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Temporal and Spatial Variations in the Age Structure and Growth Rates of *Nephrops norvegicus* in the Western Irish Sea

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Abstract

A number of standard survey stations in the western Irish Sea were sampled by both the Republic and Northern Irish research vessels. This provided a 12 year time series of sexed length frequency distributions for the Norway lobster, *Nephrops norvegicus*. The male length frequency distributions were analysed using the computer programme MULTIFAN. This programme identifies length at age cohorts in the length frequency distributions, which it follows over time providing information on the mean lengths at age and the von Bertalanffy growth parameters for that population. These results were briefly discussed in relation to spatial and temporal differences and with a view to analysing commercial catch data in the future.

Keywords: cohort, growth rate, length frequency, MULTIFAN, *Nephrops norvegicus*

Introduction

Size frequency distributions in animal populations are often polymodal, each mode representing an individual cohort. By separating these distributions into their component size classes using Bhattacharya's method (Bhattacharya, 1967), changes in position of these modes over time, allow a population growth curve to be produced. In *Nephrops*, this method has moderate application due to the variability in individual growth rates along with very slow growth rates in the older age classes, especially for mature females, which results in the inevitable merging of age classes (Nicholson, 1979; Bailey *et al.*, 1983; Hillis, 1996). Nevertheless, this method has been used successfully by several workers (Tully *et al.*, 1989; Hillis, 1996; Tuck *et al.*, 1997) and in areas where the size frequency distributions of size classes run together recruitment can still be identified from the occurrence of a new and definite mode. Two possible limitations of the method are that, firstly, individual growth rates are obscured, as only an average growth rate for the *Nephrops* within the population is obtained and if these individual growth rates are genetically determined then interpretation of the environmental correlates is difficult. Secondly, selective natural mortality can modify the growth curves constructed from population data of this type (Smith *et al.*, 1997).

Crustaceans have no permanent hard body parts such as fish otoliths or molluscan shells, which carry within them a record of annual changes in growth rates allowing ageing or ground truthing of this method. Tagging of Irish Sea *Nephrops norvegicus* has, to date, had limited success (Hillis, 1985) and the results from analysis of lipofuscin pigments are very imprecise (Tully, 1993; Anon., 1996). As a result, the fitting of normal curves to polymodal length-frequency distributions appears to be the most promising means available.

Materials & Methods

A time-series of *Nephrops norvegicus* trawl data from research vessel surveys in the western Irish Sea commenced in 1987. The survey stations analysed were those which had a sampling overlap by the Fisheries Research Centre (FRC), Marine Institute, Republic of Ireland and Department of Agriculture, Northern Ireland (DANI). For these stations, survey data was available on an annual basis from the FRC from 1987, biannually from the FRC from approximately 1990 and quarterly from the combined FRC and DANI surveys between 1994 and 1998.

The nets used by both institutes to fish for *Nephrops* over the 12 year period varied. At the FRC, 30 minute trawls were carried out using a 40mm mesh codend net between 1987 and 1997 and in 1998, changed to a 80mm mesh net with 15mm meshed covers at the base of the wings of the bottom sheet of the net, called wing covers (Hillis *et al.*, 1982), while at DANI a 50mm mesh net was used for 30-60 minute trawls in conjunction with a 5-10mm beam trawl for 5 minute tows. Catches were sorted, weighed and either all or weighed subsamples of *Nephrops* were sexed and the stage of maturity was noted in females. The carapace length (CL) was measured to the mm below and the subsamples were then raised to the total catch weight.

Length-frequency distributions were derived from the survey data for the sexes. The population structure was separated into its component size/age classes and the von Bertalanffy growth parameters (K and L_∞) calculated using the computer programme MULTIFAN* (Fournier *et al.*, 1990). The programme simultaneously analyses multiple length-frequency distributions obtained over a period of time from a fisheries population. User inputs set the constraints on some of the mean lengths to ensure the model fits the obvious modes properly (Fournier *et al.*, 1990), and a log-likelihood function is used to produce maximum likelihood estimates for a mixture of normal distributions within a multinomial distribution (Otter-Research, 1991). The main assumptions of the MULTIFAN model are that the lengths in each age class are normally distributed, the mean lengths at age lie close to a von Bertalanffy growth curve and the standard deviations of the lengths at age are simple functions of their means (Fournier *et al.*, 1990; Otter-Research, 1991). MULTIFAN follows the progression of modes over time which strongly suggests that these modes represent year classes or age groups (Fournier *et al.*, 1990; 1991; Hilborn *et al.*, 1992; Tuck *et al.*, 1997). The programme follows the strong modes over time, which, along with the constraints set on some of the mean lengths by the operator, enables the programme to analyse the actual numbers per size class rather than percentage frequency. MULTIFAN has been used in the past mainly to analyse length-frequency distributions of finfish, *e.g.* tuna (Fournier *et al.*, 1990; Labelle *et al.*, 1993), however, work has been done on *Nephrops* (Tuck *et al.*, 1997) and other decapods, such as the Northern shrimp, *Pandalus borealis* (Fournier *et al.*, 1991).

After the initial data entry and parameter estimation, the model can be modified to produce more biologically correct best fits for the mean length at age of each of the normal curves. Model modification options used when analysing western Irish Sea *Nephrops* data included varying standard deviations with age, varying seasonal rates of growth and the addition of a correction factor to compensate for mesh selection in the first age group.

The mesh of the net exercises size selectivity on the animals in the first age class so that the mean length of the age group 0 animals in the sample length-frequency distributions is longer then the mean length of the age class 0 animals in the natural population (Otter-

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* *Unlimited Sample Version 32, 1992, Otter Research Ltd., Nanaimo, Canada.*

Research, 1991). Following Fournier, the correction factor used to compensate for mesh selection on the first age group and hence biasing of the mean length of age group 0, was calculated using the following equation *(1)*, from the MULTIFAN User's Manual (Otter-Research, 1991).

$$X\ (11/12) = Y \qquad (1)$$

Where X = correction factor

Y = difference in mean length of the first mode between the population and the sample

Since the mean length of age class 0 in the natural population is not known for western Irish Sea *Nephrops*, the mean length of the smallest mode known was used. This mode came from the 5-10mm mesh beam trawl data collected by DANI at Station 107 (J8) in August 1997 and had a mean length of 7.23mm.

