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REPORT OF THE

STUDY GROUP ON LIFE HISTORY OF *NEPHROPS*

Reykjavik, Iceland
2–5 May 2000

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Terms of Reference

The Study Group on Life History of *Nephrops* [SGNEPH] (Chair: N. Bailey, UK) will meet in Reykjavik, Iceland from 2–5 May 2000 to:

a) make comparison of trends in various assessment, fishery data and survey indices including the use of time series and other statistical techniques;

b) review progress on the development of *Nephrops* specific assessment methodologies;

c) attempt to define a likely stock and recruitment relationship for *Nephrops*;

d) report on refinements in the use of independent methods and present spatial distribution data where available;

e) develop logistical plans for co-operative work on *Hematodinium*;

f) summarise available data on the fate of discards and by-catch from *Nephrops* fisheries;

g) present new data on the biology of *Nephrops* and on parameter values.

Some of the above Terms of Reference are set up to provide ACFM with the information required to respond to requests for advice/information from EC DGXIV and NEAFC. SGNEPH will report to ACFM before its October 2000 meeting and to the Living Resources Committee at the 2000 Annual Science Conference.

2 PARTICIPANTS

The following scientists attended the Study Group meeting:

M. Afonso-Dias	Portugal
J. Atkinson	UK
N. Bailey (Chair)	UK
M. Bell	UK
R. Briggs	UK
H. Eiríksson	Iceland
C. Farina	Spain
P. Hillis	Ireland
N. McQuaid	UK
S. Marrs	UK
S. Munch-Petersen	Denmark
F. Redant	Belgium
C. Silva	Portugal
G. Stentiford	UK
C. Talidec	France
D. Taylor	Canada
I. Tuck	UK
M. Ulmestrand	Sweden
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3 COMPARISON OF TRENDS IN VARIOUS ASSESSMENT OUTPUTS, FISHERY DATA AND SURVEY INDICES – USE OF TIME SERIES ANALYSIS

This term of reference was addressed through three different approaches. These were a dynamic factor analysis of long term (> 20 years) LPUE series for Scottish, Icelandic and a selection of other stocks; a comparison of VPA generated outputs; and an examination of long term trends in size of *Nephrops* in landings.

3.1 Common Trends in *Nephrops* CPUE and LPUE Time Series

Dynamic factor analysis was used to analyse *Nephrops* CPUE (catch per unit effort) time series of 11 stocks from Iceland, and LPUE (landings per unit effort) time series of 10 stocks from various places in Europe.

Introduction

Dynamic factor analysis is a technique to estimate underlying patterns (also called common trends) in a set of time series. It shows which of the common trends are important for the original time series. Various statistical tools exist to choose the number of common trends and Appendix 1 describes how Akaike's Information Criterion (AIC) can be used for this purpose. The overall technique is discussed in more detail in Zuur et al (submitted), Harvey (1989) and in Appendix 1 of this report.

Results for the Icelandic LPUE series

The Icelandic trawl fishery for *Nephrops* dates back to the late 1950´s. Most importantly, LPUE has been monitored by fishery log-books since the early 1960´s and sampling of catches (length compositions by sex) was initiated as early as 1959. Therefore, some valuable time series of fishery data extend back to the pristine years of the fishery.

The distribution of *Nephrops* is limited to the warmer waters off the southern part of the country at depths ranging from 100-300 m. The *Nephrops* distribution on the southeastern continental shelf is typified by muddy ravines down to 250 m depth, whereas *Nephrops* is more usually confined to muddy banks of some 130-180 m depth to the southwest of Iceland.

Eiríksson (1999) described cross correlations between annual LPUE of areas up to 250 nautical miles distant, based on log-book data from 1960-1997. Significant correlations ($r^2 = 0.64 - 0.84$) were observed for all sets of relationships between the areas to the southwest of Iceland, ranging in distance up to about 100 n.miles apart. However, when comparing the southwestern LPUEs to ones from the more distant areas southeast of Iceland (150-250 n. miles), the correlation coefficients fell to 0.21 - 0.46. Although reasonable correlations were observed within areas at SE Iceland ($r^2 = 0.65- 0.68$), the most easterly areas, i.e. those at the limit of the *Nephrops* distribution, show a somewhat different trend in LPUE than the rest. This may be related to greater variations in bottom temperatures observed in this region.

VPA assessments show a very different trend in stock parameters, e.g. recruitment, at SW and SE Iceland, which relate well with time series of relationships in LPUE for those areas. Therefore, a separate management regime has been recommended for SW and SE Iceland (Eiríksson 1999).

The 11 LPUE time series are presented in Figure 3.1.1. The AIC values for models containing 1, 2 and 3 common trends are presented in Table 3.1.1. These values indicated that 2 common trends resulted in the most appropriate model.

The 2 estimated common trends and factor loadings are presented in Figure 3.1.2. The first common trend was related to the stocks 373, 372, 320, 371, 319 and 321. These are all in the Southwest of Iceland. The second common trend was related to the stocks 365, 366, 364, 367 and 414. These were all in the Southeast of Iceland. The first common trend was a slow moving curve. The second common trend showed more variation. The fitted curves are presented on a standardised scale in Figure 3.1.3. All time series showed good fits. This can be inferred by plotting the original data and fitted curve and 95% confidence intervals for each stock in one figure (not shown here) or by comparing Figures 3.1.1 and 3.1.3.

One weakness of dynamic factor analysis, as discussed in the working paper, is that it takes limited account of time lags in the data. However, cross-correlations between the 11 original time series indicated that there were only 5 combinations of stocks which had significant cross-correlations for time lags other than 0, see Table 3.1.2.

Dynamic Factor Analysis applied on 10 LPUE Time Series

The 10 LPUE series are from 10 stocks around Europe, namely FU3 (Sweden single), FU4 (Sweden single), FU5 (Belgium), FU6 (UK), FU14 (UK), FU15 (UK), FU16 (Spain), FU25 (Spain), FU26 (Spain, Muros) and FU26 (Spain, Riveira). The 10 series are plotted in Figure 3.1.4.

