IRISH FISHERIES INVESTIGATIONS

SERIES B (Marine)

No. 13 (1974)

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J. P. HILLIS.

FIELD OBSERVATIONS ON LARVAE OF THE DUBLIN BAY PRAWN *NEPHROPS NORVEGICUS* (L.) IN THE WESTERN IRISH SEA.

Field Observations on Larvae of the Dublin Bay Prawn *Nephrops norvegicus* (L.) in the Western Irish Sea.

by

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ABSTRACT

The occurrence of *Nephrops norvegicus* larvae in the western Irish Sea determined by survey cruises during 1969, 1970 and 1971 showed distribution patterns of the Irish coastal population which appeared to be, to some extent, separated from others adjacent (e.g. S.W. Manx). Vertical distribution showed the greatest numbers at 10-15 fm depth by day, ascending by approximately 5 fm around dusk; numbers deeper than 20 fm were very small except late in the season when they increased greatly. Differences between the Irish Sea and Faeroe, north-eastern English and Adriatic waters in larval season and rate of development were also found.

INTRODUCTION

The three larval stages of *Nephrops* have been known since the work of Sars (1884, 1889). Other early descriptions were those of Williamson (1914), Jorgensen (1925) and Santucci (1926, 1927). These stages are readily distinguished by the following diagnostic characters:

Stage	*Supraorbital spine*	*Pleopods*	*Uropods*
1	Absent	Absent	Absent
2	Present	Small	Absent
3	Present	Large and setose	Present

The stages are simply referred to here as "first stage", "second stage" and "third stage", following the precedent of Karlovac (1953).

Nephrops larvae have been noted in general plankton surveys by Rees (1952) in the North Sea, Kurian (1956) in the Adriatic, and Williamson (1956) in the Irish Sea where the great majority were taken on a line from the southern end of the Isle of Man to Dublin.

Data on distribution and changes in stage-composition during the larval season are scarce. Karlovac (*op.cit.*) working in the Adriatic, Andersen (1962), (Faeroe Islands) and O'Riordan (1964), (Irish Sea) recorded stage-composition with distribution, but of these only Karlovac examined the rate of advancement of stage-composition with season to any extent. Jorgensen (1923, 1924, 1925) recorded only whether each stage was present or absent or formed a majority of the larval catch of the species off Northumberland. Thomas (1954) and Fraser (1965) indicated relative frequency of occurrence monthly off Scotland but did not classify data by stages.

In addition to the work of Williamson (1956), there were two other sources of data prior to 1969. These are both in the form of surveys covering all depths (except close to the sea bed) in one diagonal haul, made with the Lowestoft-built Modified Gulf III tin townet.

C. E. O'Riordan sampled four stations within the area 5°48'W-6°00'W and 53°30'-53°46'N on 21st April, 1961, and thirty-one stations within the area 5°49'W-6°04'W and 53°36'N-54°00'N, plus one (barren) station at 53°57'N, 6°14'W, on 25th-27th April, 1962. Results are described briefly by O'Riordan (1964). In 1961 98 larvae at stage 1 were taken, 15 at stage 2 and one described as intermediate (86% of catch stage 1, 14% stage 2). Three only were taken at the westernmost station (6°00'W), elsewhere catches ranged from 13 to 32. In 1962, 103 larvae at stage 1 and one at stage 2 were taken (99% stage 1, 1% stage 2) and the eastern edge of

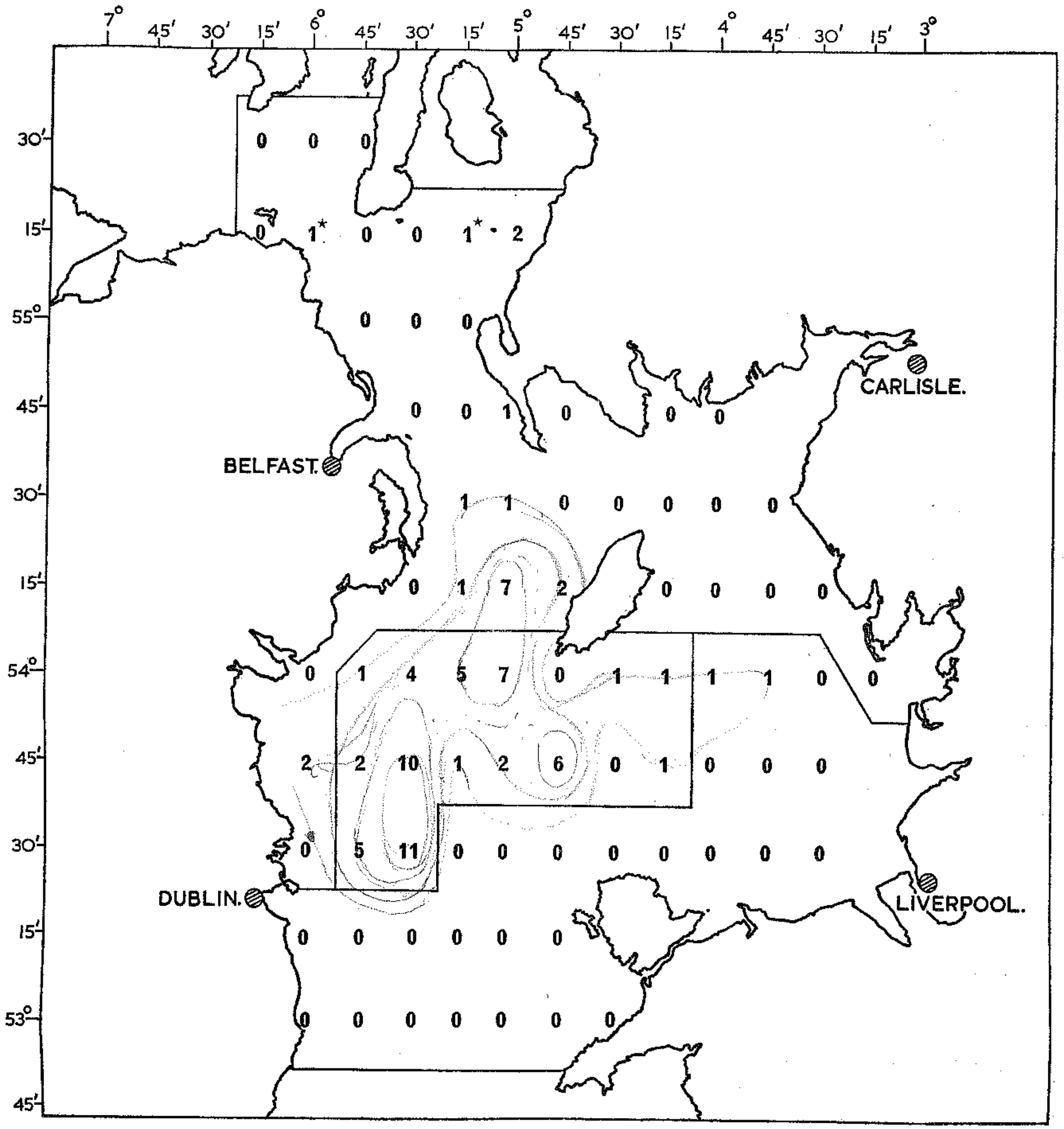

Fig. 1. Numbers of *Nephrops* larvae per haul taken in survey of northern Irish Sea and approaches, May-June 1966. Dividing lines indicate areas covered in three stages of the survey thus:— A (north), 17-20 May; B (south, 24-26 May; C (central), 1-2 June.

* = stage 2 larvae in area A (see text).

the area was the most productive part, especially its southern half. The catch per haul was notably lower in 1962 than in 1961.

A survey of the entire northern Irish Sea and its approaches was made in 1966 (Hillis, 1968). The catches taken at all stations and the three sections into which the area was divided, North, South and Central, are shown in Fig. 1. Larvae were abundant only off the Irish coast and south and west of the Isle of Man. All larvae caught in sections A and B were stage 1 with two exceptions in the north-west (marked *) which were stage 2, but the Central section C, the last surveyed, yielded 20 at stage 1 (35%), 20 at stage 2 (35%) and 17 at stage 3 (30%).

METHOD

From 1969 to 1971, survey cruises were made in the western Irish Sea as shown in Table 1, using the research vessels Cu Feasa and Cu na Mara. The area lay within the limits 53°20′N to 54°00′N and from the Irish coast eastwards to 5°20′W. For reference, a code (originally designed for trawling surveys in part of the area) was used, designating stations by letters for latitude and numbers for longitude, as follows:—

Latitude	Longitude
53° 20′N = ZZ	6° 10′W = 2
53° 30′N = D	6° 00′W = 4
53° 40′N = H	5° 50′W = 6
53° 50′N = L	5° 40′W = 8
54° 00′N = P	5° 30′W = 10
	5° 20′W = 12

Thus, station D6 lay at 53° 30′N, 5° 50′W.

