On some plankton animals occurring in spring off Wajima, Noto Peninsula, Japan Sea, with special reference to their vertical distribution

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Abstract

Plankton collectings by pumping method were made out of seven different water depths: 0.2, 2, 5, 10, 20, 30 and 50 m., yielding samples comprizing both cold-water and warm-water plankters. Brief comments were given to respective species with special respect to their vertical distribution. A relatively discontinuous layer in vertical distribution of many of the discussed animals appeared existing in the neighbourhood of the 20 to 30 m. depth. Cold-water species including *Metridia lucens*, *Calanus plumchrus*, *Parathemisto oblivia*, *Aglantha digitale* and the like occupied principally waters below this layer, whilst sardine eggs were markedly abundant above it. Sardine prolarvae, early copepodite larvae of *Calanus helgolandicus* and *C. tenuicornis* were common in and around this layer. Considerations were made on the nature of this discontinuous layer, suggesting possible causes for the midwater abundance of sardine prolarvae and larval Calanus.

Introduction

Plankton collectings by pumping method were carried out with the aim of investigating the vertical distribution of some important plankton organisms, especially that of sardine eggs and larvae, in the sea adjacent to Wajima, Noto Peninsula, Japan Sea, in the spring of 1955.

Each 90 litres of sea water was taken by an ordinary hand pump out of seven different depths, *viz.*, 0.2, 2, 5, 10, 20, 30, and 50 metres, then filtered through a net made of grit gauze 196 meshes per inch, thus plankton samples obtained for laboratory analysis. On filtrating sea water from the respective depths, a definite volume (ca. 45 *l*) equivalent to the capacity of the hose as well as the pump was previously drained away. It took about 30 - 40 minutes to complete a series of samplings from the above-mentioned seven depths, and one to three series were made in each experiment.

The station where each experiment was carried out is close to one another (37°28′ N, 136°56′ E), the water depth being 80 m. and its neighbourhood.

Some planktologically important species were picked out of these samples under a binocular microscope and their number enumerated. The results are shown in the appended table.

Comments on respective organisms

Under are given brief comments on respective plankton animals listed in the table, with special reference to their vertical distribution.

(1) Sardine egg

Sardine eggs are abundant in the surface and decrease gradually with increasing depth. Below the 50 meter depth they are supposed to be only sparsely distributed.

This general tendency of distribution, which is in good accord with the conclusion obtained by SILLIMAN (1943) who worked on the vertical distribution of the California sardine egg, is, however, sometimes disturbed and as results is met with such abnormal, as is considered so, distribution as observed on May 10, 20.33 - 21.04, when the eggs were most abundant in the intermediate depth and fell down both upwards and downwards, and such as observed on May 21, 16.20 - 16.48, when the eggs were somewhat uniformly dispersed throughout the depths.

Since the sardine eggs have a specific gravity slightly smaller than that of sea water, they float gradually up to the surface and accumulate there resulting in the above-mentioned general pattern of distribution, when the sea is tranquil with no prominent vertical motion or mixing of water prevailing. In case, however, there are vigorous eddy turbulences or vertical movements, *e.g.*, thermal convection and sinking in the convergence, the eggs would be easily stirred and transported in opposition to buoyancy resulting in various (abnormal) patterns of distribution according to the type of water movement. This is because the differnce in specific gravity between the egg and the sea water is so small and that the egg has a property to change its specific gravity along with the variation in that of the ambient water, always keeping it in contiguity to that of the latter.*

Results from the vertical and the horizontal nettings carried out simultaneously with pumpings have revealed the presence of difference in the pattern of

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* The sardine egg has a very large perivitelline space which occupies adout 85 % of the total volume. This space is filled with sea water as well as a certain colloidal substance ; the latter is, however, considered to be of so small amount as to enable us to assume that the space be entirely filled with sea water only. In addition, the egg membrane is quite permeable to sea water, the free and unceasing exchange of which is established between the inside and the outside of the membrane. The consequence upon the above-mentioned is that when the surrounding water undergoes any change in specific gravity, readily occurs in the sardine egg a corresponding change 0.85 time as large in magnitude. Thus we are led to the understanding that the sardine egg has a tendency to be conservative, non-conservative as it is, in a water block and consequently that in case the water block is making vertical movement or mixing, the egg would be transported quite easily together with the ambient waters.

vertical distribution at times to be observed between different developmental stages of the egg. Detailed discussion on this problem, however, is to be reserved for future papers.