The AIC values for a dynamic factor model containing 1, 2 and 3 common trends are presented in Table 3.1.3. Results indicated that 2 common trends should be used. The 2 estimated common trends and factor loadings are presented in Figure 3.1.5. The results in this figure indicated that

- the first common trend was important for the stocks:
  Fu3 (Sweden single), Fu4 (Sweden single), Fu15 (UK), Fu6 (UK), Fu25 (Spain), Fu26 (Spain, Riveira)

- the second common trend was important for the stocks
  Fu16 (Porcupine Bank), Fu26 (Spain, Muros), Fu26 (Spain, Riveira)

- the following stocks behaved similar
  Fu3 (Sweden single), Fu4 (Sweden single), Fu15 (UK)

- stock FU25 had opposite behaviour compared to stocks FU3,FU4 and FU15

Ad hoc comparison between common trends

In the appendix, LPUE series of 6 stocks around Scotland were analysed. The most optimal dynamic factor model contained 2 common trends. The 11 time series of stocks from Iceland also required 2 common trends. The 10 series from stocks around Europe were best fitted by a 2-common trend model as well. The later data set will be denoted as European stocks. A 'quick-and-dirty' approach to obtain insight on whether there are any similar patterns in these common trends is to calculate cross-correlations between them. These are presented in Table 3.1.4. The results suggested that the correlation between the first Icelandic common trend and the European trends are reasonably high (0.64). The same holds for the first Scottish and first European trends (0.72). Furthermore, note that cross-correlations between Icelandic trends and most of the other trends were high for time lags other than 0.

Another way to obtain more insight in the behaviour of the trends is by plotting them in one figure. All 5 common trends are presented in Figure 3.1.6. This figure not only confirms that (i) the first Icelandic common trend and the European trends, and (ii) the first Scottish and first European trends follow a similar pattern but also the first common trends of the Icelandic and Scottish stocks during the period 1965-1993 are similar. Summarising, the first common trends of the Iceland stocks (representing the southwest stocks), Scottish stocks (representing the overall pattern) and the European series (representing most of the stocks) follow a similar pattern over time. Note that there is indication of time lags between the series.

Conclusions and Discussion

Dynamic factor analysis applied to the *Nephrops* LPUE time series indicated that the 11 time series had 2 underlying main patterns. The first main pattern was associated with the southwest stocks, the second main pattern was related to the southeast stocks. The first main pattern was a slow moving curve whereas the second main pattern showed more variation over time. To obtain more insight in the behaviour of the common trends, possible explanatory variables like sea surface temperature need to be incorporated into the analysis. This would result in a model of the form:

$$\text{Data} = \text{trends} + \text{explanatory variables} + \text{noise}$$

The LPUE series had two main underlying patterns. The first common trend was related to the stocks FU3, FU4, FU15, FU6, FU25, and FU26. The second common trend was important for the stocks FU16 and FU26.

An informal comparison of all the common trends indicated that the first common trend of the Icelandic stocks (representing the southwest stocks), that the first common trend of the Scottish stocks (representing the overall pattern) and European stocks (representing most of the stocks) followed a similar pattern over time. Cross-correlations indicated that there are time lags between the first Icelandic trend and the first Scottish and European trends.

The comparisons between the common trends were based on visual inspection and cross-correlations between trends. Although this turned out to be very informative, further work is needed to compare the common trends in a more formal way. Dynamic factor analysis also needs to be extended in order to detect possible time lags.

3.2 Correspondence between state of exploitation indices and outputs of analytical assessments

The correspondence between exploitation indices (catch per unit effort and mean size) and outputs from the analytical assessment (VPA) was explored for those Functional Units for which appropriate data were available. The comparisons were restricted to male *Nephrops* since assessments are generally considered to perform better for this sex.

Methodology

Biomass, F_{bar} and recruit estimates from the extended survivors analysis (XSA) performed in 1999 (ICES, 1999) were examined for 9 functional Units as detailed in Table 3.2.1. Trends in these indices were compared with CPUE and mean size data (above and below 35mm CL, the size limit above which discarding becomes unimportant).

Results

Table 3.2.1 shows the overall trend in exploitation indices and VPA outputs for each Functional Unit. More detail is given in Figures 3.2.1 to 3.2.9. There were no obvious similarities between Functional Units but a more detailed examination did show a relationships between indices and VPA outputs for individual Functional Units.

<u>Farn Deeps (FU 6)</u>: Figure 3.2.1

A general relationship between Biomass and F_{bar} with CPUE occurs, though a recent upturn in biomass and fishing mortality is not reflected in the CPUE. There is a slight relationship between recruitment and mean size but this is not apparent in recent years. TV survey data follows a similar but more marked downward trend than biomass and CPUE.

<u>Firth of Forth (FU 8)</u>: Figure 3.2.2

Biomass and F_{bar} show a similar trend to CPUE, with an upward trend in recent years. Biomass and CPUE for larger (> 35mm CL) animals seems more closely related. Recruitment and mean size, especially mean size of under 35mm CL individuals are related. TV survey data follows a similar trend to recruitment.

<u>Moray Firth (FU 9)</u>: Figure 3.2.3

CPUE for > 35mm animals increased in 1995 but subsequently decreased. An increase in CPUE coincided with a drop in mean size and suggests good recruitment. CPUE for larger *Nephrops* remained stable, but TV abundance estimates suggest a decline since the mid 1990s, suggesting a reduction in smaller animals.

<u>North Minch (FU 11)</u>: Figure 3.2.4

Fishing mortality, biomass and CPUE appear to correlate, especially in recent years. Recruitment and mean size are not so well correlated as in other FUs. TV data and recruitment appear to be related.

<u>Firth of Clyde (FU 13)</u>: Figure 3.2.5

CPUE for < 35mm CL *Nephrops* shows an increase since the early 90s while CPUE of larger animals is stable. Years when the CPUE of small individuals peaked (1995 and 1998) coincide with years in which the mean size of this group of individuals is low and suggests an influx of small animals (recruits) to the fishery. TV data showed a similar increase as < 35mm CL animals, suggesting that TV data are influenced by recruiting age classes. Biomass and recruitment estimates also increased, but this is to be expected because they are not independent of CPUE.

<u>Irish Sea West (FU 15)</u>: Figure 3.2.6

F_{bar} and biomass show a poor relationship since 1992. CPUE and biomass appear closely related throughout the time series 1987-1998. A peak in estimated recruitment in 1993 corresponds with a drop in mean size in the same year. A poor relationship in other years could be attributed to the mean size data not being presented for small and large animals separately.

Celtic Sea (FU 21-22): Figure 3.2.7

A slight fall in biomass in 1991 is reflected by marked drop in CPUE and F_{bar} in this year. Downward trends in biomass and CPUE are seen since 1996. Recruitment and mean size show an inverse relation as would be expected by a reduction in the number of small individuals being recruited to the fishery.

Bay of Biscay (FU 23-24): Figure 3.2.8

Biomass and F_{bar} show a similar trend between 1986 and 1990. A peak of F_{bar} in 1996 is not reflected by a peak in biomass. An increasing trend in recruitment since 1995 is reflected by a downward trend in mean size.