Whilst previous work in the area had been based on diagonal hauls sampling all depths simultaneously at each station (O'Riordan 1964, Hillis, 1968) it was decided to make separate hauls at each depth to be sampled. The depths sampled initially were 2, 5, 10, 20, 30 and 40 fathoms (4, 9, 18, 36, 55 and 73 metres) but, acting on the finding of the first few hauls of the first cruise, sampling at 15 fm (27 m) was introduced and that at 2 fm abandoned. Standard tows of 15 minutes duration were carried out in an approximately circular path to reduce the effect of tidal currents, which were sometimes noticeable in the south-eastern part of the area. Diurnal variation in vertical distribution was investigated during the cruise in early June 1970 and was the sole object of an overnight cruise 28-29 June, 1971. During these experiments plankton hauls were alternated with readings made with a lightmeter of the type devised by Craig and Lawrie (1962) but substituting a Chance-Pilkington type OGR3 filter for the same manufacturers' type OBA2 filter mentioned by the authors. This instrument has a spectral response with a peak at about λmax = 525 nm. The unit of light-intensity measurement is designated "metre-candle", of which the derivation is similar to that of the 'lux' save that the 'lux' is based on the response of the human eye, with λmax = 555 nm, whereas the metre-candle used here is designed to correspond with the expected response of the *Nephrops* eye. This was not known, but that of the lobster *Homarus americanus*, another marine Astacidean species was *viz* λmax = 515 nm (Waterman, 1961). (As this paper approaches publication it has been learnt that Dr. E. R. Loew at the M.R.C. Vision Research Unit, University of Sussex, has determined λmax = 498 nm for the absorbtion spectrum of the visual pigment of *Nephrops*, a value which, unless further screening pigments are discovered, is expected to be very closely linked to the λmax value for the spectral response of the species).

Diurnal variation data in June 1970, other than those of daytime hauls, are not included in data of Table 1 as they affect three stations only out of eighteen in the survey, but data of 28th-29th June, 1971 are, as their inclusion increases the period of coverage during that year. Also included in Table 1 is the catch of a short cruise undertaken on 19th May, 1969 to obtain stock for laboratory studies.

In 1969 and April 1970, the modified Gulf III townet (intake cross-section area 314 mm) was used, with in addition experimental nets in June 1969 and Icelandic plankton samplers loaned by the Fisheries Laboratory, Lowestoft in April 1970. All data for these cruises have been corrected to equate to the intake cross-section area of the Gulf III, but the data so obtained are only used for assessing stage-composition of catches and (where the Gulf III was used alone) for 'within cruise' distribution data, and not for inter-cruise or inter-year comparisons.

Table 1. Cruises, catches and Mean Stage value (= degree of larval advancement).

Dates of Cruises	Total Area: Total Numbers (Actual)	Total Area: Total Numbers (Corrected)*	Total Area: Number by stages, corrected date where available: 1	3	3	Total Area: Mean Stage	Standard Area: Corrected total Nos.*	Standard Area: Mean Stage
1969								
30 April-2 May†	217	—	164	53	—	1.24	—	—
7-9 May†	115	—	66	47	2	1.45	—	—
12-13 May	316	—	159	125	32	1.60	—	—
19 May**	33	—	15	15	3	1.63	—	—
11 June**	76	—	10	30	36	2.34	—	—
25 June-2 July	9	—	4	2	3	1.89	—	—
1970								
9-10 April	15	—	15	—	—	1.00	—	—
20-24 April	42	—	42	—	—	1.00	—	—
6-12 May	464	476	425	49	2	1.11	404	1.11
18-20 May	284	322	258	60	4	1.21	219	1.23
4-11 June	1,104	1,267	395	505	367	1.98	1,073	1.98
23-26 June	638	804	102	253	449	2.43	736	2.42
1971								
27-30 April	194	231	172	59	—	1.26	82	1.32
17-20 May	623	699	333	286	75	1.62	504	1.58
22-25 June††	359	244	116	79	49	1.73	104	1.83
28-29 June**	171	—	51	72	48	1.98	—	—

* Adjusted to uniform vertical sampling interval of 5 fm.

† Two complementary cruises together covering total area.

** Experiments confined to one or two sampling stations.

†† Correction includes adjustment factor $\frac{2}{3}$, for net catching power.

At the beginning of May 1970, four identical nets built for the programme were completed. These had the netting cone suspending in an open frame on the 'Nackthai' principle of Nellen & Hempel (1969) for economy, ease of handling and ease of washing down.

The body was constructed of steel struts, with a circular flange at the front end with twelve forward facing threaded lugs, which secured the net and nose cone in place by fitting through holes in the strengthened border of the net mouth and holes in a corresponding flange in the nose cone, both of which were held in place by wing nuts screwed on to the lugs. The net-cone was made of St. Martin brand "62 GGN Heavy Quality" nylon mesh specified by the makers to include 46% hole area, with detachable canister constructed from PVC piping and held in place with rubber strops. The nets were 230 cm in total length with an intake cross-section area of 962 cm², maximum internal cross-section area of 1,288 cm² and a total area of aperture in the netting cone of about 5,950 cm². They were towed at a low speed attached by detachable leads to a main lead at intervals equal to those separating the depths to be sampled.

The main lead was kept approximately vertical (80°-90° with horizontal) by a heavy weight at its end (ca.200 kg). This system worked effectively. *Nephrops* larvae being slow moving, though calibration experiments showed that at the low speeds involved they operated at a considerable front-to-rear angle (ca.50°) downwards from the horizontal, and the introduction of floats in June 1971 altered this to a slight angle upwards (ca.20°). Correction for these angles is made by multiplying the intake area by their cosines (to one decimal place), 0.6 (without floats) or 0.9 (with floats), giving an effective intake cross-section area value of 580 cm² without floats. (Data of June 1971 were corrected to be comparable by use of the factor $\frac{2}{3}$). None of the nets had automatic mouth opening/closing devices, so it is possible that some larvae were caught during shooting or hauling at lesser depths than that which the nets were meant to sample, but the extreme scarcity or absence of specimens from hauls made at great depths is in itself a strong suggestion that this was not a serious source of error.

Calibration experiments in 1971 gave mean distance covered during a 15 minute haul as 1.1 km giving the volume of water sampled with an effective intake area of 580 cm² as 64 m³. The volume sampling interval (10′ lat x 10′ long x 5 fm) was 1.87 km³ giving a raising factor of (1.87 x 10^9)/64, = 2.92 x 10^7. Thus, with 580 cm² intake and 5 fm vertical sampling interval about one twenty-nine millionth part of the sea and hence of the larval *Nephrops* population is estimated to have been sampled within the area surveyed.

RESULTS

Stage-Composition and Distribution

Overall numbers of larvae taken and their stage-composition are given in Table 1. This includes actual totals, and, from May 1970 onwards, totals corrected to a uniform vertical sampling interval of 5 fm by multiplication of numbers at 20 fm depth by 1.5 and at 30 fm and 40 fm by 2 (except where sampling was carried out at 25 and 35 fm). In view of the reduction in numbers ascending from 10 fm to 5 fm, a factor of 1.5 was not applied to 5 fm data. The effect of this correction is of course greatest where substantial catches were made at depths greater than 20 fm, as in June 1970. In the case of data of 22nd-25th June 1971, a further factor of $\frac{2}{3}$ was applied to cover the differential in catching power of the gear. Owing to non-standard vertical sampling intervals (especially at depths in excess of 20 fm) and gear, correction of data prior to May 1970 is not undertaken.

Overall numbers, actual and corrected, numbers of each stage (corrected where available) and mean stage values are given for the total area; overall total numbers and mean stage values (corrected where available) are given for a "standard area", comprising stations D4, D6, D8, D10, H4, H6, H8, H0,—the largest area common to all main cruises. "Mean stage" is a simple measure of degree of advancement of the larval population calculated as follows:

$$\text{Mean stage} = (N_1 + 2N_2 + 3N_3)/\Sigma N$$

Where N_x = Number of larvae in stage x,

and ΣN = overall number of larvae (all stages summed).

This is used later for comparison of the season of larval occurrence in very different parts of the range of *Nephrops*.