(2) Sardine prolarva

Sardine prolarvae are most common in the intermediate depth, *viz.*, in the 10-30 meter layer. Abundant distribution in the surface, which is the case with the egg, has not been noticed. That is to say, the prolarva shows a different pattern of vertical distribution from its antecedent. Similarity was observed on the California sardine eggs and larvae (AHLSTROM, 1948).

This discrepancy in vertical distribution is supposed due to the possible subsurface hatching out of larvae as well as to their superiority in magnitude of specific gravity to their antecedents. This conjecture may be corroborated first by the observation that richer portion of the eggs immediately before hatching are collected in the main from subsurface waters rather than from the surface, and secondly by another observation upon the behaviour of the egg and the prolarva contained in a jar, the former slowly floating up to the surface, while the latter rapidly sinking down to the bottom. Consulting the latter observation and taking into account as well the prominent adaptation to flotation in prolarval morphology, *e.g.*, the long and slender body axis, the broad marginal fin and so on, is considered the prolarva to be fairly larger than sea water in specific gravity.

The limitedness to principally 10 to 30 m. layer in vertical distribution may be partly maintained through the gravitational sinking intermitted by active but not lasting swimming up of the animals, as is easily watched on the captives in a containing jar.

(3) *Etrumeus micropus* egg

None of this fish egg was collected on April 22, which is interpreted as no spawning was yet taking place. In every experiment since May 10 - 11, eggs were obtained from various depths by small numbers, suggesting anyhow dispersed distribution. On May 10 - 11, however, they were collected only from the middle layer and deeper. This pattern of vertical distribution is in noticeable contrast against that of the sardine egg.

(4) *Metridia lucens*, *Calanus plumchrus* & *Parathemisto oblivia*

These cold-water planktonic crustaceans were caught only on April 22 - 23 and since then was sampled none at all.

The copepodite larva of *Metridia lucens* was collected only from the 50 m. depth during daytime and in the evening, but at midnight it was obtained from the surface. This may suggest the vertical migration of this species, which has been reported by many authors including CLARKE (1933, 1934), MOTODA & ANRAKU (1951, 1952). The present writer also has experienced during the cruises across the Bay of Toyama that this copepod migrates up to the sea surface about at midnight and emits strong light as disturbed by bow waves of the sailing vessel.

Calanus plumchrus copepodite larvae (stage V, 4; stage IV, 3; stage III, 2; stage II, 2) were, on the other hand, collected from 30 and 50 meter layers throughout the experiment.

Parathemisto oblivia,* an amphipod widely populated in the Japan Sea, showed an apparent vertical migration, since it was obtained from the 30 - 50 m. depth in the daytime but from the intermediate to surface layer at night. The migratory habit of this species has been also described by MOTODA & ANRAKU (1954).

All the specimens of *Metridia lucens*, *Calanus plumchrus* and *Parathemisto oblivia* sampled in this experiment were small immature individuals. These species are distinguished representatives of the Japan Sea deep water plankton as reported by many investigators (FURUHASHI 1953; YAMAZI, 1953; *etc.*) and are estimated to inhabit the cold deep waters in great quantities including the adult forms. Immature individuals, however, can be obtained from relatively small depth like in the present case. MOTODA & ANRAKU (1954) have reported that individuals of large size of *Metridia lucens* and *Calanus cristatus* are distributed in greater depth and that only small-sized ones are obtained from shallower depth, while FURUHASHI (1953) has informed that *Parathemisto oblivia* collected from shallow layer is of immature stage and large mature specimens are obtained from greater depth. Similar nature in *Calanus plumchrus* is widely known (MOTODA, 1944; *etc.*).