S & SW Portugal (FU 28): Figure 3.2.9

A similar declining trend in biomass and F_{bar} is apparent since 1992. This is accompanied by a similar trend in recruitment. F_{bar} shows an increase in 1998. No CPUE or mean size data were available for this FU.

Conclusions

Although CPUE for larger individuals (> 35mm CL) in many stocks seems stable, CPUE for small *Nephrops* (< 35mm CL) exhibits more variation and could reflect recruitment variation. This is supported by a strong relationship between mean size and recruitment estimates from the XSA for a number of stocks. CPUE of small animals may therefore prove to be a useful index of recruitment. It would appear that TV estimates are influenced by a prevalence of juvenile individuals. These are numerically more dominant than large animals and give higher burrow counts. TV data may therefore be a useful fishery independent measure of recruitment.

Although more rigorous statistical analysis is essential, the data examined appears to indicate a correspondence between exploitation indices and outputs of analytical assessments. This correspondence suggests that such exploitation indices may be used to provide advice on stocks for which there are insufficient data to reliably run analytical assessments. For example, mean size of small (< 35mm CL) *Nephrops* seems to be a reasonable indicator of recruitment. The mean size of the total catch, however can be affected by both over fishing, which removes large animals and by recruitment, which introduces small animals to the population. Mean size of catch is therefore not a reliable index of the state of exploitation. CPUE on large (> 35mm CL) individuals may prove to be a useful indicator of stock biomass as has been demonstrated in a number of FUs examined. The poor correlation between F_{bar} and effort for some stocks suggests the assessments are not performing properly and the quality of the input data should be investigated more fully before drawing conclusions from the generated outputs.

3.3 Long term trends in mean sizes of landings

Annual mean sizes of male and female *Nephrops* landings were plotted for each Functional Unit (FU) across years. Although mean sizes of catches might have been used, landings data were selected because of irregular discards sampling for many FU. It should also be noted that in recent years, the Working Group has been moving towards the expression of ‘landings mean size’ as animals > 35mm carapace length in an effort to avoid the index being subject to factors others than fishing effort; for example, recruitment or discarding effects. Unfortunately, this measure is still not available for all FUs so that the various data series available to and utilised by the Study Group are not all derived in the same way and are not necessarily comparable to one another. Not too much should, therefore, be read into ‘inter-Functional Unit’ differences.

Preliminary plots of annual mean sizes of landings of males from all FUs on the same graph showed that they could be split in two groups; i) FUs with mean sizes 40-45 mm (males) and 35-45mm (females) – this group contained most of the FUs where the index described above has been adopted and ii) FUs with mean size 25-40 mm (males) and 25-35mm (females) **–** for convenience these are shown on separate graphs.

Results

Males (Figures 3.3.1 and 3.3.2)

The most striking feature is the stability of mean sizes across years, except for a few FUs (26, 27 and 31). This should be taken into consideration when examining mean size plots generated by the *Nephrops* Working Group, where the axes scales used often give the appearance of large variations from a year to another. These variations are often interpreted in relation to fishery characteristics, but may only be noise. Differences do not necessarily reflect the state of exploitation because landing size is probably more heavily influenced by crew selection and market forces than by changes in the stock.

Females (Figures 3.3.3 and 3.3.4)

Mean size of landed females also shows long term stability across years, except for the most southern stocks (FUs 25 to 29). The grouping of FUs is similar for both sexes, except for FUs 25 and 27.

Conclusions

Use of mean size as a crude indicator or stock condition has long been questioned owing to the fact that mean size of total or landed catch can be influenced by both recruitment and exploitation. Mean size is also affected by gear selectivity which varies between stocks and discarding which arises from crews selection, market demand and the interplay between MLS legislation and selectivity. Until the use of 'mean size below and above 35mm' has been tested over a longer period and across a range of FUs (as a means to assess recruitment and the size stability of the fully exploited stock respectively) temporal mean size data continue to be of limited value to stock assessment.

Despite these reservations, relative stability within many stocks was demonstrated by the exercise. Owing to the way in which a variety of mean size calculations were used it is not possible to say much about observed differences between stocks. Nevertheless there were one or two examples (eg. FU 16) where mean size was quite high in total landings compared with others (eg FU6). It would be interesting to examine these apparent population differences in more detail.

4 PROGRESS ON THE DEVELOPMENT OF *NEPHROPS* SPECIFIC ASSESSMENT METHODOLOGIES AND INCORPORATION OF SPATIAL DATA

4.1 Development of *Nephrops*-specific assessment methodologies

Concerns have recently been raised about the validity of some analytical assessments of *Nephrops* fishery data as a basis for setting international TACs. Three issues may be raised: (1) Given the biological characteristics of *Nephrops* populations and the nature of their exploitation, how valid are the assessment models and their assumptions? (2) How certain are the values of the biological and fishery parameters used to drive the assessments? and (3) Are the sampling data of sufficient quality to support the assessments?

Detailed examination of the second two issues is beyond the present remit. It is enough to note that for several stocks it is at least questionable whether sampling levels and frequencies are sufficient to represent quantities and size distributions of landings and particularly discards, and that values of crucial assessment inputs, notably growth parameters are often assumed or 'borrowed' from adjacent stocks. However, it is appropriate to consider here whether there are feasible assessment approaches that are less demanding of sampling data and less sensitive to uncertain input parameters.

In response to the first issue, we can ask: what are the essential features that should be captured in an ideal *Nephrops* assessment model? In particular, how would such a model differ from the standard methodology? *Nephrops* differ from most fin fish in one very obvious way – they are sedentary, i.e. a stock cannot spatially re-distribute itself in response to exploitation. Thus, by seeking out the highest density patches a fisherman should be able to maintain CPUE at relatively high levels even in the face of a stock decline. An important consequence for fishery assessment is that the CPUE may well not be directly proportional to stock abundance. Under standard assessment models using data at a large spatial scale, stability of catches and CPUE during the early stages of a stock decline might falsely indicate stability of stock abundance and recruitment. An apparent lack of variability in stock and recruitment levels is a common feature of *Nephrops* stocks assessed by XSA and it has been suggested that this is a consequence of (unspecified) life-history characteristics. The possibility that this feature is a dangerous artefact of assessment methodology needs serious consideration.

Apparent stability of stock and recruitment levels may also arise from the fact that it is not routinely possible to make direct measurements of age in *Nephrops*. Age-based methods are applied by 'slicing' length frequency distributions into nominal age-classes using growth parameters. As has previously been noted (ICES, 1991), nominal age-classes will not correspond directly with true year-classes, but will contain a mixture of cohorts. Moreover, variance of length at age will lead to protracted recruitment at length by any year-class (ICES, 1991). Both effects will tend to obscure annual variation in recruitment (ICES, 1991, 1994).