The samples analysed using the MULTIFAN computer model for this report were taken from sampling stations at both the edge and the centre of the *Nephrops* ground. To date, analysis has only been conducted on male *Nephrops* data.

Results

Generally, the most dominant mode in the catch was the second mode, which corresponded to the year 1 age group. The year 0 age group was generally too small to be caught in the main net and/or codend in representative numbers and as a result, small mesh wing covers were used catch the escapees. The final age group of the analysed data is assumed to be a plus age group. MULTIFAN produces a best-fit model for the time-series of length frequency distributions as a whole analysed over time rather than individual length frequency distributions and the resulting mean lengths at age do not always fit the individual modes.

Stations J8 (Fig: 2) in the centre of the ground and L2 (Fig: 3) in a shallow location at the edge of the ground both produced best fits for 5 age classes. The von Bertalanffy growth parameters are shown in Table 1. L2 had a greater L_∞ and a higher K value than those at J8. After analysis of Station H7 (Fig: 4), from the centre of the fishing ground, it was decided from visual examination of the printouts that the result of 6 year classes was only producing best fits of normal curves for the second half of the time series. As a consequence, the time series was divided into two discrete samples, pre-1994 (Fig: 5) and 1994 to 1998 (Fig: 6) which were analysed separately. The pre-1994 sample still showed best fits for 6 year classes, however, the L_{∞} was greater and the K value was lower than that for the original sample (Table 1). The 1994 to 1998 H7 sample had best fits for 7 age classes, with an L_{∞} value that was approximately the same as the original H7 sample but with only a slightly lower K value (Table 1), confirming the visual observations made on the original sample.

Table 2 shows the mean carapace length at age for each year class at each station in chronological. This format allows comparisons to be made between stations while taking into account the differences in size at month 1 at different times of the year. From this table it is more obvious that male *Nephrops* at L2 grow bigger, *i.e.* have a greater mean carapace length, than those at the other stations examined. Between 1994 and 1998, the mean carapace length of the H7 males was larger than those of pre-1994 males at the same station. J8 males had a similar, though slightly smaller, mean length at age than the males at H7 (1994-1998).

It would appear from the samples analysed, that the male *Nephrops* population at H7 had a higher growth rate between 1994 and 1998 than between 1987 and 1993 (Table 1). The K values shown in Table 1 suggest that the more recent male population at H7 has the fastest growth rate, followed by that at L2, while the male *Nephrops* population at J8 has the slowest growth rate of the samples analysed. The von Bertalanffy growth curves constructed by MULTIFAN for the data in Table 1 are given in Figure 7 and show the seasonal variations in growth rate which have been added to each sample by modifications to the model during the analysis.

Discussion

The analysis from the selected sampling stations reconfirms previous observations in the western Irish Sea area that there are small scale, local variations in the density, biomass, size composition and growth of *Nephrops norvegicus*, resulting in small sub-populations within the main population, which have been referred to as "stocklets" (Chapman *et al.*, 1988; Tully *et al.*, 1990; Briggs, 1995). *Nephrops* are a relatively sedentary organism (Hillis, 1979; Bailey *et al.*, 1983; Chapman *et al.*, 1988), and as a consequence, the biological characteristics of these stocklets are affected by local environmental conditions such as food availability, depth, light intensity, current speed, predation and fishing effort (Tully *et al.*, 1990). There has also been much speculation about the effects of sediment grain size on the density and hence size composition of a population at any given location within a *Nephrops* ground (Bailey *et al.*, 1983; Chapman *et al.*, 1988; Howard, 1989). In the Irish Sea, the percentage of silt-clay content of the sediment is said to account for 20% of the variation in *Nephrops* density (Tully *et al.*, 1990). It is probable that the stations analysed for this report are somewhat influenced by this particular parameter, as they are located in areas of differing substrate. Station L2 is situated in a muddy sand area, H7 in sandy mud, while station J8 is in an area of mud sediment, as shown on the British Geological Survey sea-bed sediment map[†] (see Hillis, 1988). However, it is not clear exactly how sediment effects density though both may simply covary as a result of oceanographic conditions and larval settlement (Tully *et al.*, 1990).

The K values for each station given in Table 1 only give an indication of the growth characteristics of each of the "stocklets" and it may of more use to examine the mean lengths at age. For example, L2 has the greatest mean lengths and the highest L_∞, suggesting that the sub-population at L2 generally has greater mean carapace lengths at age than those at H7 or J8. However, care must be taken when comparing the growth parameters from the J8 "stocklet" with those from the other "stocklets" as the J8 month 1 sample was in August as opposed to February for both L2 and H7. As a consequence, the mean lengths at age in month 1 for J8 are six months behind, *i.e.* shorter than, the mean lengths at age in month 1 for the other stations according to the method of dating the samples in MULTIFAN. This is clarified in Table 2. With reference to sediment type, it would appear that the animals with the largest mean carapace lengths are found on the coarsest sediments, L2, and the relatively smaller *Nephrops* are found on the finer sediments, H7 and J8, respectively. This contradicts the findings of Chapman *et al.* (1987), who showed that on the west coast of Scotland, larger *Nephrops* were found in areas with higher clay/silt content. However, the relationship between carapace length and sediment grain size is not a linear relationship (Anon., 1988). The western Irish Sea has relatively coarse sediment, 4-49% silt/clay, and the west coast of Scotland has relatively fine sediment, 30-96% silt/clay content (Anon., 1988; Tuck *et al.*, 1997). With the smallest *Nephrops* occurring at sediment grain sizes which are intermediate to those in these two locations (Anon., 1988; Tuck *et al.*, 1997).