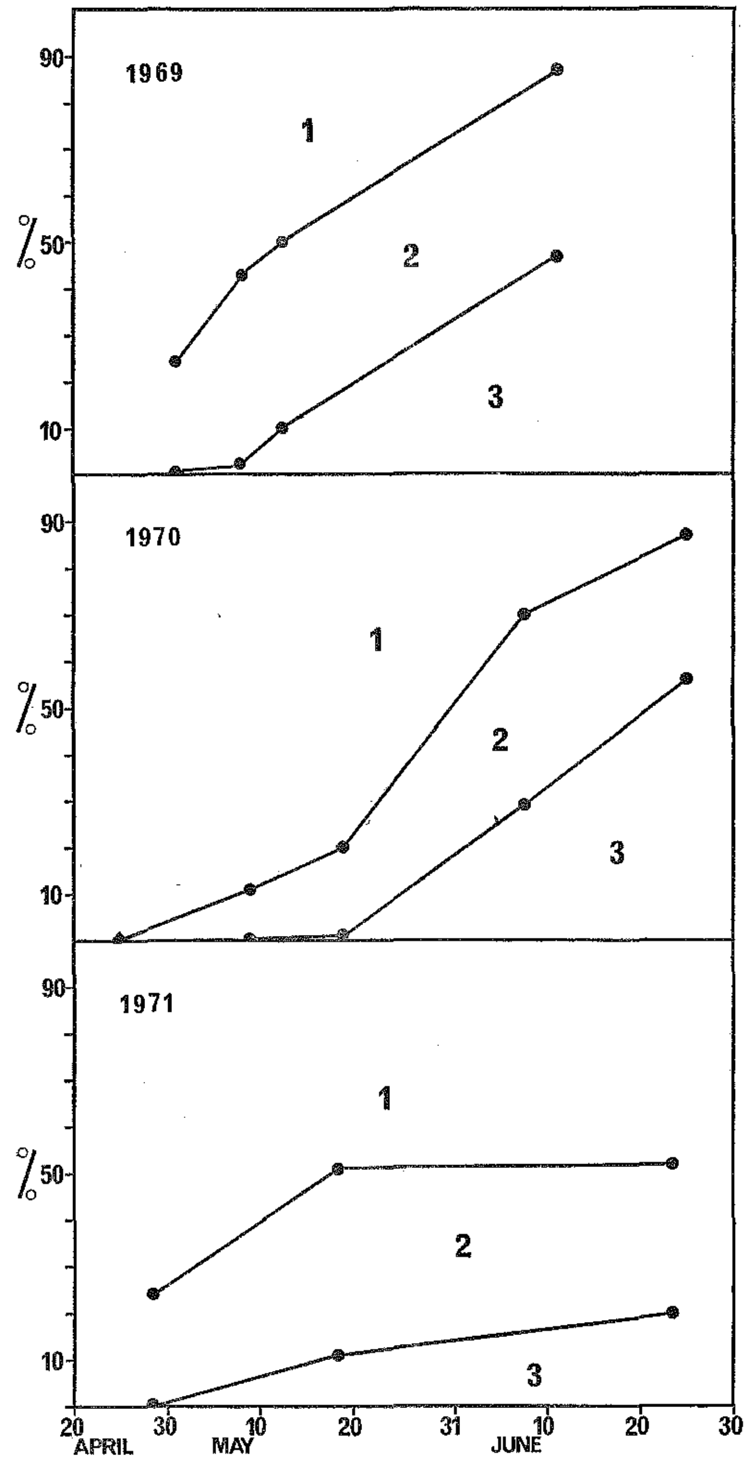

Fig. 2. Seasonal changes in percentage stage composition, 1969, 1970 and 1971.

It will be seen that 1970 was both the latest season for hatching and apparently the most successful, numbers present in both of the two June cruises being considerably higher than those obtained in other years. A check in the larval progress is also noticeable between the two cruises during May 1970, numbers of stage 1 larvae dropping markedly without, however, a corresponding rise in the numbers of older larvae. Mean Stage values of around 2.0 fell about 11 days later in 1970 than they did in 1969, whilst if the check at the second cruise in May 1970 is ignored, the speed of development between early May and late June 1970 was similar to that of 1969, with the time lag reducing gradually from 13 to 10 days over a period of six weeks.

In 1971, development was slower and, as in 1969, the last main cruise of the season recorded both a great diminution in numbers and a lower mean stage value than anticipated (although the overnight experiment of 28-29 June—which was not however a comprehensive survey — showed a considerably more advanced larval population than the last survey cruise, about five days earlier). A possible reason for this is that hatching rates may rise swiftly to a peak from the start of the season, but "tail off" slowly after the peak is past, thus creating a greater uniformity of stage early in the season than later on and also, well advanced larvae late in the season may possibly be more difficult to catch.

Changes in percentage in stage-composition for total areas of cruises using corrected data where available are shown in Fig. 2, (excluding the small scale data of 19th May 1969, 25 June-2 July 1969 and 28-29 June 1971). The expected pattern of decrease in stage 1 and increase in stage 3 with the passage of the season is clearly seen while stage 2 numbers were found to rise to a maximum of approximately 40% in mid-season during all three years. In 1969 this value was sustained for a fairly long period (early May to early June), suggesting that stage 2 gains and losses occurred at approximately equal rates during this period. This figure would appear to suggest that 40% of the duration of the larval period is spent in stage 2, but laboratory evidence suggests that it is rather less, probably about 33% (Hillis, 1972b). Possible explanations of this phenomenon are that stage 3 is under-represented in larval catches due to behaviour, or else numerically weaker than the earlier stages, due to larval mortality.

Distribution patterns of total numbers and mean stage values are given for the main surveys in the three years in Figs. 3, 4 and 5, with numbers contoured 10, 50 and 200, and mean stage values contoured at 1.1, 1.25, 1.5, 2.0, 2.5 and 2.75, with extra contours in several cases where they substantially improve the detail shown. The completion of the first cruise in 1969 in two stages (due to weather) is indicated by dashed lines separating the area covered in the first stage (the main part of the area, 30th April-2nd May) from that of the second north-east and south, 7th-9th May). (One station, D6, was sampled in both stages). This circumstance is bound to have some considerable effect on the distribution pattern of mean stage values found, but the changes actually recorded at the combined depths sampled twice at D6, 1.23 at first stage and 1.39 at second can be regarded as maximal since the former was obtained on the first day of the cruise, and the latter on the last.

From the figures, it may be seen that the area sampled usually embraced the area of greatest larval population density effectively; this was especially true in the first 1969 survey and in early May and early June 1970. In 1971, however, population density appeared to be very patchy, with maximum numbers on the southern margin of the area in April and at the north-western corner in May and June. In all years, large numbers at peripheral stations, where they occurred, tended to occur at the south and north or north-west rather than the east or west margins of the survey area.

The area of the fishery for adult *Nephrops* is considerably smaller than that surveyed for larvae (Hillis, 1972b) and lies well within its bounds, except in the north-west, near Clogherhead, and to some extent the north-east, where a rather sparse population exists, apparently linking that in the area under study with one in the outer reaches of Dundrum Bay. It is therefore probable that even where higher densities were found at peripheral stations, the larval population did not extend greatly outside the area sampled except to some extent at the northern end.

There is little evidence of larval movement within the area. The population as a whole appeared to shift northwards somewhat during the 1971 season, and southwards in the brief inter-cruise period of early May 1969, whilst in 1970 it remained more or less static.

A strongly marked feature found in every cruise to a varying extent was a progressive increase in mean stage values going from north-west to south-east. Fig. 6 shows the distribution of stages in 1970 and bears this out whilst giving a comparison of distribution patterns between the three stages.

Whilst it is possible that this is due to movement with growth, this interpretation would require a corre-

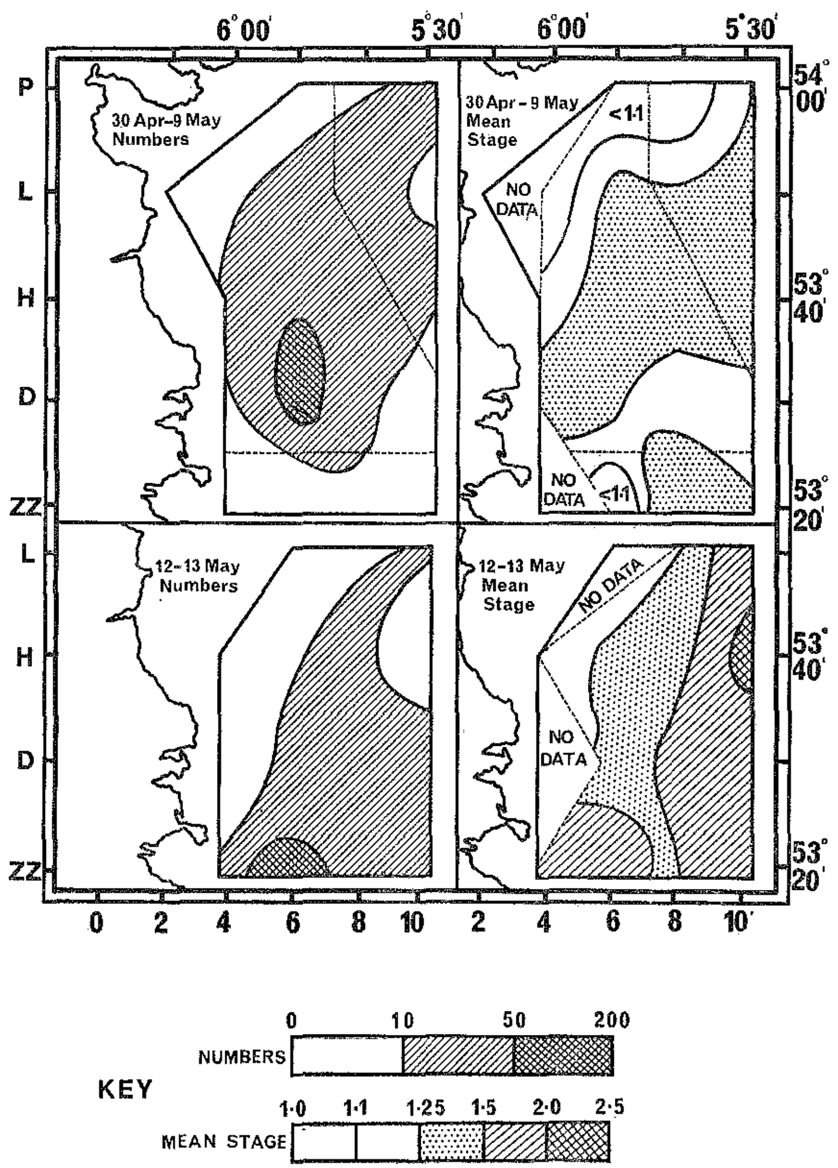

Fig. 3. Distribution of overall total numbers of larvae per station (left), and distribution of mean stage values (right) April-May 1969. Dashed lines in upper maps separate main area (surveyed 30 April-2 May) from north-east and south (7-9 May).