Spatial effects are not the only reason why CPUE is unlikely to be proportional to abundance. Catchability of *Nephrops* is closely related to burrow emergence behaviour, known to vary in relation to seasonal, nyctheremal, reproductive and other factors. The most obvious catchability feature is the much lower vulnerability of mature females to trawling. The WG already accounts for this by undertaking separate assessments for males and females. Separate assessments are, however, unsatisfactory in two respects. Firstly, since there are usually lower catches of females than males, particularly in winter fisheries, female assessments are of lower quality because they are based on fewer data. Lower exploitation rates further compromise female assessments since unaccounted variations in natural mortality assume a much greater importance. Secondly, separate assessments are wasteful of information because they do not take account of features common to both males and females. If seasonal patterns of effort and catchability remain stable, parallel trends in male and female fishing mortality would be expected, matching changes in fishing effort. Females first appear in the catch before the age of maturity, so that assuming 1:1 sex ratios at recruitment, male and female recruitment trends should be identical. These parallel features could be exploited to produce a robust combined assessment that makes distinctions between males and females only where dictated by features of biology, fisheries or data.

Clearly, greater biological realism in *Nephrops* assessment models is highly desirable. As suggested above, there is some scope for introducing greater realism whilst reducing the number of assessment parameters to be estimated. However, for the most part greater realism means more complicated models. This is particularly true of introducing greater spatial resolution to the current age- and length-based assessment framework. Sampling data for most stocks are already stretched to the limit in supporting current assessments, so that greater spatial resolution is likely to remain an unrealisable ideal under the current assessment framework of most stocks. Instead, new approaches to assessment that accommodate such realism whilst reducing dependence on sampling data and biological input parameters may be preferable.

Three different assessment approaches were attempted. Statistical catch-at-age models were constructed to assess male and female stocks at the same time, giving greater economy of estimated parameters as compared with VPA. The applicability of depletion models to *Nephrops* catch and effort data was investigated in an attempt to remove dependence on sampling data and ‘slicing’ whilst also incorporating spatial effects. Finally, biomass dynamic (production) models were considered as a very simple approach with minimal data requirements.

Statistical catch-at-age models

The underlying model in statistical catch-at-age analysis (SCA) is the same as in VPA, with expected catch numbers given by the product of fishing mortality and cohort strength discounted for previous fishing and natural mortality. SCA differs in that constraints are applied such that there are fewer parameters to estimate than data points, and the model is fitted by statistical methods. This approach was first developed by Doubleday (1976) and extended by Paloheimo (1980), Fournier & Archibald (1982) and Deriso et al. (1985). In principle, estimates of both natural and fishing mortality are possible, but there is rarely enough contrast in the data for this to be possible in practice (Hilborn & Walters, 1992).

SCA is here applied to Farn Deeps *Nephrops* using the same assumptions about natural mortality as are applied in the standard XSA: M = 0.3 in males and immature females, M = 0.2 in mature females (> 24 mm CL). Fishing mortality is estimated under a separable model:

$$F_{ij} = v_i F_j$$

where v_i is the vulnerability to fishing at age i relative to the oldest age and F_j is the fishing mortality in year j on the oldest age class. This encapsulates the assumption that gear selection remains constant across years. The v_i are separately estimable from the F_j under the constraint that $v_{\text{oldest}} = 1$.

The v_i can be simplified by assuming that gear selectivity is described by a logistic curve:

$$v_i = \frac{1 + e^{-(a+bI)}}{1 + e^{-(a+bi)}}$$

where I is the number of age classes and a and b are parameters of a logistic curve. The numerator term of this expression applies the scaling constraint that $v_{\text{oldest}} = 1$.

The F_j can be simplified by assuming a proportional relationship with fishing effort:

$$F_j = qE_j$$

where q is the catchability coefficient at full gear selection and E_j is the total fishing effort in year j.

This framework can be extended to cover both male and female catch-at-age matrices for *Nephrops* by defining

$$R_{j,\text{female}} = R_{j,\text{male}}$$

which is a reasonable constraint if recruitment occurs before sexual maturity – i.e. before sex-related differences in catchability are expressed – and there is a 1:1 sex ratio at recruitment, and

$$F_{j,\text{female}} = kF_{j,\text{male}}$$

where k is a factor scaling female to male fishing mortality in the oldest age-group. This expresses the assumption that the annual component to fishing mortality, perhaps related to effort, is the same for both males and females. The v_i component of fishing mortality is defined separately for each sex, reflecting different gear selection at age for the two sexes.

As defined above, SCA provides a similar framework to VPA for *Nephrops* assessments, but with a number of constraints and simplifications that reflect beliefs about patterns of recruitment and vulnerability to fishing. This offers a number of potential advantages over VPA: (1) more robust assessment outputs owing to fewer parameter estimates; (2) statistical fitting allows examination of uncertainty in abundance and fishing mortality estimates; and (3) more robust assessment of females owing to constrained parallels between male and female stocks.

The chief disadvantage of this SCA framework is that gear selection at age is assumed to be the same in each year. Departures from this assumption could cause severe biases in either or both fishing mortality and stock estimates. The validity of the assumption could be examined through analysis of residual patterns. This might allow sub-sets of years to be identified, within which the constant selection assumption might be more valid. A separable model for fishing mortality has previously been applied to Firth of Clyde *Nephrops* through use of separable VPA (ICES, 1991). Encouraging results were obtained, but it cannot be inferred that a separable model would be generally applicable.

Appropriate SCA models for Farn Deeps *Nephrops* were implemented using the NLIN procedure of the SAS statistical package. Lognormal errors were assumed for catch numbers. Recruitment was estimated on a log scale, with expected catch values formed in a similar way to equation 11.6.2 of Hilborn & Walters (1992). The fishery year was defined as June-July, rather than calendar year, since it is a largely winter fishery (October-March) in the Farn Deeps. This may also be a better reflection of a ‘biological year’ for *Nephrops*. Catch data for 1985/86 to 1997/98 were analysed, sliced into ten nominal age-classes for each sex. Four SCA models were considered:

Model 1 – unconstrained year and age effects for fishing mortality;
Model 2 – year effect for fishing mortality constrained to be a function of effort;
Model 3 – age-class vulnerabilities constrained to be logistic functions; and
Model 4 – constraints on both age and year effects for fishing mortality.

