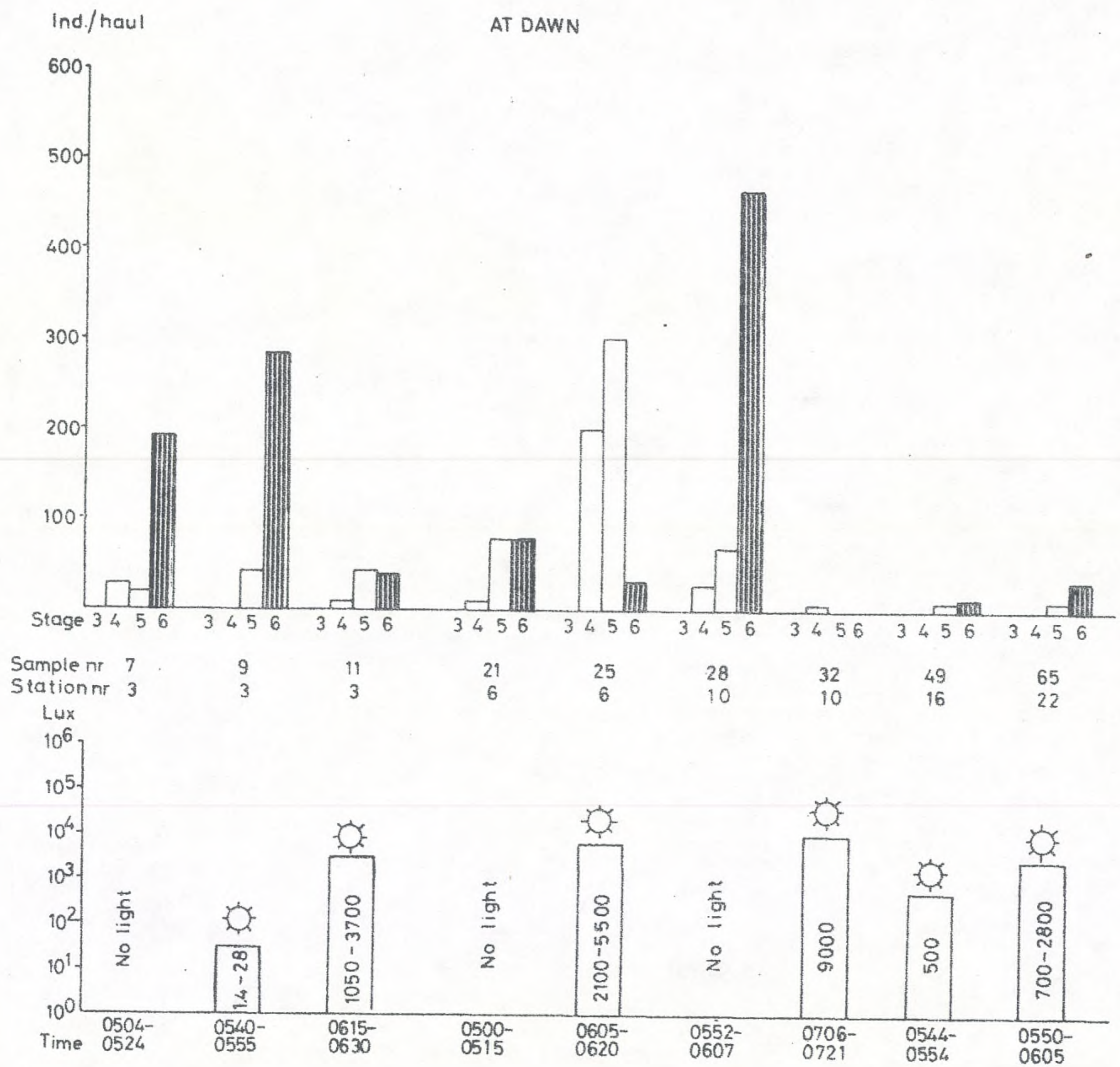


Fig. 4

AT MIDNIGHT


Ind./haul
600
500
400
300
200
100
Stage 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6
Sample nr 6 46 57 63
Station nr 2 15 19 21
Lux
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1/4 moon
3/4 moon
Nearly full moon
Full moon
Time 2353-0008 2350-0000 2330-2340 2343-2353



Ind./haul
AT DAWN
600
500
400
300
200
100
Stage 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6
Sample nr 7 9 11 21 25 28 32 49 65
Station nr 3 3 3 6 6 10 10 16 22
Lux
10^6
10^5
10^4
10^3
10^2
10^1
10^0
No light
14-28
1050-3700
No light
2100-5500
No light
9000
500
700-2800
Time 0504-0524 0540-0555 0615-0630 0500-0515 0605-0620 0552-0607 0706-0721 0544-0554 0550-0605