As yet we have no reason for the apparent change in the growth characteristics of the male *Nephrops* sub-population at station H7 in 1994, whether it is an environmental, anthropogenic or artifactual change is not known. Likewise, there is no indication that a break in the annual growth characteristics has occurred at other stations or years.

To provide biologically representative data for *Nephrops norvegicus* it is essential to have representatives from the smallest age group to produce a reasonable von Bertalanffy growth curve, as the means of the older age groups are spaced almost equidistantly and produce a linear growth relationship with a huge L_∞ value. Initial size distributions without either small or large size classes bias the data within the von Bertalanffy growth equation and

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[†] *British Geological Survey, Edinburgh, UK - Anglesey Sheet, 54N, 06W (Ss).*

cause a magnification of parameter estimation errors (Smith *et al.*, 1997). Therefore, in the case of the research vessel data for *Nephrops*, there is a need for more actual data from both the smaller and the larger length classes. It is only recently that the smallest age group in the western Irish Sea survey data has been represented, and than only by a relatively small number of individuals from a limited number of samples taken in the winter months, January or February, during the Republic of Ireland surveys. These younger individuals were collected in the small mesh wing covers where the greatest number of escapees from the main net occur (Hillis *et al.*, 1982). It is hoped that the number of samples containing these smaller animals can be increased during the remainder of the project, along with the inclusion of beam trawl data for several of the Northern Ireland stations, which also contain greater numbers of very small *Nephrops*. At present, FRC station J8 and DANI Station 107 combined is the only station to have data from the small meshed beam trawl, collected in August 1997.

The presence of very low numbers in the first age group results in a higher mean length at age for this mode, particularly as only the larger animals from that cohort are caught. To try and alleviate this problem somewhat, the option that corrects for mesh selection is used. It is hoped that once a value has been produced for the smallest age group in this area it can be artificially added to the Irish Sea commercial catch data to provide a reasonable von Bertalanffy growth curve for the commercial samples. The commercial data may also have the advantage of better representation of the larger size classes than in the research vessel data and thus providing a truer estimate of the growth parameters for the older age groups.

The MULTIFAN computer programme allows the simultaneous analysis of multiple length frequency distributions and as a consequence, produces a more accurate estimation of the number of age-classes represented in the data, the mean length at age and the proportion of each mode\age-class in the population as a whole, than can be obtained from analysis of single samples, as is the case with computer programmes such as ELEFAN (Pauly *et al.*, 1987) or MIX (MacDonald *et al.*, 1979). However, at times the lack of obvious modes results in difficulties when assigning constraints onto the data in MULTIFAN and as such the programme tends to revert to equal growth rates with increasing age and hence does not follow the von Bertalanffy growth curve. This can be especially problematic in *Nephrops*, where during the moulting season, April to July, when modes become divided in terms of mean length at age but still represent a single year class and in the older age groups which have become merged together due to slow rates of growth, especially in mature females (Nicholson, 1979; Bailey *et al.*, 1983; Hillis, 1996).

Acknowledgements

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Table 1: Growth parameters and mean lengths at age for *Nephrops norvegicus* populations at sampling stations in the western Irish Sea calculated by the computer programme MULTIFAN.

Station	von Bertalanffy		Mean Length at Age in MULTIFAN Month 1 (mm)						
	K	L infinity (mm)	1	2	3	4	5	6	7
H7 (1987-1998)	0.264	49.6	11.8	20.5	27.3	32.5	36.4	39.5	-
H7 (pre 1994)	0.167	55.3	14.7	21.0	26.2	30.7	34.5	37.7	-
H7 (1994 to 1998)	0.239	50.3	11.5	19.8	26.3	31.4	35.4	38.6	41.0
J8	0.209	51.3	8.1	16.2	22.9	28.2	32.6	-	-
L2	0.221	57.4	14.4	21.7	28.8	34.4	39.0	-	-

Table 2: Mean lengths at age for *Nephrops norvegicus* year classes at sampling stations in the western Irish Sea calculated by the computer programme MULTIFAN.

Station	Month 1	Mean Length at Age in Year Class Month 1 (mm)																							
		0			1			2			3			4			5			6			7		
		Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug	Feb	Jun	Aug
H7 (1987-1998)	Feb	-	-	-	11.8	-	-	20.5	-	-	27.3	-	-	32.5	-	-	36.4	-	-	39.5	-	-	-	-	-
H7 (1994 to 1998)	Feb	-	-	-	11.5	-	-	19.8	-	-	26.3	-	-	31.4	-	-	35.4	-	-	38.6	-	-	41.0	-	-
L2	Feb	-	-	-	14.4	-	-	21.7	-	-	28.8	-	-	34.4	-	-	39.0	-	-	-	-	-	-	-	-
H7 (pre 1994)	Jun	-	-	-	-	14.7	-	-	21.0	-	-	26.2	-	-	30.7	-	-	34.5	-	-	37.7	-	-	-	-
J8	Aug	-	-	8.1	-	-	16.2	-	-	22.9	-	-	28.2	-	-	32.6	-	-	-	-	-	-	-	-	-