In the May 10 - 11 and the following experiments, not an individual of these species occurred. This complete disappearance from samplings would be explained by taking into account the raise in water temperature. Below is shown the mean temperture on respective experiments.

Depth (m)	Mean water temperature (deg. in C.)			
	April 22 (6 obs.)	May 10-11 (6 obs.)	May 15 (6 obs.)	May 21 (4 obs.)
0	12.08	15.93	16.12	17.18
10	11.71	15.13	15.97	16.60
25	11.54	13.88	15.45	16.46
50	11.21	13.28	13.57	14.87
75	10.69	12.71	12.98	13.74

It can be seen that the water temperature at the 50–75 m. depth on May 10–11 had been raised by some two degrees as compared with that on the preceding

* Though there is left some question for identification of this amphipod, the writer tentatively followed the customary way.

experiment. FURUHASHI (1953) has proposed to take 11°C as the upper thermal limit in the distribution of cold-water plankton animals in the Japan Sea. With the fact into consideration that the specimens collected in the present experiment were all immature and small-sized individuals which were possibly regarded as fitted to the temperature a little higher or as of more eurythermal nature than adult forms, is clearly understood by following FURUHASHI's view the disappearance or the diminution in distributional density of the above-named cold-water zooplankters in the observed sea area from the May 10 - 11 experiment onwards.

(5) *Limacina helicina*

This pteropod mollusk was abundantly found in and below the 20 - 30 meter layer in every sampling except in May 15, 16.29 - 16.53, where it was obtained in a considerable number from both the surface and the 50 meter depth.

This tiny planktonic gastropod is one of the cold-water elements as stated by KOKUBO (1948), FURUHASHI (1952) and many others. If the distribution of this species were completely subject only to the water temperature, it would be possible to refer its midwater to deep layer abundance to its cold-loving nature. This is not, however, the case in actual, since on April 22 - 23, when the temperature was low throughout the depths, it was markedly abundant below the 20 meter depth with scanty appearance in the upper layers. Consulting the present datum, the vertically migrating habit of this species, if any, is not observed.

The above-given lines may hint that the distribution of this zooplankter is not completely controlled by temperature but is also affected by some factors else, one of which would appear to be water mass distribution in the sea.

Alike to other cold-water species, the bulk of the sampled specimens belonged to small size category.

(6) *Aglantha digitale*

This medusa, another important member of the cold-water plankton, was abundant in and below the 20 - 30 meter layer with one exception of sampling made in May 11, 05.00 - 05.40, when it was distributed almost evenly from surface to 30 meters.

Like other cold-water plankton animals, only small-sized medusae were collected. The large individuals can be caught from deep waters in the offing.

(7) *Euphausia pacifica*

Larvae (Calyptopis stage) and youngs (Furcilia—Cyrtopia stage) were sampled rather in great quantities on April 22 - 23, after then, however, only poorly. Below are given the sums of specimens obtained in respective sampling series.

It can be seen from the table that the samplings made at night contained more individuals than those made in the daytime or in the morning, further that the number of specimens obtained in the sampling made at about the same time at night remarkably decreased with the progress of season.

April 22 - 23,*	19.27 - 20.04	....	50
〃 ,	23.28 - 00.11	....	63
May 10 - 11,	20.33 - 21.04	....	more than 12**
〃 ,	05.00 - 05.40	....	2
May 15,	12.30 - 13.08	....	1
〃 ,	16.29 - 16.53	....	0
〃 ,	20.33 - 21.05	....	2
May 21,	16.20 - 16.43	....	0

As NAKAI (1942), UDA (1952) and other authors have decribed, this euphausiid crustacean inhabits the Japan Sea very abundantly and makes an outbursting propagation in the spring. In the neighboring waters of Waiima, too, not only the larvae of this crustacean species are caught very commonly by plankton netting but also a large amount of the adult forms are occasionally obtained by surface towing made at night.