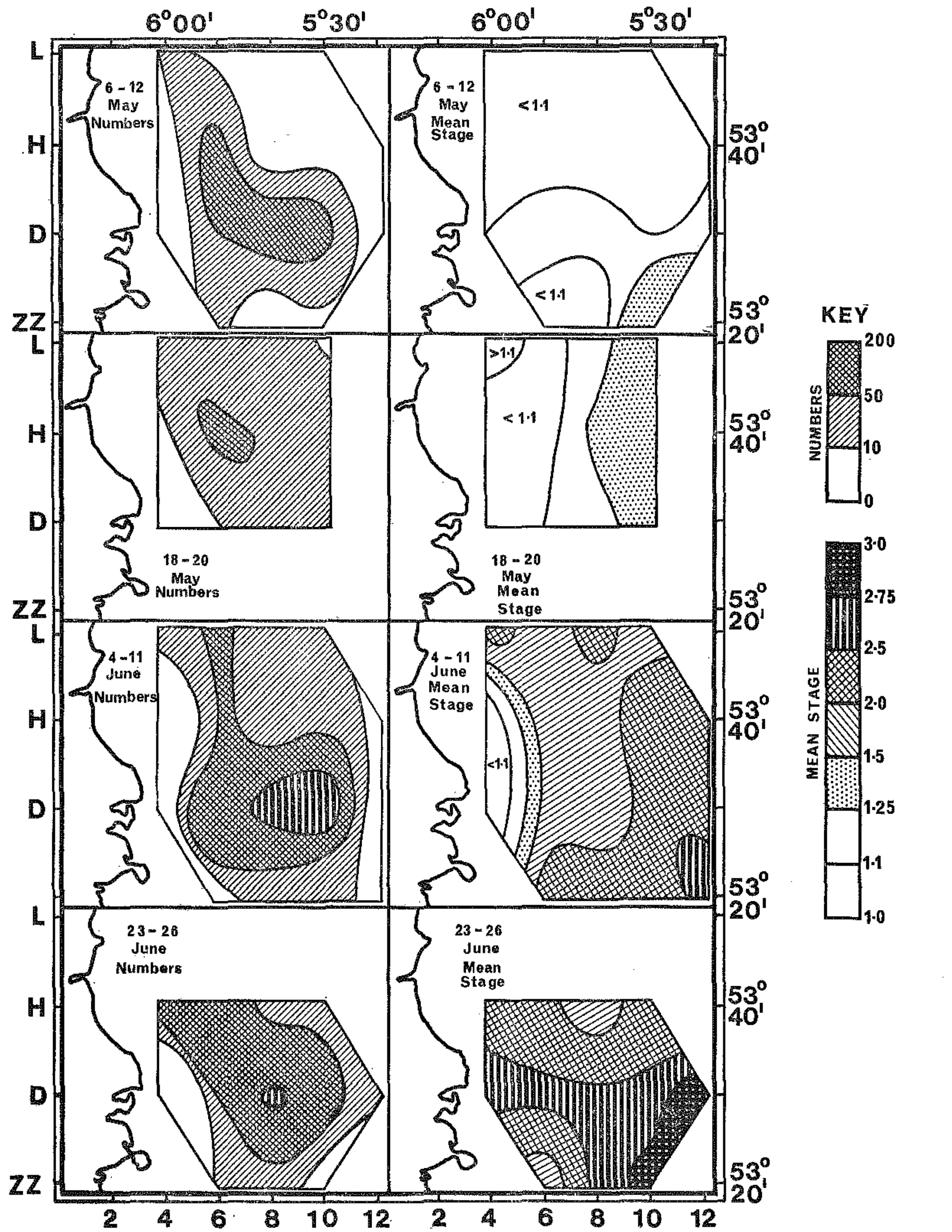

Fig. 4. Distribution of corrected overall total numbers of larvae per station (left), and distribution of mean stage values (right), May-June 1970. For key, see Fig. 4.

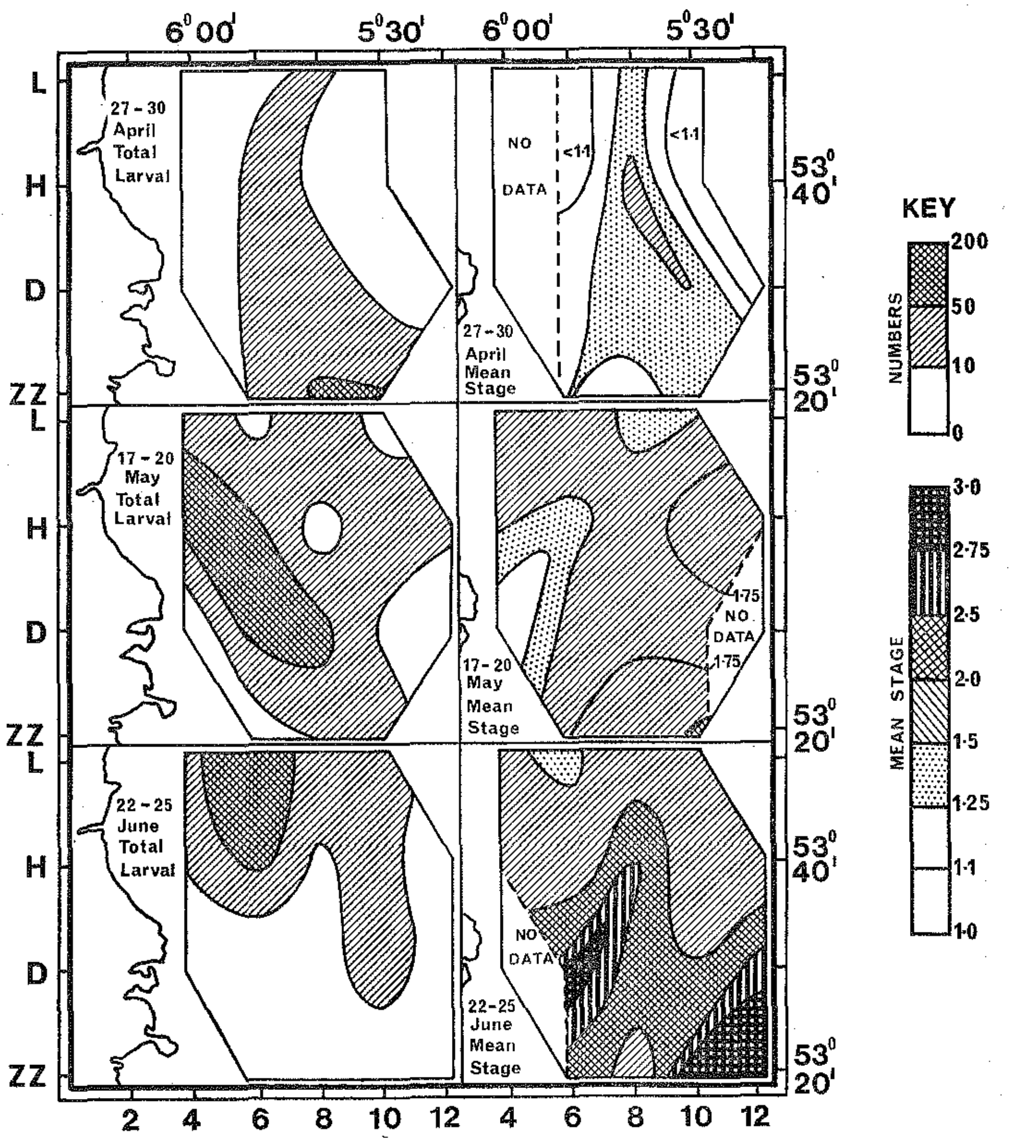

Fig. 5. Distribution of corrected overall total numbers of larvae per station (left), and distribution of mean stage values (right), April-June 1971.