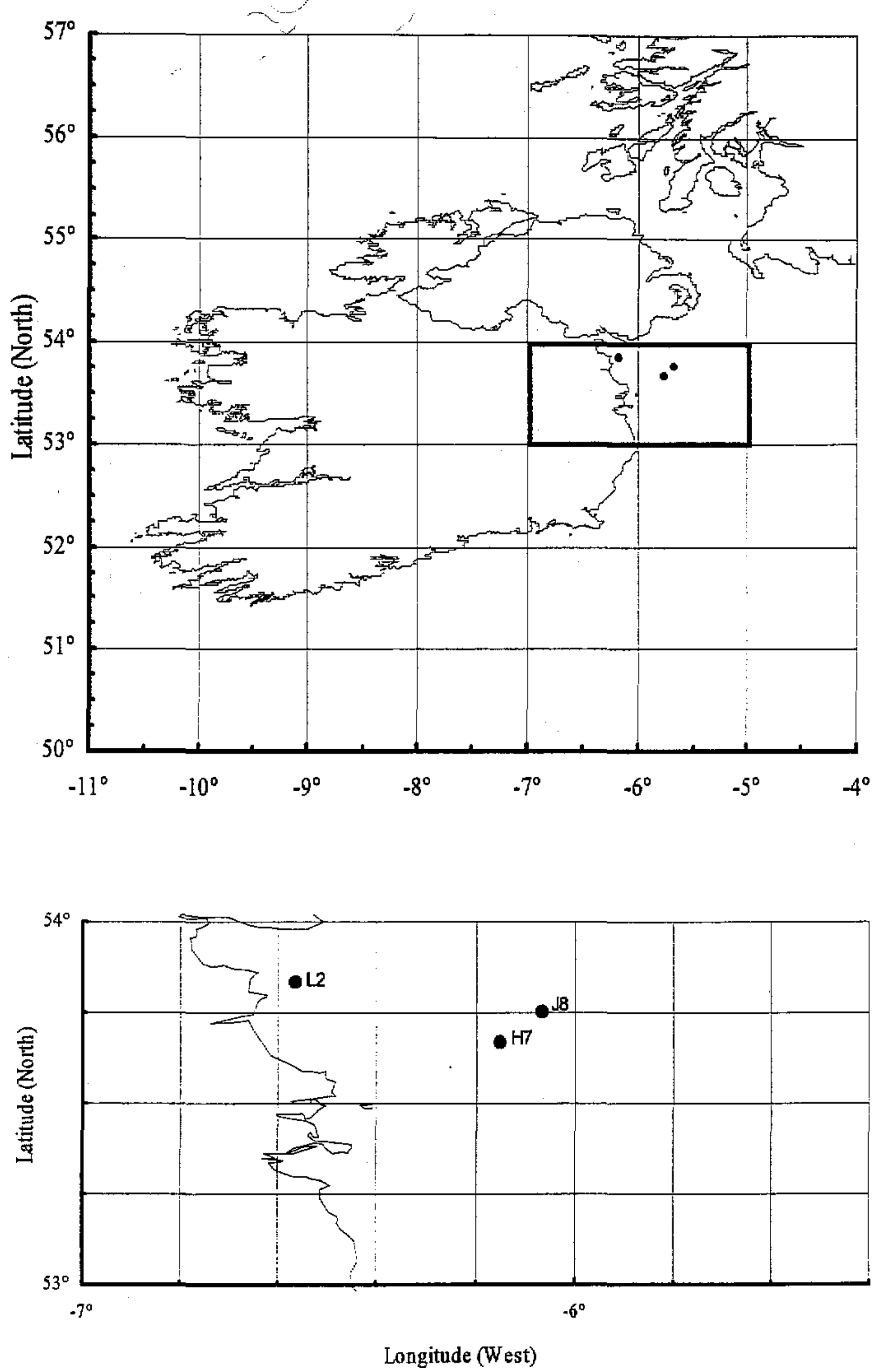


Figure 1: Southern section of Western Irish Sea *Nephrops norvegicus* fishing grounds, showing the location of the standard sampling stations which were analysed for this report.