The above-mentioned decrease in number of sampled larvae and youngs with the progress of season may be due either to the termination of spring propagation or to the dispersal of the population towards the offing and deep in accompany with the raise in temperature in littoral waters. Similarity is delineated by MATSUE & KOMAKI (1954), who observed in the Goto-Izu region, that in the beginning the patches of euphausiid larvae and youngs were commonly found in the littoral waters, but from March on, as was especially distinguished in the Izu region, their distribution was diminished in extent and shifted north, *i.e.*, towards the offing.

It is well known that most euphausiid species have a marked habit to practise vertical migration (II, 1947; NAKAI *et al.*, 1953; *etc.*) and is also mentioned by MOTODA & ANRAKU (1954) that the young of *Euphausia pacifica* as well acts the same behabiour. On the samples obtained April 22 - 23, this migratory habit is clearly observed in the youngs, as they were caught in a considerable number from the 0.2 - 5 meter layer at midnight after aggregation in the 10 - 30 meter layer in the evening. In the daytime their inhabiting depth might be somewhat greater. Concerning the larvae, on the other hand, this habit is not clear, their core of distribution lying at about the 20 meter depth all day long with possible dispersion at night.

(8) *Calanus helgolandicus*

Greater part of the sampled specimens was occupied by copepodite larvae. They were most abundant in the intermediate layer with 30 m. depth as core.

* The series: April 22 - 23, 15.45 - 16.48 lacks two samples of 2 and 10 meter depths, the rest five samples giving sum of 9 specimens, so this series was omitted from tabulation.

** This series lacks 0.2 meter depth sample.

This tendency is particularly apparent in copepodite stages I—III. As for the stage V and the adult forms, on the other hand, a distinct tendency in vertical distribution was not detected, as they were obtained from various depths by small numbers. This may be due to the complexity caused by their diurnal migration and possibly in part due to their dodging movement. Copepodite stage IV appears to be of intermediate nature between the above two categories as concerns vertical distribution.

This copepod is one of the temperate elements and is reported by MOTODA & ANRAKU (1954) to be distributed mainly upper of 150 m. depth. The present study, however, has shown that this copepod species is not the surface plankter in the strict sense, but is distributed, more distinguished as is in the case of early copepodite stages, commonly at some distance below the surface.

The spawning of the Calanus takes place at night near the surface and the spawned eggs begin to sink slowly as soon as it has been laid (MARSHALL & ORR, 1955) so that the hatching out of nauplius larvae and later development are to ensue in middle to deep waters. By paying respect to the foregoing is understood clealy the lack in surface waters of early copepodite larvae, which may be, as seen from the present datum, not yet equipped with the habit or capacity of performing vertical migration.

(9) *Calanus tenuicornis*

Nearly all specimens were copepodite larvae; and the bulk of them were obtained from the layers deeper than 20 meters. Three individuals taken from waters not deeper than 10 m. throughout all the samplings, which were obtained by night pumpings made on April 22, were composed of 2 adult females and 1 stage V, whereas all copepodite larvae younger than stage V were collected from waters 20 meters and deeper.

This copepod has been reported on one hand as a tropical and subtropical species (MORI, 1937) or a warm water species (YAMAZI, 1953; MOTODA & ANRAKU, 1954), and to be distributed in the main in the upper layers shallower than 100-150 m. in the central and northern Japan Sea, but, on the other, TANAKA (1956) has described as a deep water form from the Izu region in the Pacific Ocean. According to the present research, the copepodite larvae are mostly found occupying the layers some distance below the surface as was observed in the larvae of *Calanus helgolandicus.*

(10) *Muggiaea atlantica*

This siphonophoran medusa was dispersed throughout the depths day and night, but was sampled in many specimens from the midwater: 10 to 30 m. on May 15 and 21.