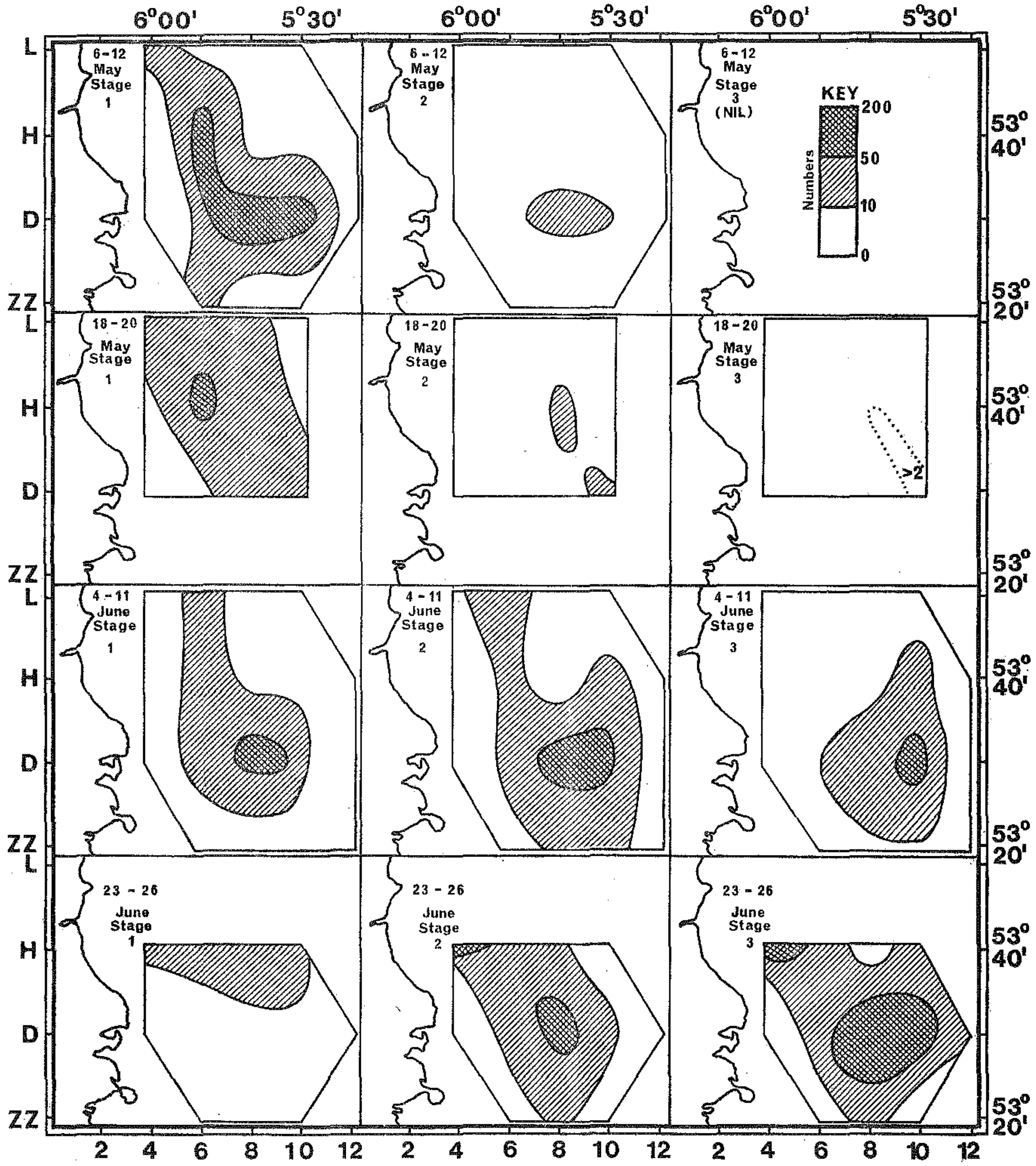

Fig. 6. Distributions of corrected numbers of larvae per station by stages, May-June 1970.

sponding shift south-eastwards in absolute numbers, and there is no clear evidence that such a shift occurred. A more likely explanation of the differential in mean stage values is to be found in swifter development and possibly earlier hatching in the south-east than in the north-west. Samples from the south-east were normally richer in zooplankton than those from the north-west and the south-east is more in the path of tidal currents entering the northern Irish Sea between Co. Dublin and Anglesey (Hydrographer of the Navy, 1943). As the plankton of the Irish Sea is to some extent impoverished (Williamson, 1956), contact with currents from outside might be expected to produce a beneficial effect.

Vertical Distribution by Day

Maximum numbers of larvae were taken at depths of 5-15 fm by day with relatively few below 15 fm until late in the season, when catches at depths of 20, 30 and 40 fm rose to become comparable with those at lesser depths. Fig. 7 illustrates this phenomenon in five successive cruises in 1970, overall numbers at each depth being shown above, with percentage stage-composition below.

The depth of occurrence of peak numbers will be seen to have decreased between late April and early May (5 fm being almost as productive as 10 fm in the latter cruise) from which it dropped to 15 fm (but with 10 fm also very productive) by early June, while numbers deeper than 20 fm showed some increase and there were large numbers at 30 and 40 fm in late June. The limited data of 1969 suggests a similar pattern when catches at 20 fm were quite high on 11th June, but in 1971, when the mean stage value never rose above 2.0 the pattern remained similar to that of the early parts of 1969 and 1970 throughout all cruises. Stage composition also showed a tendency towards increased advancement with increasing depth, in all years.

In connection with this, it is interesting to note that on 19th June, 1970, during an attempt to catch early post-larvae by making short hauls with a trawl having an experimental extra fine mesh cover over the cod-end, the catch included, in addition to five post-larvae (Hillis, 1972a), two larvae (one each at stage 2 and stage 3) and more may have been concealed in the substantial amount of mud collected by the gear, thus demonstrating conclusively presence of a few at least of the two more advanced stages of larvae at the sea-bed in June, a feature also found by Jorgensen (1923, 1924, 1925).

Fig. 8 shows vertical distribution in a cross section of the sea along latitude 53°40′ ('D' stations) in 1970, showing considerable patchiness in distribution and also the phenomenon of reduction of the depth of maximum numbers in shallow water, presumably to avoid turbid waters close to the bottom.

Environmental factors

Illumination

The data for diurnal variation in vertical distribution are given in Table 2 for the 1970 experiment and Table 3 for that of 1971. In 1970, peak numbers of larvae ascended from 10 fm depth to 5 fm between daytime and dusk at D10 on 8th June, the peak remaining at 5 fm, but becoming more diffuse and less marked between dusk and night-time. H6 on 9th June showed a similar daytime to dusk ascent though between 15 fm and 10 fm; only daytime and dusk hauls were made on that date. Data of L6 on 10th June were less conclusive, but nonetheless the proportion of the total catch still increased between daytime and dusk at 5 fm and 10 fm, and decreased at 15 fm and 20 fm. The strongly marked nature of the peaks in numbers at given depths and the clarity of the 5 fm rise on 8th and 9th June are well illustrated in Fig. 9.

Table 3 shows catches obtained during the all-night survey on 28-29 June 1971. This was commenced at station H6, but moved to D10 at 23.30 hrs., owing to apparently poor catches at the former station. (On subsequent examination, the catches at H6 were found to be moderately good, with a maximum of 25 larvae at 10 fm in haul 4, many larvae being found concealed among filaments of green algae). Variation in vertical distribution, however, was not well demonstrated at either station. At D10 hauls at 5, 10, 15 and 20 fm were alternated with hauls at 2½, 7½, 12½ and 17½ fm to give more detailed vertical coverage, and two hauls, one before and one after sunrise, were made at depths greater than 20 fm to survey numbers at those depths, with largely negative results. Maximum numbers were found at 2½-5 fm between 01.30 and 02.30 hours (BST), at 10 fm between 03.30 and 04.30 hours and at 12½ fm after 05.00 hours.