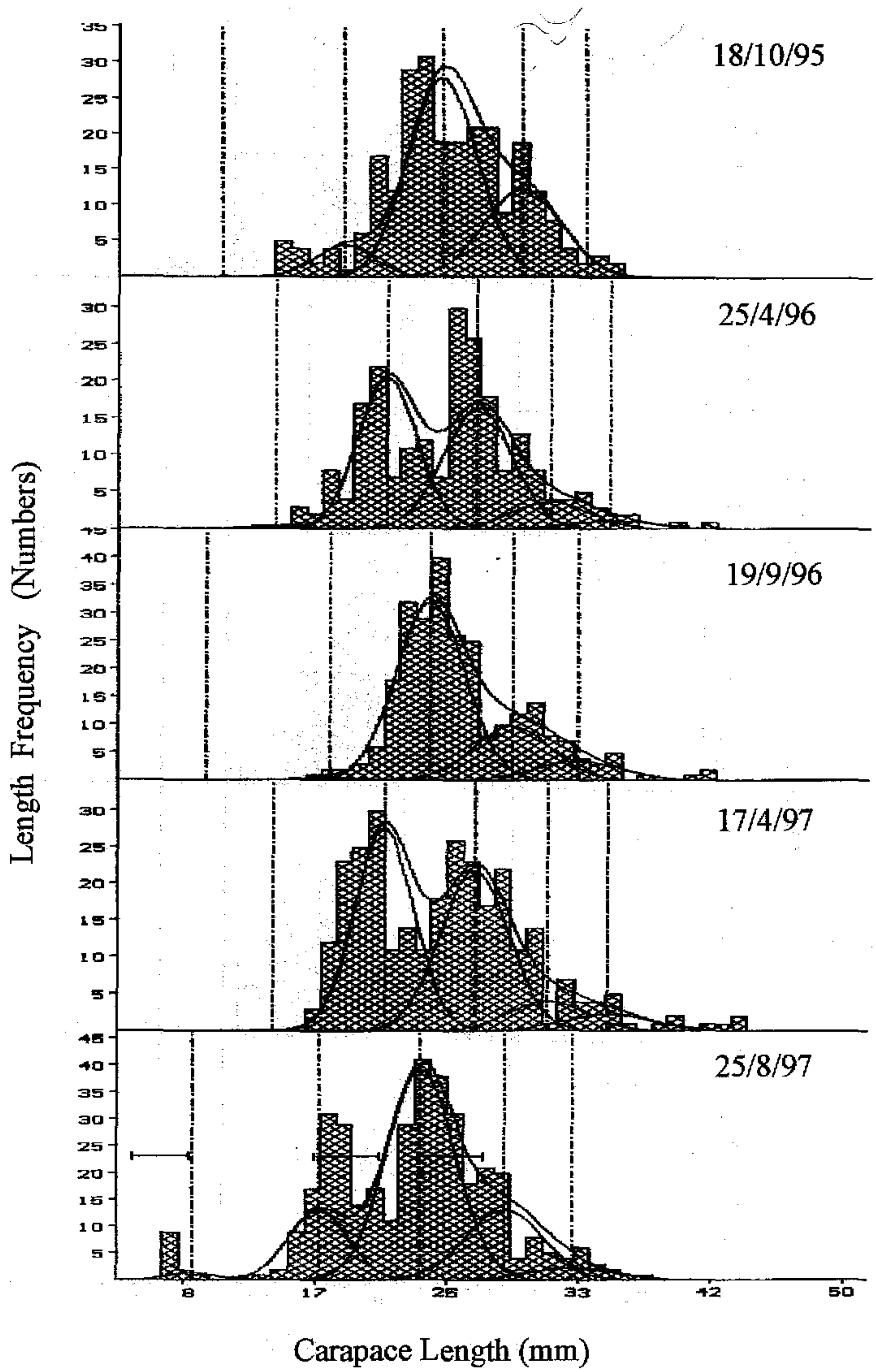


Figure 2: A sample of the MULTIFAN analysis of male *Nephrops norvegicus* length frequency distributions showing seasonal growth for the combined FRC J8 station and the DANI Station 107 for the period 1988-1998.
|——| user defined constraints on mean lengths, ⋮ mean length at age.

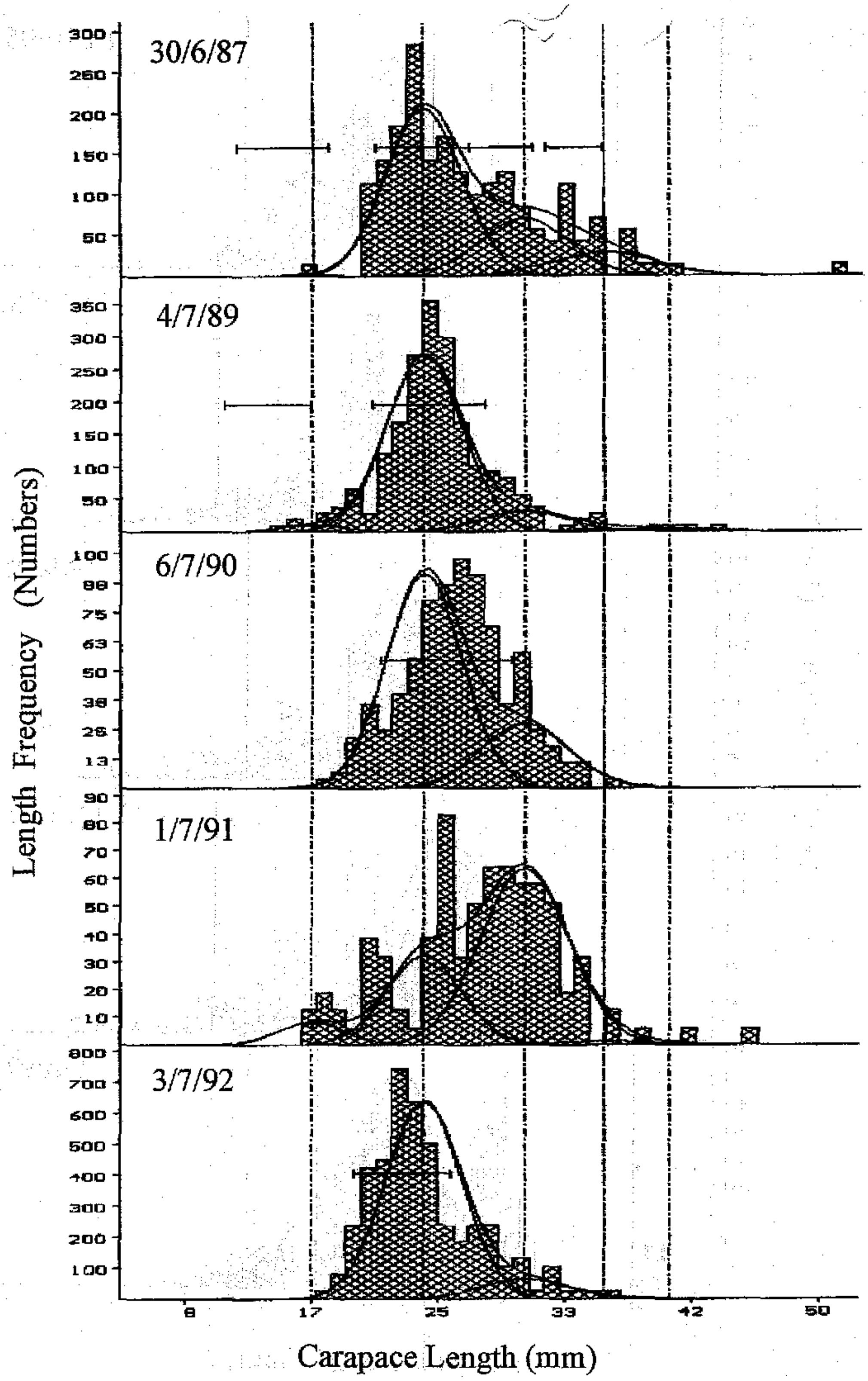


Figure 3: A sample of the MULTIFAN analysis of male *Nephrops norvegicus* length frequency distributions showing annual growth for the FRC L2 station for the period 1987-1998. |——| user defined constraints on mean lengths, ⁝ mean length at age.