Fig. 6

AT NOON

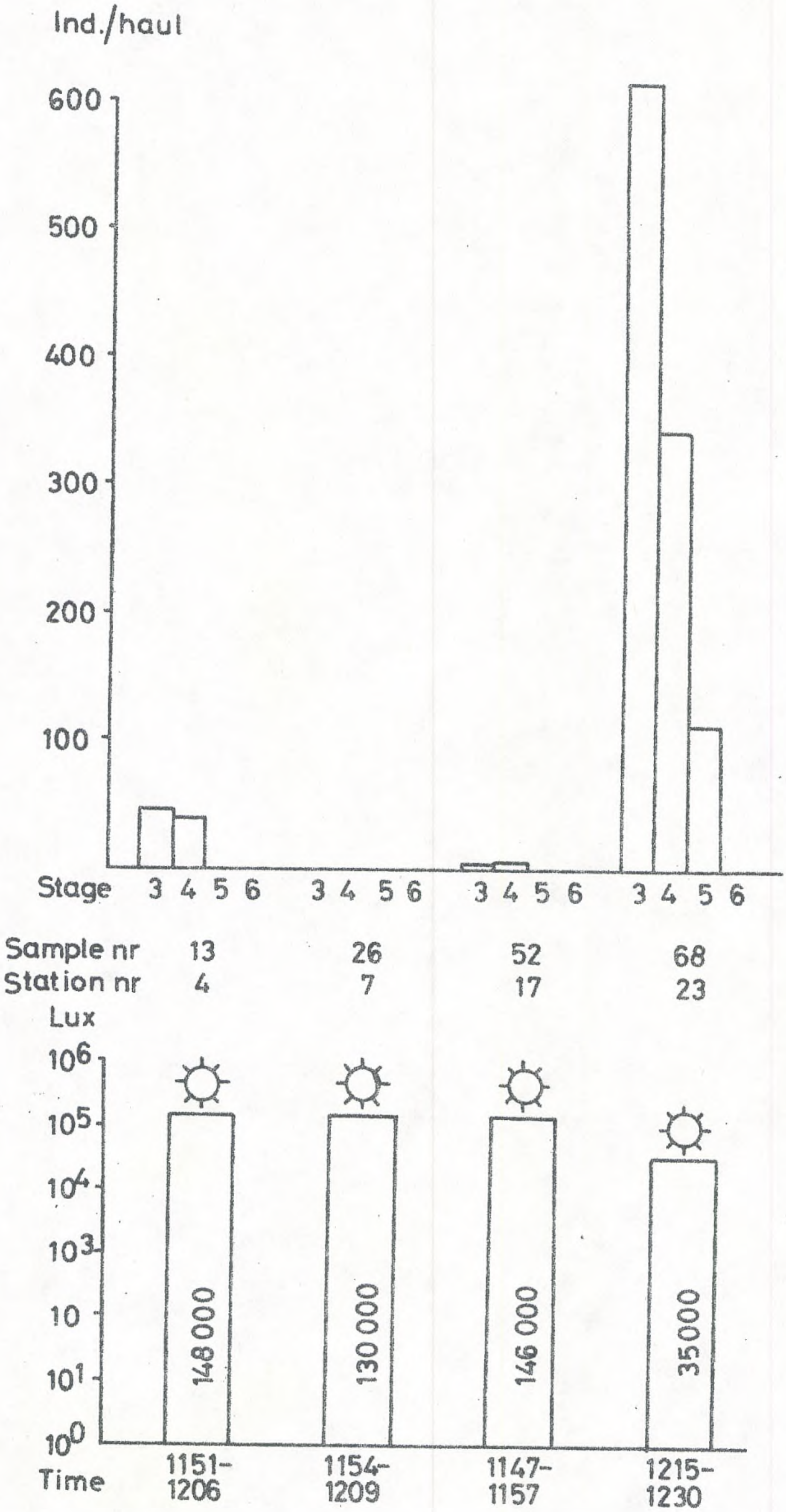

Ind./haul
600
500
400
300
200
100
Stage 3 4 5 6 3 4 5 6 3 4 5 6 3 4 5 6
Sample nr 13 26 52 68
Station nr 4 7 17 23
Lux
10^6
10^5
10^4
10^3
10
10^1
10^0
148000
130 000
146 000
35000
Time 1151-1206 1154-1209 1147-1157 1215-1230

Table 1. The number per relative unit volume of the two copepods *Undinula vulgaris* (Dana) and *Calanus minor* (Dana) in the area Florida Current - Carribean Sea. Surface tows, 15 minutes. Light conditions above surface. Samples 1-65 was taken on the cruise of R.V. Columbus Iselin, April 2-17, 1973 (cf. fig. 1). Sample 68 on April 25, 1973; 71 on January 1, 1974; 73 on January 31, 1974; 76-77 on February 14, 1974.