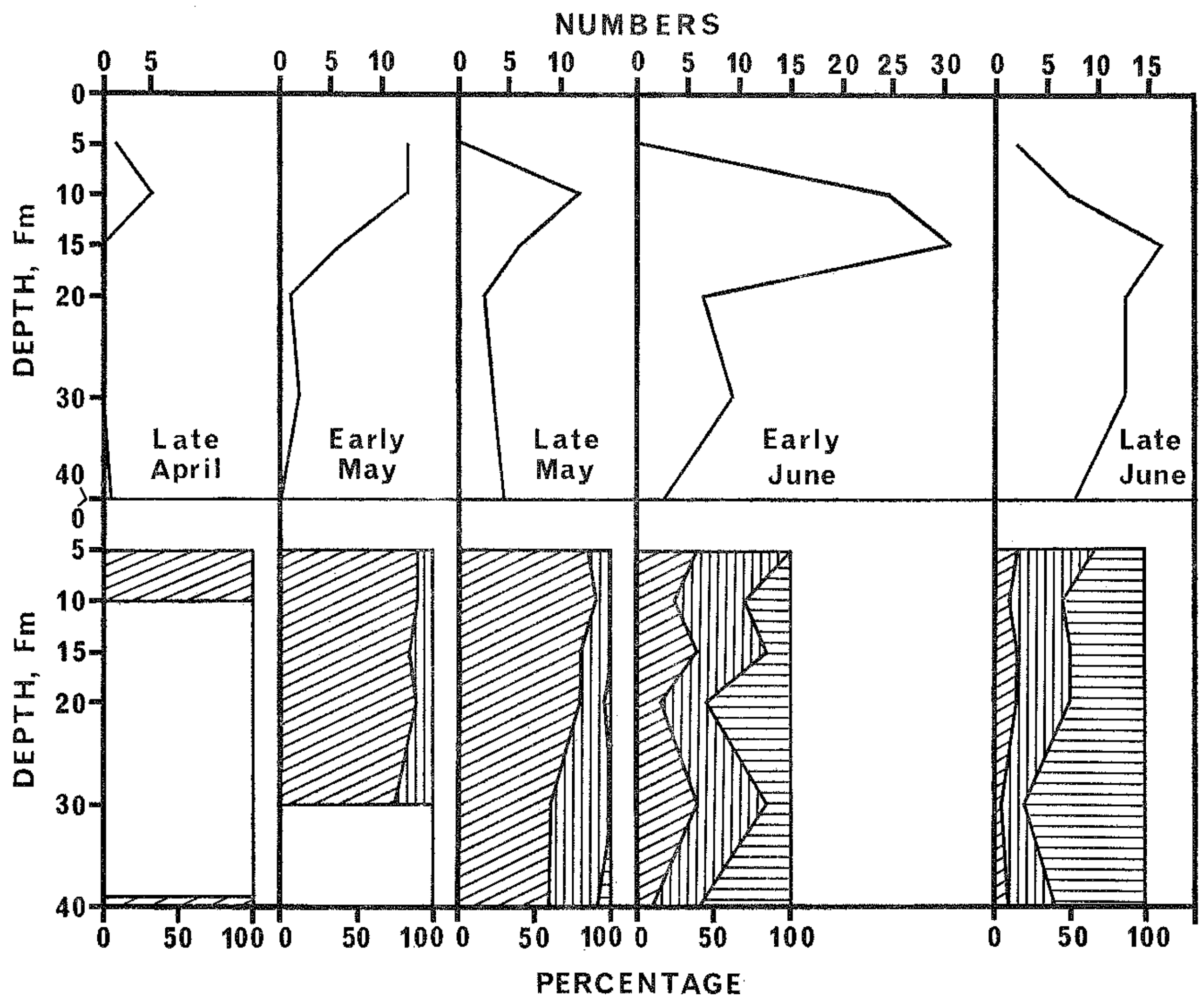

Fig. 7. Variations with depth of numbers (above) and percentage stage composition (below) in daytime catches during 1970 season, excluding data of shallow stations of code No. '2' stations at 6°00'W). Stages in percentage diagrams indicated by line shading, as follows:— 1—diagonal; 2—vertical; 3—horizontal.

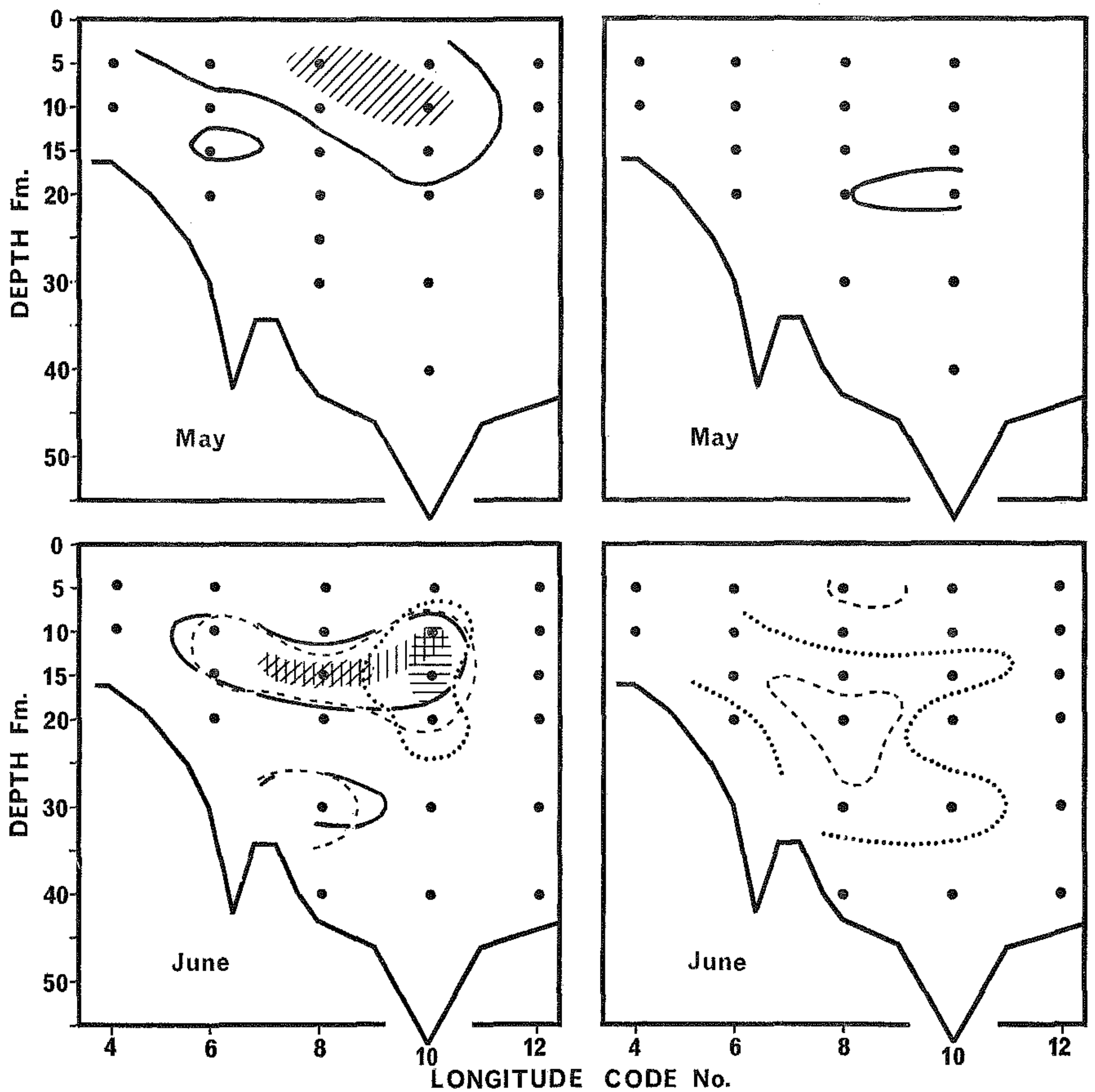

Fig. 8. Vertical distribution pattern of larval stages along west-east cross section of sea at 53°30'N during cruises in early (left) and late (right) May and June 1970. Dots indicate positions of hauls. Numbers of stages contoured at 10 and 50, thus:—

Stage :—	1	2	3
N = 10 (line) :—	solid	dashed	dotted
N = 50 (shading) :—	diagonal	vertical	horizontal

Table 2. Catch (N) by stages and depths with light-intensity in metre-candles (mc) in vertical distribution surveys, evenings of 8, 9 and 10 June, 1970.

Times of hauls at different depths are indicated as follows:

All hauls at 5 and 10 fm and hauls on 8 June at 15 fm—A.

Hauls on 9 and 10 June at 15 fm and all hauls at 20, 30 and 40 fm—B.

Station / Date	Haul serial number	Time (BST)	Larval Stage	Numbers and light-intensity (mc) by depth (fm) 5	10	15	20	30	40
D 10	1A	21.26-21.41	1	1	34	18	4	5	2
			2	1	101	26	14	1	1
8 June	1B	21.51-22.06	3	0	108	77	34	2	5
			Total	2	243	121	52	8	8
			Light	80	24	8.5	.30	.019	...
	2A	22.22-22.37	1	24	3	5	0	4	1
			2	38	17	3	7	2	3
	2B	22.52-23.07	3	72	22	18	12	6	1
			Total	134	42	26	19	12	5
			Light	1.0	.30	.085	.0018	...	...
	3A	23.25-23.40	1	28	27	5			
			2	26	29	9			
			3	53	29	29			
			Total	107	85	43			
			Light	.0065	.0023	.0007			
H 6	1A	21.22-21.37	1	0	0	26	2		
			2	0	0	22	1		
9 June	1B	21.41-21.56	3	0	0	4	4		
			Total	0	0	52	7		
			Light	80	45	2.8	.55		
	2A	22.29-22.44	1	1	24	1	0		
			2	0	17	0	1		
	2B	22.49-23.04	3	0	7	1	1		
			Total	1	48	2	2		
			Light	1.4	.65	.09	.04		
L 6	1A	21.43-21.58	1	1	13	16	2		
			2	0	5	14	4		
	1B	22.04-22.19	3	0	1	1	2		
10 June			Total	1	19	31	8		
			Light	45	14	.70	.26		
	2A	22.24-22.39	1	2	1	5	0		
			2	0	5	2	0		
	2B	22.43-22.58	3	0	1	1	2		
			Total	2	7	8	2		
			Light	1.5	.55	.026	.0055		

Table 3. Catch (N) by stages and depths with light-intensity in metre-candles (mc) during overnight survey, 28-29 June 1971. Station—H6 to haul 4, D10 from haul 5 onwards. In some cases, where data of two or three consecutive hauls are combined in one row where these sampled different depths, Serial Number of haul is given for each depth.