Results

Comparison of residual sums-of-squares showed that significant explanatory power was lost by constraining the annual component of fishing mortality to be a function of effort (Model 1 vs Model 2: $F_{12,197} = 5.44$, $P < 0.001$). However, it was possible to simplify age-class vulnerabilities to logistic functions (Model 1 vs Model 3: $F_{14,197} = 0.95$, $P = 0.510$). Model 3 is thus the most appropriate for the Farn Deeps data.

The pattern of annual fishing mortality estimated from Model 3 is very similar to those from XSA for the same data, with a relatively narrow 95% confidence region (Figure 4.1.1). The year effect for fishing mortality is significantly correlated with effort ($r = 0.646$, $P = 0.017$). Failure to constrain F as a function of effort (Models 2 and 4), may be because the most recent two years are outliers from this relationship (Figure 4.1.2). XSA estimates are more highly correlated with effort ($P < 0.001$), but this is not unexpected since effort was used to tune these assessments.

Relative selection at age is very similar between Model 3 and XSA for males, but for females there is a sharp divergence in the older age-classes (Figure 4.1.3). This may be because the number of females in the plus group was fairly large, while the logistic constraint in the SCA model has forced a relatively low selection value. Despite the selection of Model 3 as the most appropriate for the data, there may in fact be departures from a logistic selection curve at older ages/larger sizes. This has been identified as a problem in Catch at Size Analysis (CASA) applied to *Nephrops*, which also applies a logistic selectivity constraint (ICES, 1991).

Recruitment estimates (Figure 4.1.4) are similar between Model 3 and XSA up to 1994/95, with a confidence region of about ±30% for the SCA estimates. The SCA estimates show a sharp decline in recruitment after 1994/95, whereas the XSA estimates are relatively stable. A decline in recruitment cannot be ruled out, and this is being investigated, but this pattern is more likely to be an artefact introduced by the assumption of stable selection at age. Due to uncertainty about discard sampling, the method used to raise the catch size distribution for the Farn Deeps fishery was different for data from 1994 onwards. Prior to 1994, discard data were combined with landings data to provide an overall catch size distribution. From 1994 onwards, data from sampling of unsorted catches was introduced, and the raised catch size distributions are weighted means incorporating discard, landings and unsorted catch data. This is likely to be manifest in the data in the form of an apparent change in selection at size/age. The assumption of constant selection may have caused a spurious trend in the SCA estimates.

Overall, SCA modelling has been fairly successful for the Farn Deeps stock. SCA has provided a useful framework for testing of hypotheses and confirming that the estimated trend in fishing mortality is not just forced by tuning in XSA. However, XSA for this stock is regarded as satisfactory, and SCA has added little beyond estimates of parameter uncertainty and has almost certainly produced a spurious trend in recruitment. On this basis, one would not choose SCA rather than XSA as the main assessment tool for Farn Deeps *Nephrops*. SCA may be more useful in some other stocks where XSA is unsatisfactory – for example, where male and female recruitment estimates differ widely or no correlation between F and effort is found – but only if the data are of sufficient quality for the analysis. SCA is no more appropriate than XSA in cases where there is inadequate discard sampling.

Depletion models

Depletion models depend on a measurable change in abundance as individuals are removed from the stock by fishing. The De Lury method (De Lury, 1947) uses the relationship between CPUE and cumulative effort. The Leslie method (Leslie & Davis, 1939) can use any index of abundance and depends on a relationship between abundance and cumulative catch. Both methods yield estimates of catchability and population number or biomass at the start of fishing. Bias in these estimates is considered to be lower in the Leslie method, and this approach is generally preferred (Hilborn & Walters, 1992).

At the simplest level, the Leslie method involves regressing abundance on cumulative catch. Methot & Botsford (1982) used this approach to assess *Cancer magister* in California, using CPUE as an index of abundance. Elaborations of the model have been developed to deal with recruitment to the stock in open populations (Hilborn & Walters, 1992) and natural mortality coinciding with fishing (Rosenberg et al., 1990).

Nephrops may be suitable for depletion modelling because: (1) they are sedentary, hence abundance is not influenced by immigration or emigration; and (2) they have discontinuous growth. If moulting is synchronised, or at least does not occur during part of the year, then we can define periods over which the population is effectively closed – influenced neither by movement nor by recruitment to the fishable stock through growth. Lack of growth offers the further advantage that catch weight should maintain the same proportionality to catch numbers throughout the period. It is not reasonable to suppose that no natural mortality occurs during the period, so that the model of Rosenberg et al. (1990) is appropriate:

$$\mathrm{CPUE}_t = qN_0 e^{-(t+0.5)M} - q\sum_{i=0}^{t-1} C_i e^{-(t-i)M}$$

Regression of CPUE_t on $e^{-(t+0.5)M}$ and $\sum_{i=0}^{t-1} C_i e^{-(t-i)M}$, without an intercept term, yields estimates of catchability q and abundance at the start of fishing N_0.

This method is here applied to Farn Deeps *Nephrops* using monthly LPUE data for the period November to March of 1985/86 to 1997/98. This is considered to be a period of low temperatures during which moulting is unlikely to occur. LPUE, expressed as tonnes live weight per thousand hours, was calculated over all gears for which effort is recorded. Cumulative landings in tonnes live weight for all gears were used in place of catch. By using LPUE and landings rather than CPUE and catch, and weight rather than numbers, the assessment does not depend on sampling of size distributions and discards. N_0 is replaced by B_0, the landable portion of total biomass at the start of November. Monthly natural mortality was assumed to be 0.3/12 = 0.025.

The main assumptions of this assessment are that catchability remains constant during the depletion period and that LPUE is proportional to abundance. As noted above, searching behaviour by fishermen means that the latter assumption is unlikely to be valid for a sedentary stock as a whole. However, spatial effects can potentially be accounted for by examining the data at a spatial scale that is at least as small as the scale of spatial discrimination possible in fishing operations. The highest resolution of LPUE and landings data for the Farn Deeps is the ICES statistical rectangle, 1°of longitude by 0.5° of latitude. This scale is probably about an order of magnitude greater than the scale of fishing operations, but may offer some improvements in LPUE as an abundance index. Seven rectangles cover the Farn Deeps FU, each of which was considered a separate unit for assessment by depletion modelling. Four models of catchability were considered:

Model 1 – catchability varies by year and rectangle;
Model 2 – catchability varies by year;
Model 3 – catchability varies by rectangle; and
Model 4 – catchability constant across all years and rectangles.

There were insufficient data to estimate B_0 in all combinations of years and rectangles. In order to get complete estimates of landable biomass for the fishery in each year missing values were imputed from a log-linear model for B_0 with year and rectangle as additive class variables.