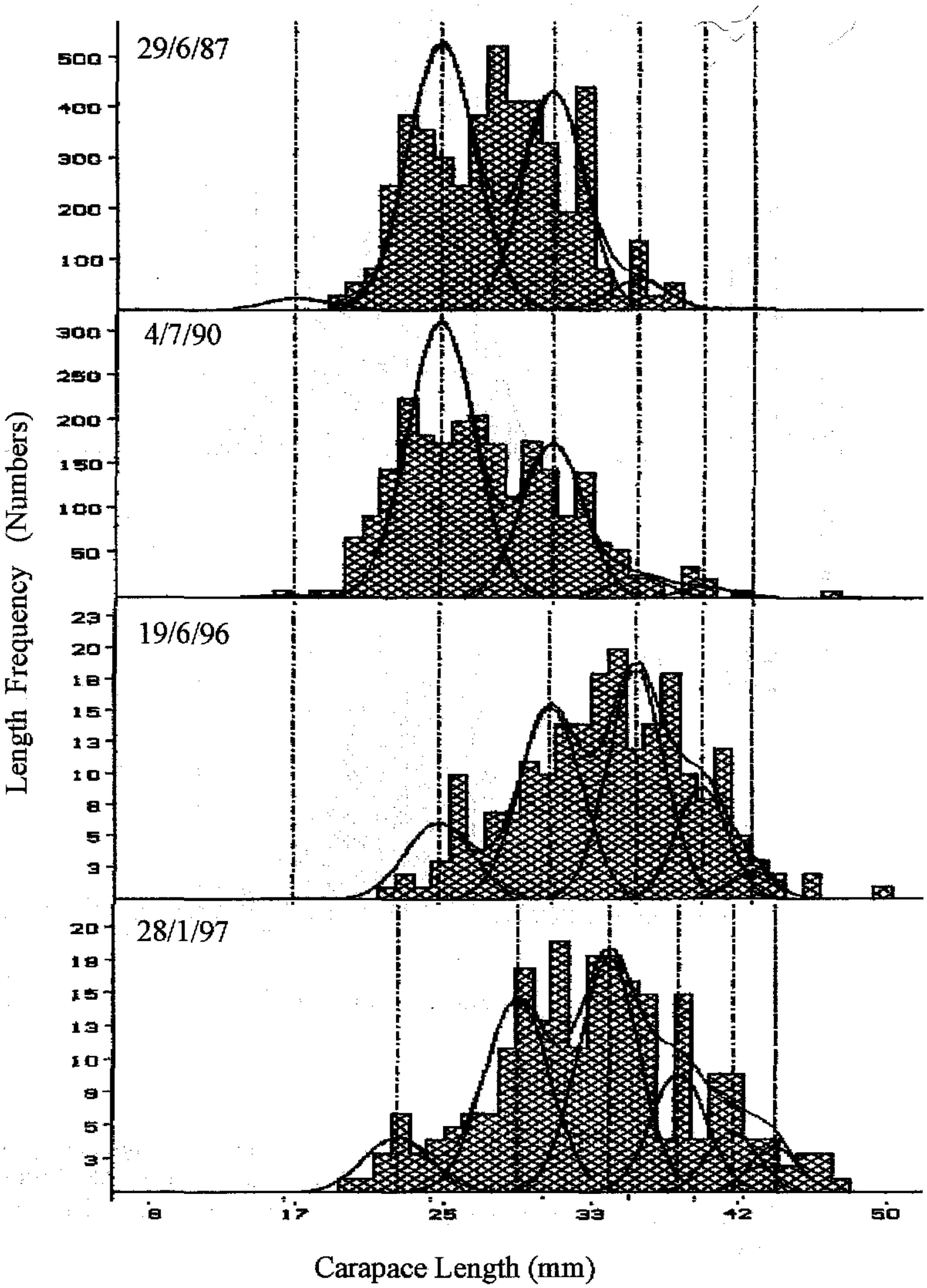


Figure 4: A sample of the MULTIFAN analysis of male *Nephrops norvegicus* length frequency distributions pre and post 1994 for the FRC H7 station and the DANI Station 106 for the period 1987-1998. ├──┤ user defined constraints on mean lengths, ⁝ mean length at age.