Discussion

Taking a general view of what has been mentioned, it may be recognized that a discontinuous or singular layer, naturally in a relative sense, for the vertical distribution of many of the discussed plankton animals, existed in the neighbourhood of the 20 to 30 m. depth. The cold-water plankton animals including *Metridia lucens*, *Calanus plumchrus*, *Parathemisto oblivia*, *Aglantha digitale* and the like were in the main distributed below this layer, the copepodite larvae of *Calanus helgolandicus* as well as *C. tenuicornis*, sardine prolarvae, and possibly *Muggiaea atlantica* with *Etrumeus micropus* eggs, both of which though showed a somewhat dispersed distribution, were common in the vicinity of it, and lastly sardine eggs were markedly abundant above it.

Consulting the informations by previous authors on the general hydrography of the Japan Sea leads to the understanding of this layer as a boundary or transitional layer between the surface water and the core water of Tsushima Warm Current. The former is warmer, less saline and consequently smaller in both density and molecular viscosity than the latter, so the sinking of plankton organisms may be somewhat retarded when entering into waters beneath the boundary layer. Furthermore, vertical diffusivity is, as is well known, reduced at the junction of water masses of different density, making possible the compaction of the individuals that are constantly sinking from waters above. Thus a consequent accumulation of plankters may occur in the vicinity of the above-mentioned boundary layer.

This will apply not only to the sinking forms such as sardine prolarvae, copepod eggs and early-stage larvae, but no doubt also to most of phytoplankters which are besides accelerated to concentrate there as influenced by the deleterious effect of strong sunlight near the surface. It is common to observe supersaturation of oxygen in standardized expression in waters some distance, say, 20 to 30 m., below the surface in and around the areas surveyed, and this may no doubt be due to photosynthetic activity of flourishing phytoplankton population in those layers. Intermediate-depth abundance in some of the zooplankters such as early copepodite larvae of the Calanus which depend largely on phytoplankton as their principal energy source may be, partly at least, attributed to this rich occurrence of phytoplankton in the midwater layer.

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Appended table. Number of some plankton animals contained in respective 90 litres of sea water pumped from seven different depths.