Results

There were consistent measurable declines in LPUE as landings accumulated during the winter in almost all combinations of year and rectangle in the Farn Deeps. As an example, Figure 4.1.5 shows depletion plots for 1992 in the three most important rectangles. The most striking feature is that the slope, i.e. catchability, differs widely between rectangles.

Comparison of residual sums-of-squares between Models 1 to 4 shows that significant explanatory power is lost if catchability is simplified by removal of year (Model 1 vs Model 2: $F_{69,210} = 4.37$, $P< 0.001$) or rectangle effects (Model 1 vs Model 3: $F_{75,210} = 3.04$, $P< 0.001$). However, differences in catchability between rectangles appear to be more important than differences between years. Figure 4.1.6 shows that estimates of landable biomass for 1994 and 1997 are well out of line with estimates for other years in models with catchability varying between years (Models 1 and 2). Model 3 estimates (q by rectangle) are otherwise very similar to those from the full model, suggesting that the difference in explanatory power is due to these two years. Declines in LPUE during winters 1994/95 and 1997/98 were negligible, leading to very low estimates of catchability and hence excessively high biomass estimates. Outside these two years, landable biomass estimates from the two models are stable at around 4000 tonnes. Removal of rectangle effects on catchability (Models 2 and 4) appears to cause an upward bias in landable biomass estimates.

Initial results from the depletion modelling approach are quite encouraging. Using landings and effort data at the crudest level, it appears to be possible to measure consistent depletions during the winter in the Farn Deeps. Biomass estimates are obtained without any dependence on growth or age parameters. Improved estimates should be possible using gear-specific LPUE or preferably CPUE data and log-book data if available. Statistical models could be used to combine data from different sources to obtain an overall index of abundance and to account for spatial effects, as suggested by Hilborn & Walters (1992). Furthermore, more rigorous maximum likelihood approaches to depletion model fitting could be used, as by Rosenberg et al. (1990). In principle, recruitment estimates could be obtained if the analysis was framed in terms of numbers rather than biomass – the amount by which N_0 in year t+1 exceeds N_0 minus the catch in year t represents recruitment to the fishable stock.

The main question mark over the analysis concerns the assumption of constant catchability. Catchability almost certainly will not be constant over any five month period, but it is difficult to comment on what kind of changes might be expected over November to March. One serious possibility is that catchability is positively correlated with temperature. Given that November to March is a period of declining sea temperature, this would mean that a decline in LPUE could reflect a fall in catchability rather than a depletion. Very low catchability values were estimated for 1994/95 and 1997/98, but there is no evidence of any kind of temperature anomaly for these winters. Nevertheless, the possibility that apparent depletions are in fact an artefact of changing catchability needs to be carefully examined before a depletion analysis of this kind could be accepted as a valid stock assessment.

Biomass dynamic models

Biomass dynamic (production) models are based on the simple premise that stock biomass next year will equal stock biomass this year plus production (growth and recruitment) and minus mortality. The Schaefer model describes changes in stock biomass in terms of r, the intrinsic rate of population growth, and k, unfished equilibrium stock size. If it is assumed that catch is related to stock biomass by a catchability coefficient q, these parameters may be estimated from catch and effort data. Maximum sustainable yield and associated stock and effort statistics are found as simple functions of these parameters.

Production models are commonly fitted to catch and effort data by quadratic regression, under the assumption that the stock is at equilibrium. A quadratic relationship has been noted between *Nephrops* landings and effort in the Skagerrak and Kattegat (ICES, 1997). Although a production model was not explicitly fitted to these data, the relationship has been used to infer optimum effort levels at which landings are maximised.

Several methods are available to estimate Schaefer model parameters without equilibrium assumptions. Regression methods using CPUE and effort data are due to Schnute (1977) and Walters & Hilborn (1976). A non-linear approach, termed 'observation error/time-series fitting' by Hilborn & Walters (1992), is considered preferable owing to more realistic assumptions about CPUE error distributions. The non-linear method has previously been applied to landings and effort data for Scottish and Swedish *Nephrops* stocks using the CEDA package (Holden et al., 1995), but few meaningful results were obtained (ICES, 1994).

Both the regression methods and the non-linear method were attempted with Farn Deeps landings and effort data for 1985 to 1997. For the non-linear method, initial biomass was estimated by applying the catchability coefficient to landings and effort data for the first year. No meaningful parameter estimates were obtained from any of the three methods. Negative catchability estimates were obtained, and there were extremely high correlations between the parameter estimates. More satisfactory estimates were obtained using the CEDA package, which applies the non-linear method with a fixed, user-selected value of initial stock biomass as a proportion of unexploited biomass ('initial proportion'). However, the results were very dependent on choice of initial proportion. Results from application of the CEDA method to landings and effort data for S & SW Portugal were similarly dependent on arbitrary input parameters.

There are two likely reasons for the failure of the biomass dynamic methods in these examples. Firstly, there is insufficient 'contrast' in the data – changes in effort, fishing mortality and corresponding stock levels – to allow clearly identifiable parameters. Secondly, the critical assumption that LPUE is proportional to abundance over a longer time span is unlikely to be valid. The second problem may be partially resolved by examining data at a finer spatial scale or by using alternative abundance indices, but in practice the first problem will probably preclude meaningful parameter estimates. The chief attraction of the approach is that it is very simple, with minimal data requirements. In practice, it would be difficult to defend management recommendations made on the basis of such an assessment.

Conclusions

Three alternative assessment approaches have been applied to *Nephrops* fishery data for the Farn Deeps with mixed success. It does appear possible to get away from some of the assumptions underlying existing assessments, for example on growth, but only at the expense of increased dependence on other assumptions. In particular, assumptions about patterns of catchability and the relationship between CPUE or LPUE and stock abundance are critical in these alternative assessment approaches.

SCA models offer some scope for efficient analysis of *Nephrops* fishery data, but do not seem preferable to XSA for those stocks were there are adequate data to support such an analysis. The chief value of SCA modelling may lie in exploring patterns in the data and testing hypotheses about sources of variation in mortality or recruitment. It is unlikely that they would be used as a routine assessment tool for the Working Group.

Biomass dynamic models are attractive in their simplicity, but there seems little possibility that meaningful results could be obtained for most stocks. For stocks without adequate data to support other types of assessment, qualitative examination of available fishery statistics is probably preferable.

Depletion modelling is the most promising of the three approaches examined. Issues about changing catchability need to be resolved, and there is a great deal of scope to improve on the data formulation and method of analysis presented above. The Study Group suggests that the application of depletion models be explored for other *Nephrops* stocks.