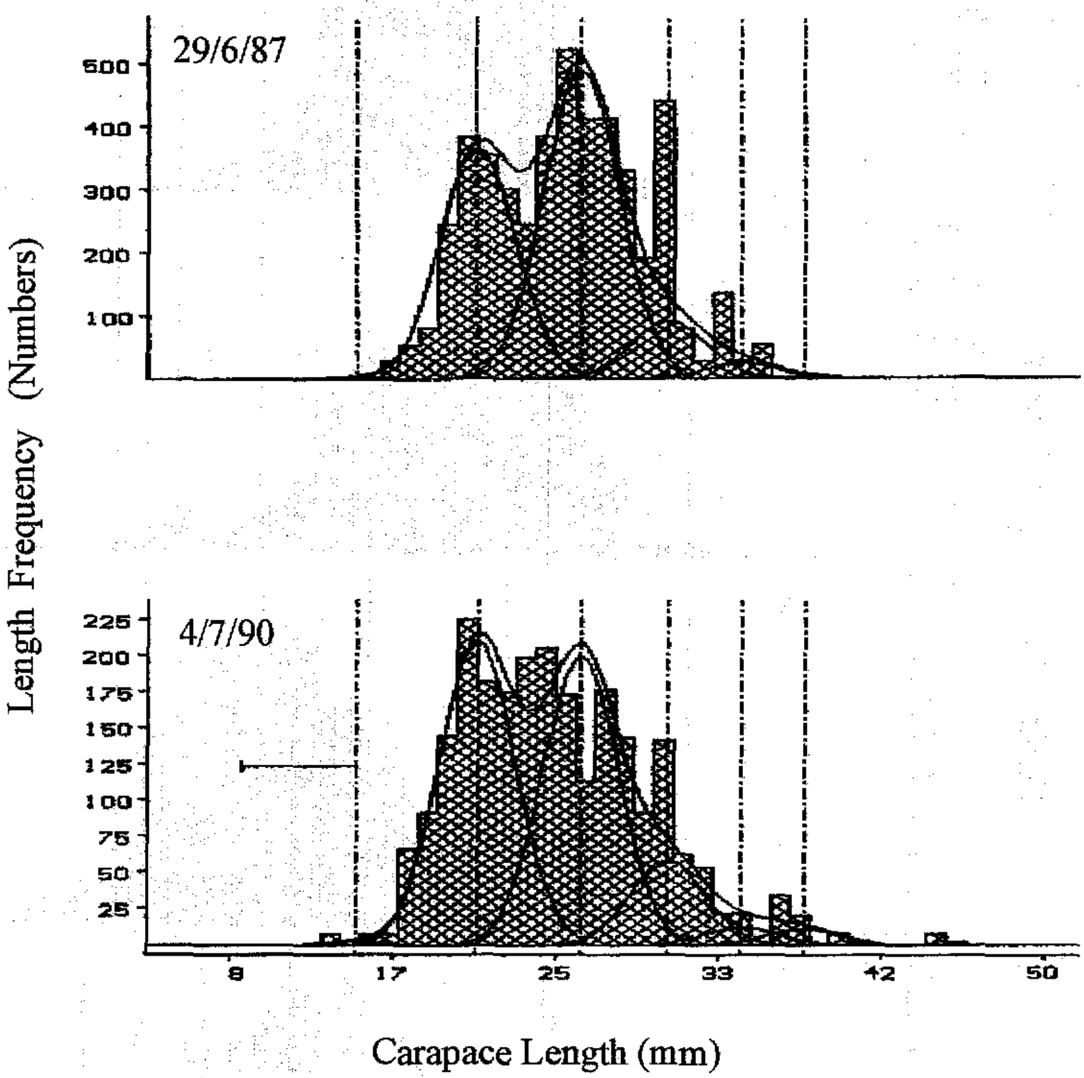


Figure 5: A sample of the MULTIFAN analysis of male *Nephrops norvegicus* length frequency distributions for the FRC H7 station and the DANI Station 106 for the period 1987-1993. |——| user defined constraints on mean lengths, ⋮ mean length at age.

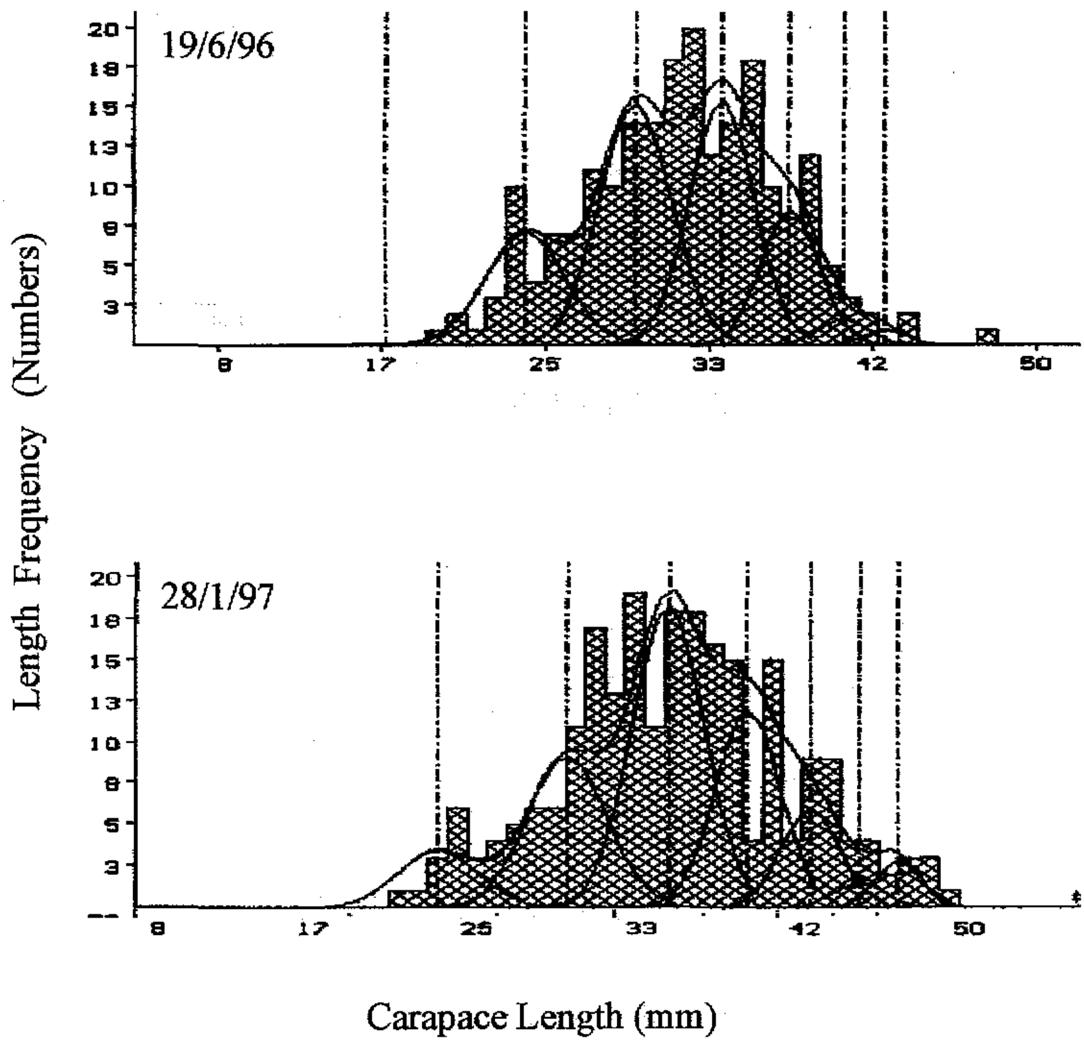
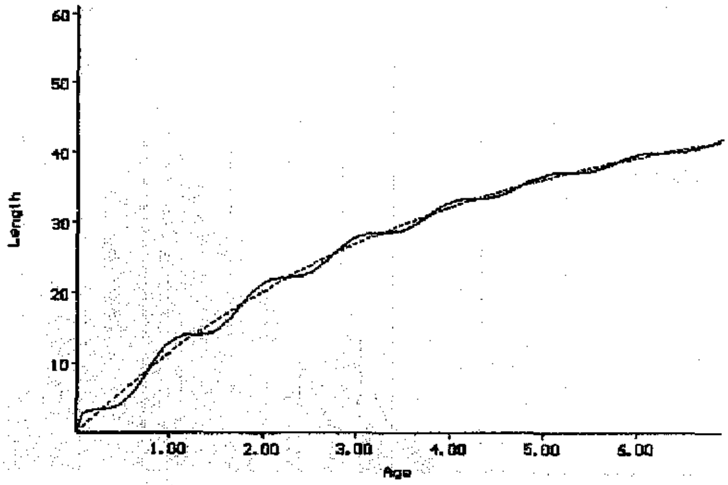
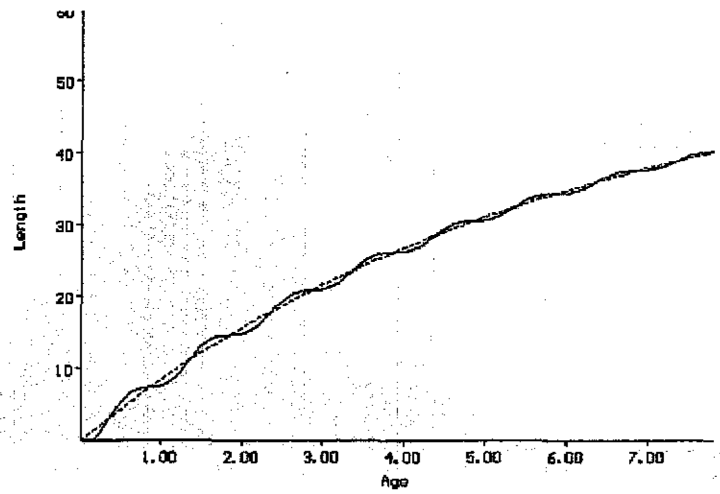