Haul Serial Number and time (BST)	Larval Stage	Numbers and light-intensity (mc) by depth (fm) 2½	5	7½	10	12½	15	17½	20	30	40
(1) 21.27	1	—	0	—	0	—	0	—	1	—	—
—21.42	2	—	0	—	2	—	1	—	1	—	—
	3	—	0	—	1	—	0	—	1	—	—
	Total	—	0	—	3	—	1	—	3	—	—
	Light	—	880	—	240	—	40	—	2.3	—	—
(2) 22.02	1	—	0	—	3	—	1	—	0	—	—
—22.17	2	—	0	—	2	—	1	—	0	—	—
	3	—	0	—	1	—	1	—	0	—	—
	Total	—	0	—	6	—	3	—	0	—	—
	Light	—	154	—	44	—	7.5	—	0.5	—	—
(3) 22.35	1	—	0	—	3	—	0	—	0	—	—
—22.50	2	—	0	—	3	—	2	—	1	—	—
	3	—	0	—	5	—	1	—	0	—	—
	Total	—	0	—	11	—	3	—	1	—	—
	Light	—	7.0	—	1.9	—	0.35	—	0.027	—	—
(4) 23.09	1	—	0	—	15	—	3	—	1	—	—
—23.24	2	—	0	—	10	—	1	—	0	—	—
	3	—	0	—	3	—	4	—	0	—	—
	Total	—	0	—	28	—	8	—	1	—	—
	Light	—	0.32	—	0.082	—	0.021	—	0.0018	—	—
(5) 01.37	haul:—	(6)	(5)	(6)	(5)	—	(5)	—	(5)	(7)	(7)
—01.52	1	3	4	1	3	—	0	—	2	1	0
(6) 02.08	2	4	4	1	2	—	0	—	2	0	0
—02.23	3	0	0	3	1	—	1	—	4	0	0
(7) 02.33	Total	7	8	5	6	—	1	—	8	1	0
—02.48	Light	0.011	0.0033	0.0034	0.0016	—	0.005	—	0.0004	0.0003	*
	haul:—	(9)	(8)	(9)	(8)	(9)	(8)	(9)	(8)	—	—
(8) 03.43	1	0	1	0	2	0	1	0	2	—	—
—03.58	2	1	2	4	6	1	4	0	4	—	—
(9) 04.12	3	0	2	1	3	1	5	1	3	—	—
—04.27	Total	1	5	5	11	2	10	1	9	—	—
	Light	10	0.45	2.5	0.12	0.75	0.038	0.23	0.012	—	—
(10) 04.43	haul:—	(11)	(10)	(11)	(10)	(11)	(10)	(11)	(10)	(12)	(12)
—04.58	1	0	1	0	0	2	0	0	0	0	0
(11) 05.16	2	0	1	3	0	6	2	0	0	1	0
—05.31	3	0	0	0	0	4	0	0	2	0	0
(12) 05.53	Total	0	2	3	0	12	2	0	2	1	0
—06.08	Light	1.900	110	550	26	150	8.0	44	2.5	5.6	0.34
(13) 06.16	1	—	1	—	0	—	0	—	0	—	—
—06.31	2	—	0	—	0	—	0	—	0	—	—
	3	—	0	—	0	—	0	—	0	—	—
	Total	—	1	—	0	—	0	—	0	—	—
	Light	—	8,600	—	2,100	—	750	—	210	—	—

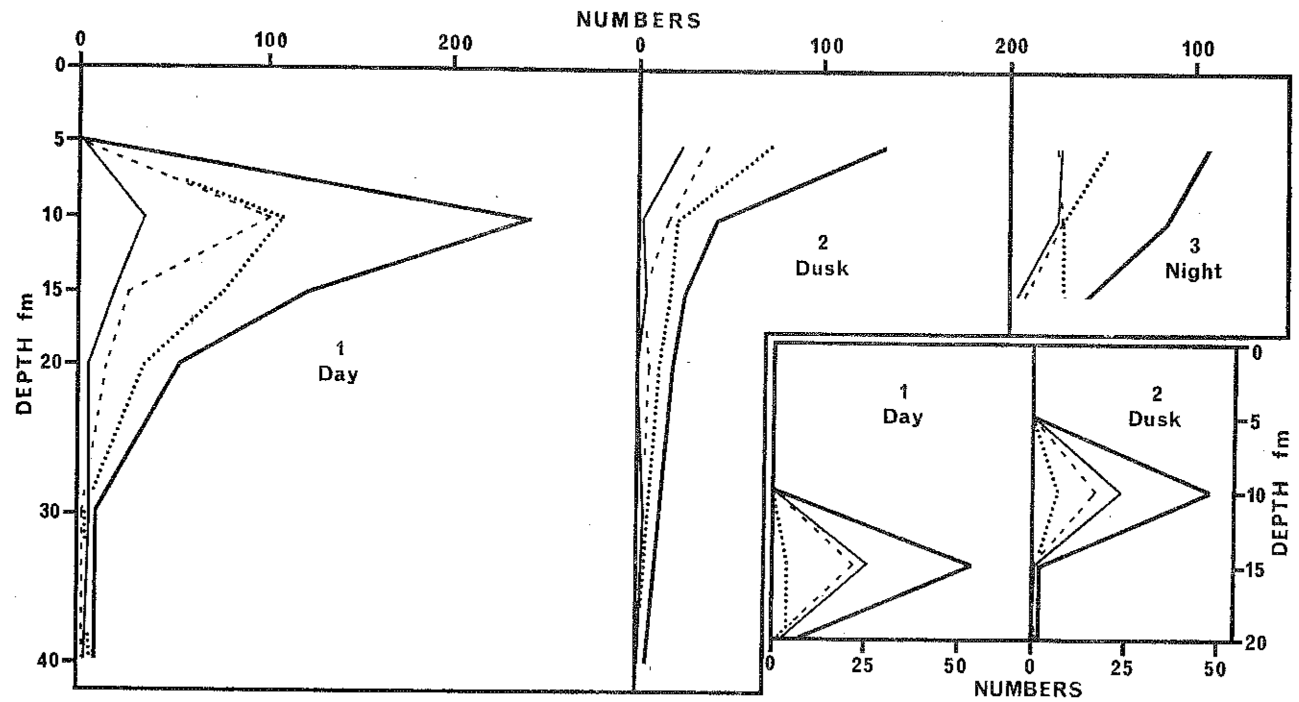

Fig. 9. Diurnal variations in vertical distribution of larvae, 8th and (inset) 9th June, 1970. For times of hauls and illumination values, see Table 3. Stages indicated as follows:— 1—light solid line; 2—dashed line; 3—dotted line; overall total—heavy solid line.

Temperature

The temperature typically increased from about 8°C to 13°C at 5 fm depth (the smallest depth sampled) and from 8°C to 11°C at depths of 20 fm or greater from April to June. Surface temperature varied considerably with short term weather fluctuations and a value of 14.5°C was recorded in early June 1970, though this was not sustained in the later cruise in that month. Fig. 10 shows the initial absence of a thermocline and its development as the season progressed in 1971. It was noticeable that the thermocline occurred over a depth range where larvae were fairly numerous and diurnal vertical migration would appear to have involved a large proportion of them in daily temperature changes of 1°C or more. Thus there was considerable variation between specimens and between time of day in the larval ambient temperature at any one time.

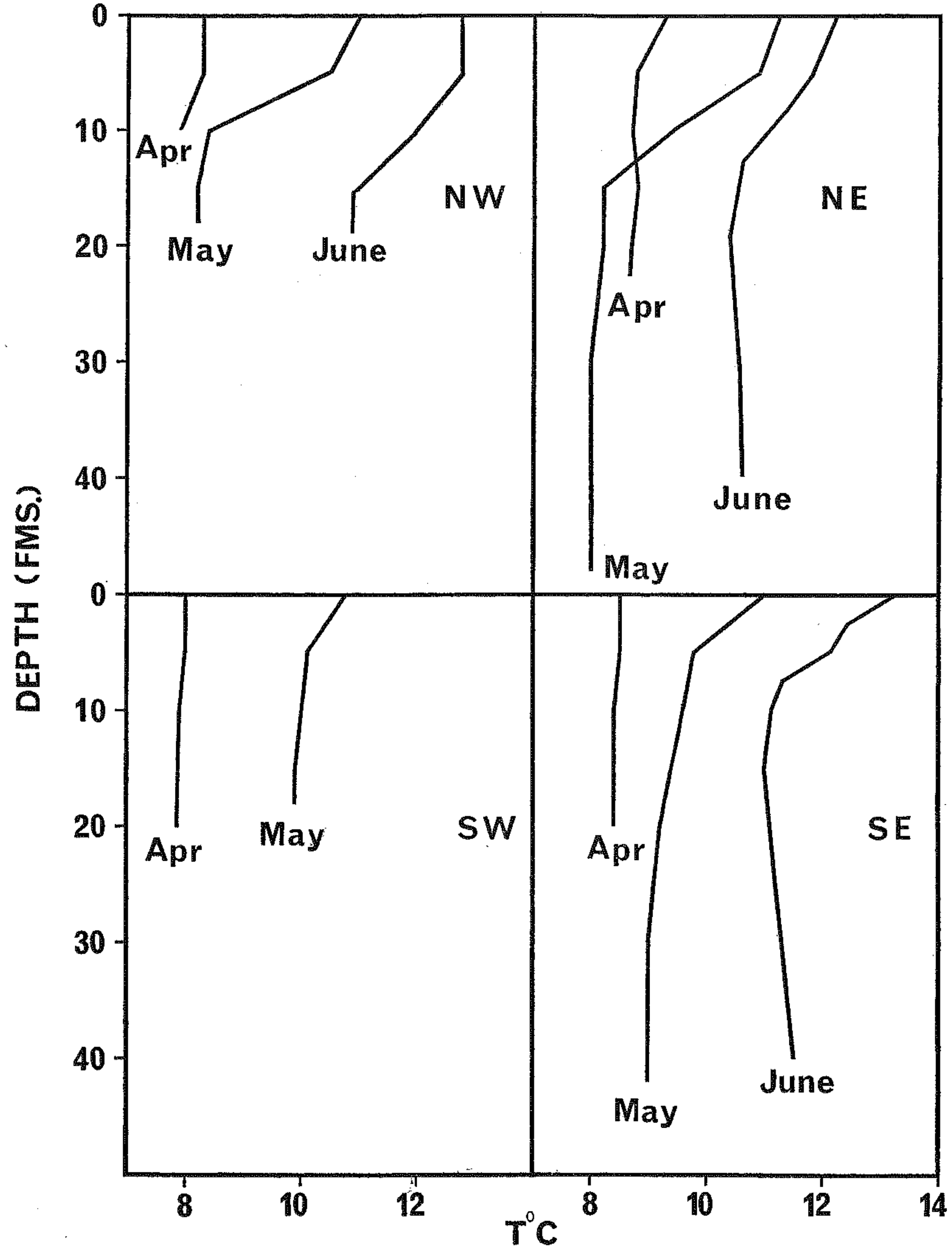

Fig. 10. Temperature (°C) by depth in four quarters of area, April-June 1971.