In conclusion, whilst there is some scope for improvement in making best use of the information available for a stock, alternative assessment approaches are no panacea to inadequate sampling and uncertainty about biological parameters. Scientific effort is best directed towards obtaining sufficient and representative data on the quantities and characteristics of fishery removals of *Nephrops*.

4.2 Microscale Mapping of Fishing Effort in the Clyde Sea Area (FU13)

The University Marine Biological Station Millport in collaboration with the Marine Laboratory Aberdeen has just completed an EU funded (contract no. EC97/100) twelve-month survey of the small scale pattern of fishing effort in the Clyde Sea area. The following text comprises a summary of some of the findings relevant to the study group.

The survey was conducted over the 12-month period from November 1998 - October 1999, inclusive. GPS data loggers were fitted to 18 vessels in the Clyde fleet whose landings for the duration of the study period represented 25 - 29% of the total fleet in rectangles 40E4, 40E5, 39E5 and 11% of the total fleet landings in statistical rectangle 39E4. Vessels were selected from ports around the Clyde in order to get a broad spatial coverage and to be representative of the whole fleet in terms of vessel characteristics.

The GPS data loggers were set to record latitude and longitude at 10 minute intervals and had sufficient memory to store *ca* 6,000 lines of data, after which the data had to be downloaded via a portable PC. Thus, with continuous use it was necessary to visit the participating fishing vessels and download the data at 6-weekly intervals. Latitude and longitude were converted to decimal degrees, then vessel speed was calculated throughout the logging period and plotted against time. Daily landings data were collected via confidential logbooks that were completed by the vessel skipper.

Figure 4.2.1 shows a typical example of one days trawling activity. Periods where the vessel is stationary (before 0320hrs and after 2000hrs) are when the vessel was in port. Steaming to and from the *Nephrops* grounds occurred at speeds greater than 6 knots. Vessels in the Clyde fleet trawl at speeds of between 1.5 and 3.2 knots, with a period between each tow where the vessels are almost stationary whilst the nets are being handled. Periods of trawling were therefore easily extracted from the data set and plotted on a digital map of the Clyde (Figure 4.2.2).

For each fished track of each vessel, a vector file of the series of locations along the tow tracks was generated. These vector files were converted to raster images (image resolution 240*288 for area 55° 0’ to 56°12’ N and 4°36’ to 5°36’ W, each pixel equating to ¼’ latitude by ¼’ longitude, representing an area of 0.121km^2) using the GIS package IDRISI (Clarke University). Any pixel a fished track passed through was assigned a value of 1 for the effort map or the daily LPUE for the landings map; unfished pixels had a background value of 0. Raster images of individual fished tracks were then summed. Occasionally a single fished track would pass through the same pixel twice, for logistic reasons these pixels were scored once.

Landings per vessel were generated using the cumulative LPUE per pixel charts. The cumulative LPUE maps were divided by the pixel value in terms of time, as calculated from the appropriate fishing effort map. The resultant distribution of landings by vessel charts were then summed to give the distribution of landings for the sampled fleet. The results were compared with the known landings from the logbook data, and were within acceptable limits (< 5%). The spatial pattern of LPUE for the sampled fleet was calculated by dividing the combined sampled fleet cumulative LPUE by the effort map. Results have been presented for the sampled fleet for the entire 12-month study. Legends on the final images were generated by linear stretching.

Fishing effort, total landings and LPUE of the sampled fleet over the 12-month sample period are shown in Figure 4.2.3. LPUE shows a distinct north/south gradient with landings rates of from between 0.1 and 20 kg.h^{-1} in the Inner Firth and parts of Loch Fyne to over 60 kg.h^{-1} south of Arran. Landing rates in the Arran Deep were intermediate and in the range 35 - 45 kg.h^{-1}. A boundary in the landing rates roughly at the latitude of the southmost tip of Arran is apparent. Interestingly, this boundary is at the same location as the boundary observed by Tuck et al., (1999) where long term trends in UWTV data are described.

Fishing effort was concentrated in areas where the LPUE was in the region of 27-40kg.h^{-1}. *Nephrops* landed from these areas are larger in size and of greater unit value than those further south where the catch rate is greater. There was a strong positive relationship between the number of times a pixel was fished and the total landings for that pixel (landings = 1.488 + 3.13*effort, r^2 = 86.58%, where effort = the number of times a pixel was fished).

The data set comprises a comprehensive survey of the spatial pattern of fishing effort and landings that may be used to fine tune the analytical assessments for this area.

The spatial pattern of *Nephrops* landings were estimated by raising monthly sampled fleet landings patterns to the whole fleet. Whole fleet landings data were then extracted by strata (based on BGS sediment map and Roxann habitat map), and LCA assessments carried out for each of the strata, using appropriate growth parameters. Given the spatial variability in *Nephrops* biological parameters known to exist within the Clyde, it was thought that this approach may be more appropriate than the existing practice of applying a single set of parameters to the whole Clyde stock. Plots of the relative changes in short term yield, and long term yield and biomass upon relative changes in effort are shown for the BGS based stratified assessments in Figure 4.2.4. The results of the LCA assessments suggest that the state of exploitation of *Nephrops* in the Clyde varied between strata, and the use of more appropriate parameters for each strata improved the usefulness of the assessments. Due to the uncertainty over changes in the spatial pattern of fishing in previous years, it was not possible to carry out any stratified VPA assessment, although with a time series of data, this may prove useful. Full details of the project will be presented in the final report to the EC, during the summer of 2000 (Marrs et al., 2000). A further study project has gained funding from the EC (April 2000 – March 2002), which will continue the work in the Clyde, also including vessels that fish in the Sound of Jura area, and also carry out a small scale study of vessels exploiting the Fladen Ground *Nephrops* stock.

4.3 GeoCrust project

The University of Algarve has just started an EC funded project (GeoCrust) using the Portuguese satellite vessel monitoring system (VMS) data and official logbook records of landings to map fishing effort and removals in the mixed crustacean fishery. A summary of the project is provided in a working paper for the Study Group (Appendix 2).

5 INDEPENDENT SURVEYS – REFINEMENTS IN METHODOLOGY AND NEW INFORMATION

The work included under this term of reference fell broadly into three categories. The first sections (5.1- 5.2) deal with developments in the methodology associated with underwater television surveys and specifically burrow counting. Secondly, new information on trawl surveys was considered (section 5.3) and at this meeting David Taylor of the Department of Fisheries and Oceans St. John’s, Newfoundland, Canada presented information on new trawl methodologies employed in assessing the snow crab (*Chionoecetes opilio*) resource in Newfoundland, Canada. Finally section 5.4 introduces some ideas on survey design for *Nephrops* and describes the use of adaptive survey methods.