Figure 6: A sample of the MULTIFAN analysis of male *Nephrops norvegicus* length frequency distributions for the FRC H7 station and the DANI Station 106 for the period 1994-1998. |——| user defined constraints on mean lengths, ⋮ mean length at age.

Station H7: 1987-1998



Station H7: pre 1994



Station H7: 1994-1998

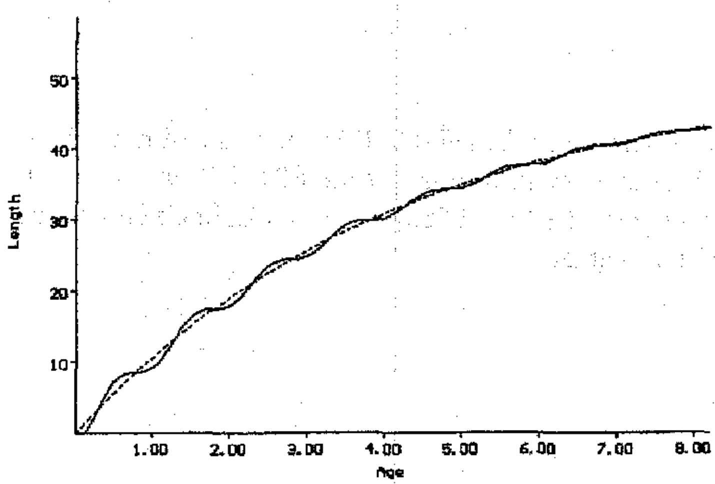
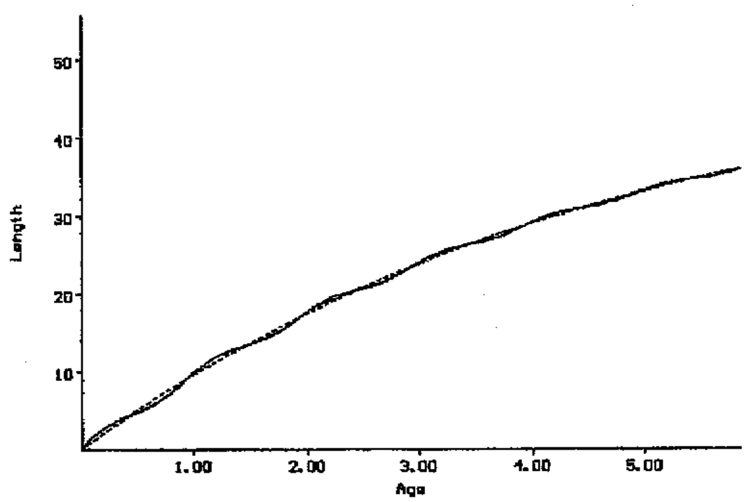


Figure 7 cont'd over page.

Station J8: 1987-1998



Station L2: 1987-1998

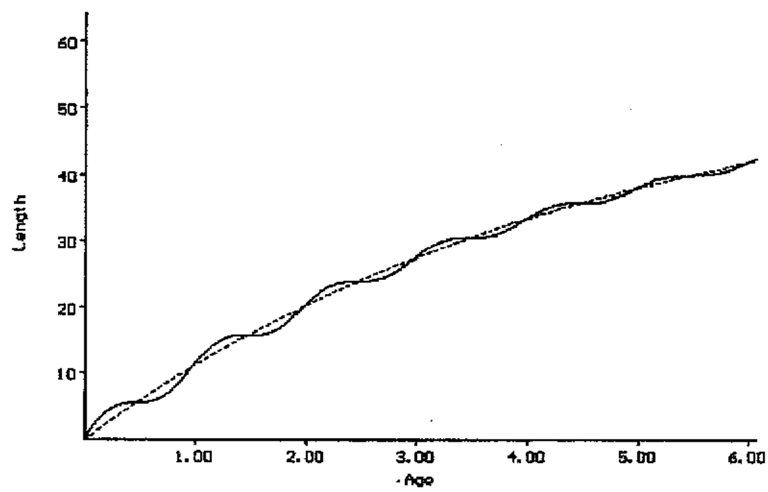


Figure 7: The von Bertalanffy growth curves for male *Nephrops norvegicus* at each of the sample stations analysed by MULTIFAN.