Plankton organisms	April 22 – 23																					May 10 – 11													
	15.45 – 16.48 hrs							19.27 – 20.04 hrs							23.28 – 00.11 hrs							20.33 – 21.04 hrs							05.00 – 05.40 hrs						
	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m
Sardine egg	7	–	2	–	0	0	0	6	7	4	4	3	0	0	4	11	3	2	1	0	0	–	2	1	2	13	6	5	46	22	7	4	3	4	0
Sardine prolarva	0	–	0	–	0	0	0	0	0	0	0	1	3	0	0	0	1	0	1	1	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0
Etrumeus micropus egg	0	–	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	0	0	1	2	1	3	0	0	1	0	3	3	0
Metridia lucens (copepodid larva)	0	–	0	–	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0
Calanus plumchrus (copepodid larva)	0	–	0	–	0	2	0	0	0	0	0	0	4	1	0	0	0	0	0	3	1	–	0	0	0	0	0	0	0	0	0	0	0	0	0
Parathemisto oblivia	0	–	0	–	0	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0
Limacina helicina	0	–	2	–	23	14	14	1	2	3	4	19	27	21	2	0	1	7	12	15	10	–	1	1	5	1	15	56	5	1	1	1	22	22	16
Aglantha digitale	0	–	0	–	3	6	2	0	0	2	7	14	45	63	5	2	7	6	15	56	49	–	3	0	0	1	37	20	7	3	3	4	4	4	0
Euphausia pacifica larva	0	–	0	–	5	0	0	0	0	0	0	3	0	0	1	0	1	0	3	0	1	–	0	0	0	0	0	0	0	0	0	0	0	1	0
young	0	–	0	–	2	2	0	1	0	1	19	4	17	5	21	8	11	4	3	9	1	–	0	0	0	2	0	10	0	0	0	0	0	1	0
Calanus helgolandicus ♀	0	–	0	–	0	1	1	1	2	0	0	1	0	0	0	0	0	0	0	0	0	–	4	4	0	0	0	0	0	1	1	1	1	0	0
♂	0	–	0	–	1	0	0	0	0	1	4	1	1	2	0	0	2	0	1	1	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0
stage V	0	–	2	–	2	2	0	2	3	5	17	3	5	2	4	2	3	2	0	4	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0
stage IV	0	–	0	–	2	0	0	1	0	1	8	2	11	0	1	0	1	0	0	4	0	–	0	0	0	0	0	1	0	0	1	0	0	1	0
stage III	0	–	0	–	5	6	0	0	0	1	0	3	26	3	0	0	0	0	2	9	0	–	0	0	1	0	2	0	0	0	0	0	0	0	0
stage II	0	–	0	–	0	0	0	0	0	0	0	1	7	2	0	0	0	0	0	3	0	–	0	0	0	0	2	1	0	0	0	0	0	3	0
stage I	0	–	0	–	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	0	1	0	1	1	1	0	0	0	0	2	0	1
Calanus tenuicornis (copepodid larva)	0	–	0	–	6	0	1	0	0	1	0	2	4	3	0	0	1	1	4	2	3	–	0	0	0	0	1	1	0	0	0	0	1	0	0
Muggiaea atlantica	1	–	0	–	6	2	0	0	1	0	0	3	0	0	0	1	4	2	2	2	2	–	7	5	7	6	7	6	8	4	6	2	8	6	0

Appended table (continued)

Plankton organisms	May 15																					May 21						
	12.30 – 13.08 hrs							16.29 – 16.53 hrs							20.33 – 21.05 hrs							16.20 – 16.48 hrs						
	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m	0.2	2	5	10	20	30	50 m
Sardine egg	19	12	12	3	4	2	0	32	18	16	2	4	8	0	20	15	17	14	2	10	0	2	1	0	2	2	0	2
Sardine prolarva	0	0	0	0	3	5	0	0	0	0	1	1	1	0	0	1	0	1	1	2	0	0	0	0	0	0	0	0
Etrumeus micropus egg	0	1	0	0	1	1	3	2	1	0	2	0	1	1	1	1	0	2	0	3	0	0	1	1	0	3	0	2
Metridia lucens (copepodid larva)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calanus plumchrus (copepodid larva)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parathemisto oblivia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limacina helicina	2	1	1	3	1	2	59	20	7	5	2	0	3	42	1	2	0	3	4	67	114	1	2	2	5	6	13	53
Aglantha digitale	0	0	1	4	4	10	49	1	0	0	0	3	3	18	0	1	0	0	1	3	40	0	0	0	0	0	2	3
Euphausia pacifica larva	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
young	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Calanus helgolandicus ♀	0	0	0	1	0	0	2	0	0	0	1	0	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0
♂	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
stage V	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0
stage IV	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	1	3	1	0	0	0	1	1	2	1
stagc III	0	0	0	0	1	2	1	0	0	0	0	1	1	2	1	0	0	0	2	1	0	0	1	0	0	2	6	2
stage II	0	0	0	0	0	1	0	0	0	0	0	0	2	3	0	0	0	0	0	5	2	0	0	0	1	0	17	3
stage I	0	0	0	1	0	4	1	0	0	1	1	1	4	0	0	0	0	0	1	13	2	0	0	1	2	2	7	0
Calanus tenuicornis (copepodid larva)	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	3	1	0	0	0	0	0	0	0
Muggiaea atlantica	5	3	6	20	19	25	4	4	4	6	16	13	4	3	6	7	7	3	14	5	4	6	0	1	5	11	5	4