DISCUSSION

The survey of all the northern Irish Sea and North channel in 1966 (Hillis, 1968) confirmed the continuous plankton recorder data of Williamson (1956) indicating numerous larvae in the area between the Isle of Man and Dublin but few elsewhere. Stations in 1966, however, were too widely spaced to show up the gap which apparently exists between the Isle of Man and Irish grounds. In the present work, sampling in 1970 and 1971 was carried east to 5° 20′W (Code No. '12' stations) and larvae were found to be scarce or absent at the easternmost stations in every survey in 1970 and to some extent, though less markedly, in 1971. This suggests a considerable degree of isolation of the population of *Nephrops* off the east coast of Ireland from others in the Irish Sea.

No firm indications of the movements of larvae emerged from the study and distribution data for females with ripe attached eggs and for young post-larvae (Hillis, 1972a, 1972b) were also too scanty to provide firm conclusions regarding larval movement.

The only previous data on vertical distribution are those of Williamson (1956) and Fraser (1965). Fraser noted that the proportion of the catch taken in depths of less than 10 m (5.7 fm) rose from 3% of the total by day to 11% during hours of dusk, dark and dawn combined, though he found no very definite clearcut pattern in variation of proportions above and below 50 m (28 fm). Williamson considered that the great majority of *Nephrops* larvae spent the daytime at depths greater than the 17 m (9.6 fm) of his daytime samples.

In the present investigations, daytime maxima occurred at 10-15 fm in 1970 and 1971, with few at 20 fm or deeper except when the season was very advanced. The 1970 diurnal variation experiments showed maximum numbers rising by about 5 fm at dusk, very strongly marked peaks rising from 10 to 5 fm at station D10 and from 15 to 10 fm at station H6. The small numbers at station L6 showed a less marked rise. In the case of D10, a third haul at 5, 10 and 15 fm after dusk showed a tendency of the peak to spread, numbers at 5 fm being reduced while those at 10 and 15 fm increased. This nocturnal vertical dispersion is well known in a variety of planktonic animal groups. The 1971 experiment was designed to sample depths of from 2½ to 20 fm at intervals of 2½ fathoms by means of alternating hauls with a view, among other things, to seeing if the dusk peak might be found actually to occur at a lesser depth than 5 fm, but unfortunately, numbers caught were so few that despite it being an all-night experiment, data were less informative than in 1970.

As regards the season of occurrence and rate of larval progress, data of a comparable nature from elsewhere are rather scarce. Karlovac (1953), working in the Adriatic Sea, provides the fullest information of this type available and Andersen (1962) and O'Riordan (1964) give composition data in isolated samples from Faeroe and Irish waters respectively. The small catches obtained by Jorgensen (1923, 1924, 1925) and her limited data (stages forming an overall majority, merely present, or absent in each haul) allow deduction of the highest and lowest possible mean stage values in her material. Thomas (1954) gives the main months of larval occurrence, which are (in descending order of frequency) May, June, then much lower April, March, July, August, September and October, but he does not give stage-composition data.

Examples of mean stage value, with dates from the data of various workers and comparisons of estimated dates of occurrence of two selected values are given in Table 5. This shows clearly the marked difference in season between the Adriatic, where spawning occurs during January-March, and waters further north, where its main months of occurrence are April-June.

O'Riordan's data largely agree with findings of the present work and Andersen's data suggest a time-lag of very roughly 10 days in the Faeroe larval season compared with that in the Irish Sea.

The value in the region of 2.0 recorded by Jorgensen (1924) off north-eastern England can probably be explained by the fact that after the main spawning season is largely finished at the end of June, spawning nonetheless continues on a small scale until autumn, as has been shown by an occurrence of larvae in the plankton (Thomas, 1954; Williamson, 1956; Fraser, 1965) and of ovigerous females bearing advanced eggs which have been found as late as 14th September (Hillis, 1972b).

Table 4. Comparison of progress of stages found in present work with data of other workers.

Area	Authority	Year	Mean Stage Value	Date	N (sample)	Estimated dates of occurrence of Mean Stage value	
						1.1	2.0
Adriatic Sea	Karlovac (1953)	1948	2.36	26-31 March	21	—	28.2
„ „	„ „	1949	1.69	9-11 February	38	—	—
„ „	„ „	1951	1.46	9-19 January	33	—	—
Irish Sea	O'Riordan (1964)	1961	1.14	21 April	115	pre 21.4	—
„ „	„ „	1962	1.01	25-27 April	104	post 26.4	—
„ „	from Hillis (1968)	1966	1.95	1-2 June	57	—	2.6
„ „	Present work	1969		See Table 1		pre 26.4	27.5
„ „	„ „	1970				5.5	6.6
„ „	„ „	1971				28.4	—
N.E. England	Jorgensen (1924)	1923	1.76-2.24	18-20 August	45	—	ca 19.8
Faeroe	Andersen (1962)	1934	1.22	4 May	ca 102	2.5	—
„	„ „	1938	1.11	11 May	ca 2,340	11.5	—

There is, however, one unusual feature of the north-eastern English population which may have a bearing on the spawning season. Adult females in this population are believed not to spawn annually (Storrow, 1912, 1913, Symonds, 1972), in contrast to the situation in Scotland and Ireland (Thomas and Figueiredo 1965, Hillis, 1972b and in preparation) and it appears that failure to spawn annually might reasonably be related to a later spawning season than that occurring elsewhere.

The present Irish Sea data indicate the time required for the mean stage value to rise by 0.5 within the limits 1.5-2.5 as about 38 days in 1969 and 33 days in 1970; unfortunately no comparable estimates can be made for elsewhere as only Karlovac's data give a wide range of successive values and there the rate of change in value is rather irregular, suggesting that in the Adriatic the individual develops faster but the larval season is less synchronised than in more northern waters. Temperatures in the Faeroe and north-eastern English areas are similar—slightly lower than in the Irish Sea—so that if the main parts of Jorgensen's and Andersen's mean stage data are correct (excluding that of 11-8-1923 and 23-8-1937) it remains difficult to explain the difference in timing between the spawning seasons in the two areas.

Attempting to deduce stage durations from stage-composition is unreliable because spawning may occur in successive waves, and hence the rate of advance of the mean stage value will not be uniform; also while the moults from stages 1 to 2 and 2 to 3 can be traced, the rate of entry to stage 1 and exit from stage 3 cannot, hence the true proportion of the year's brood to have reached a given stage cannot be determined accurately, and to obtain stage-duration data laboratory rearing is required.

Kon (1970), estimated the length of the larval phase of the tanner crab *Chionectes opilio* in nature from laboratory rearing carried out at different temperatures, but still was not quite certain about the effects of temperature varying with depth as *Chionectes* perform extensive vertical migrations in the larval phase which is estimated to last 2-3 months.

In the present work, it is believed that duration of the full larval phase at normal sea temperature might not be much longer than the one observation obtained in the laboratory at 12°C, namely 39 days (Hillis, 1972b and in preparation) the effect of the lower temperature at sea being probably to some extent counteracted by a more natural diet.

SUMMARY

1. The state of knowledge of occurrence of larval *Nephrops* in the Irish Sea up to 1969 is reviewed and a survey in May-June 1966 described.
2. During 1969-1971, larval surveys were made off the east coast of Ireland sampling each station at multiple depths. Conditions of temperature and illumination were also examined, the latter in connection with diurnal changes in vertical distribution of the larvae.
3. The main larval season was found to extend from mid or late April until late June, or possibly later. The degree of larval advancement was measured by "mean stage" of the population $(N_1 + 2N_2 + 3N_3)/(N_1 + N_2 + N_3)$ where N_x = number of larvae at stage x. A value of 2.0 (number of first and third stages equal) was estimated to occur on 27.5.69 and 6.6.70, but was not recorded in 1971.
4. The larval population in the area of the *Nephrops* fishery off the east coast of Ireland normally had its maximum density in the area surveyed, in the region of 5°30′-5°50′W, 53°25′-53°40′N.
5. The depth of occurrence of maximum numbers was about 10-15 fm by day over most of the season, tending to ascend towards the surface about 5 fm at dusk. Very few larvae inhabited depths greater than 20 fm until late in the season, when they became numerous at 20, 30 and 40 fm.
6. The capture of two larvae with several post-larvae in June 1970 in the extremely small meshed cod-end cover of a trawl is recorded.

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