Sample nr	Station nr	Position	Time	Light (lux)	*Undinula vulgaris* N1	N2	N3	N4	N5	N6	C1	C2	C3	C4	C5	C6♂	C6♀	Total excl.N	Total incl.N	*Calanus minor* C4	C5	C6♂	C6♀	Total
1	1	25°59'N 79°53'W	1730-1745	2800-1400														0	0					0
3	1	- " -	1811-1824	2300										1			1	2	2					0
5	1	- " -	1846-1901	44-3									29	200	314	686	1000	2229	2229		400	143	1000	1543
6	2	25°44'N 79°20'W	2353-0008	Night										13	148	69	144	374	374		69	69	261	419
7	3	24°46'N 79°29'W	0504-0524	Night										28	20	60	132	240	240		40	26	92	160
9	3	- " -	0540-0555	1.4-28											44	163	119	326	326		15	44	207	266
11	3	- " -	0615-0630	1050-3700										9	44	12	29	94	94	3	47	9	44	103
13	4	23°48'N 79°31'W	1151-1206	148000									45	40				85	85					0
14	5	23°00'N 78°52'W	1730-1743	44000														0	0					0
16	5	- " -	1809-1824	7300-1400										13	13			26	26				25	25
18	5	- " -	1850-1905	16-1											17	17	83	117	117			17	33	50
20	5	- " -	1930-1945	Night												50	83	133	133		117	33	267	467
21	6	22°03'N 77°15'W	0500-0515	Night										11	77	11	66	165	165			122	189	311
25	6	- " -	0605-0620	2100-5500										200	300		33	533	533		67			67
26	7	21°33'N 76°04'W	1154-1209	130000														0	0					0
27	9	19°46'N 69°50'W	1755-1810	700-5.5											325	1550	1900	3775	3775				75	75
28	10	off Mona Island	0552-0607	Night										27	67	240	227	561	561		27	27	80	134

Cont. table 1.

Sample nr	Station nr	Position	Time	Light (lux)	*Undinula vulgaris* N1	N2	N3	N4	N5	N6	C1	C2	C3	C4	C5	C6♂	C6♀	Total excl.N	Total incl.N	*Calanus minor* C4	C5	C6♂	C6♀	Total
43	14	17°52' N 69°13' W	1755–1805	350–11	7	13	39	13	13					125	88	138	275	626	711		50		200	250
46	15	17°32' N 70°16' W	2350–0000	Night				← 640 →							106	427	213	746	1386					0
49	16	17°31' N 71°13' W	0544–0554	500			100								7	7	3	17	117					0
52	17	17°23' N 72°18' W	1147–1157	146000			← 634 →						2	2				4	638					0
54	18	17°49' N 73°20' W	1810–1820	1400			← 40 →						7	13	26		21	67	107					0
57	19	18°11' N 74°20' W	2330–2340	Night										4	8	24	28	64	64					0
60	20	23°53' N 79°27' W	1838–1848	1050–88												22	6	28	28			3	3	6
63	21	24°41' N 79°47' W	2343–2353	Night–Full moon												3	6	9	9		28			28
65	22	off Miami c.25°42' N 80°08' W	0550–0605	700–2800											9	9	32	50	50		9	9	45	63
68	23	– " –	1215–1230	35000				← 2357 →					629	343	114			1086	3443					0
71	24	– " –	1115–1125	c.100000				← 632 →				256	1728	640				2624	3456					0
73	25	– " –	1427–1437	c.100000			193	230	270			135	96	77				306	1001					0
76	26	– " –	1415–1425	c.100000					← 2150 →			307						307	2457					0

Table 2. Some specimens of U. vulgaris and C. minor were measured. The mean ($\bar{m}$), the standard deviation (s) and the range with 95 % confidence interval ($\bar{m} \pm 2$ s) were calculated. All values in mm. The number of measured specimens (n).

	Undinula vulgaris				Calanus minor			
	$\bar{m}$	s	range ($\bar{m} \pm 2$ s)	n	$\bar{m}$	s	range ($\bar{m} \pm 2$ s)	n
C 6 ♀	2.44	0.09	2.26-2.62	70	1.77	0.09	1.59-1.95	47
C 6 ♂	2.23	0.12	1.99-2.47	37	1.60	0.09	1.42-1.78	15
C 5	1.94	0.08	1.78-2.10	53	1.48	0.05	1.38-1.58	18
C 4	1.53	0.05	1.43-1.63	33				
C 3	1.15	0.06	1.03-1.27	21				

Table 3. The ratio *U. vulgaris* : *C. minor* in surface samples from Florida Current to the Caribbean Sea at various stations in April.

Station	Ratio	Station	Ratio
1	1.95	14	2.50
2	0.89	15	only *U. vulgaris*
3	1.25	16	"
4	only *U. vulgaris*	17	"
5	1.90	18	"
6	1.84	19	"
7	only *U. vulgaris*	20	"
9	50.33	21	0.32
10	4.17	22	0.63
		23	only *U. vulgaris*

Total mean : 3.62

Table 4. The sex ratio (males:females) of *U. vulgaris* and *C. minor* from Florida Current to the Caribbean Sea in surface samples at various stations with more than 100 adults in the analysed samples. All samples taken in April, 1974.

	Station	*U. vulgaris*	*C. minor*
	1	0.69	0.14
	2	0.48	0.25
	3	0.84	0.24
	5	0.40	0.33
$\bar{m}$	1-5	0.60	0.24
	6	0.11	0.65
	9	0.82	-
	10	1.06	0.34
	14	0.50	-
	15	2.00	-
	19	0.86	-
$\bar{m}$	10-19	1.11	