5.1 Lowestoft meeting

In November 1999, the CEFAS lab in Lowestoft hosted a workshop on the use of underwater TV to estimate *Nephrops* abundance. This was attended by scientists from the various UK institutes using underwater TV (CEFAS Lowestoft, FRS Marine Laboratory Aberdeen (MLA), University Marine Biological Station Millport (UMBSM), University of Glasgow). A summary of the discussions has been collated in a working paper for the Study Group (Appendix 3).

5.2 Edge effects

Following the discussions at the Lowestoft meeting, two approaches were taken to examine the implications of “edge effects” on estimation of burrow density within the existing burrow counting methodology. Burrow density estimation on known densities was simulated at MLA with different widths of view and burrow extents, while at UMBSM edge effects were estimated from actual seabed video.

A simulation of “edge effects” in the underwater TV method of *Nephrops* abundance estimation

This work describes a simulation exercise to investigate the “edge effects” introduced in the current practice of counting burrow systems along a narrow transect of seabed, defined by the width of view of the camera system employed. Throughout this work, a *Nephrops* “burrow” is defined as a system of interconnecting tunnels, and an “opening” is an individual hole associated with a burrow. An individual burrow may have several openings.

Estimates of density for a given station are derived from a *Nephrops* burrow count for a known viewed area (width of view * length of track). All *Nephrops* openings identified in the field of view are allocated to a burrow, and burrow count is used to estimate density. Openings are allocated to burrows by experienced counters in a subjective manner, based on burrow orientation and distance apart. Calibration exercises have shown that there is a high degree of similarity in allocation of openings to burrows between the various laboratories involved in *Nephrops* underwater TV assessment.

Clearly, it is not possible to know how much of a burrow viewed within a transect extends beyond the viewed area. The counting methodology currently employed, counts the burrows of all openings viewed, and therefore, those burrows that extend beyond the field of view will introduce some degree of edge effect to the counts, by overestimating the density of burrows in the viewed area. A pictorial simplification of the counting methodology is provided in Figure 5.2.1.

A simulation exercise was undertaken to investigate the potential edge effects of the current burrow counting methodology. This initially investigated the effects of burrow density and field of view.

Using data from resin casts of *Nephrops* burrows collated by Marrs et al. (1996), a random burrow population was simulated. The maximum distance between openings (*MD* cm) in the burrow was drawn from a ln normal distribution (mean 3.843, st dev 0.432), while the number of openings was drawn from a Poisson distribution (2 + mean 1.39). It was assumed that the minimum number of openings a burrow could have was two. Burrow centres were then randomly located within a 4*250 m area, to generate the required density. A random spatial burrow pattern was assumed. Field studies suggest that *Nephrops* burrows may not be randomly distributed at all times of the year (Tuck et al., 1994), but for simplicity a random distribution has been assumed for this exercise. For each burrow, the first opening was randomly located on the circumference of a circle (centre randomly located above) with diameter equal to *MD*, with the second opening being opposite the centre from this. Any extra openings were located randomly within this circle. A count was then made of the number of burrows with an opening within the viewed area (width of view *200m, a typical track length for Scottish surveys), and a density calculated. One thousand simulations were carried out for each combination of width of view (0.6, 0.8 and 1.0 m) and burrow density (0.1 to 1.5 m^{-2} in $0.1m^{-2}$ increments).

Following this, the importance of edge effects for different burrow sizes were also examined. No significant relationship has yet been identified between burrow density or animal size and maximum distance between openings (Marrs et al., 1996), possibly due to the limited range of population densities which occur in diveable depth, and have therefore been available for resin casting. However, there is a non-significant positive relationship between animal size and burrow length (Marrs et al., 1996), and anecdotal observations appear to suggest that in certain low burrow density stocks (e.g. Fladen Ground) burrows may be far larger than those observed in higher density stocks (e.g. Firth of Clyde or Firth of Forth). Therefore, the mean of *MD* was varied in further simulations (from 0.4 – 1.2m, in 0.4m steps). It is likely that the standard deviation of *MD* would vary with the mean, and in the simulation, the two parameters have been assumed to be directly proportional. *MD* was assumed to be constant within an individual simulated track. Because of the difficulty in analysing very large files, the number of density increments was reduced (0.1 to 1.3 m^{-2} in $0.4m^{-2}$ increments).

For each simulation, the proportional error of the density estimate was calculated from:

$$\text{Proportional error} = \frac{\text{Estimate} - \text{Density}}{\text{Density}}$$

The effects of width of view and burrow density on proportional error in the first simulation (burrow size drawn from a single distribution) were examined within an ANOVA framework. A full model (both variables as factors, with an interaction term) was fitted, and then simplified to a minimum adequate model using a stepwise selection procedure employing AIC. The minimum adequate model is shown in Table 5.2.1, with width of view retained as a factor (2 d.f.) and density as a linear term.

Mean proportional error remained constant with burrow density, but was inversely related to width of view (reducing from 0.57 for 0.60m, to 0.43 for 0.80m and 0.34 for 1.0m). The standard deviation of the proportional error was inversely related to both width of view and burrow density.

The model including variability in burrow size was analysed in the same way as the initial model. The minimum adequate model is shown in Table 5.2.2, with burrow diameter, density and width of view retained as factors, and the burrow diameter:width of view interaction term also retained. Figure 5.2.2 shows plots of proportional error in relation to burrow density and burrow diameter. For a given burrow diameter, the proportional error was constant with burrow density, but was inversely related to the field of view. Proportional error increased with burrow diameter. The standard deviation of proportional error was inversely related to burrow density and width of view.

Proportional error in burrow density estimates varied from 0.30 (mean burrow diameter 40cm, 100cm field of view) to 1.18 (mean burrow diameter 120cm, 60cm field of view).

This simulation suggests that the current techniques employed in burrow counting have the potential to overestimate burrow density. Although within the simulation the proportional error was constant with density, *Nephrops* are generally smaller at high densities (due to slower growth), and one might expect burrows to be smaller, reducing proportional error. Using the mean burrow size from resin casts (Marrs et al, 1996), density is overestimated by between 34% and 57%, depending on the field of view.

While TV density data are used solely to generate an index of abundance, edge effects are unlikely to introduce large errors (provided the mean size of the burrows or the field of view does not change). If the data are used to estimate stock biomass, however, then both edge effects and appropriate mean size values should be taken into account. Both of these factors could lead to considerable overestimation of TSB.

Estimation of edge effects from seabed video

Nephrops burrows (not individual openings) were counted from 10 minute segments of viewable videotape taken at each station. First the segment was viewed and a rough count generated (familiarisation). The segment was then analysed at minute intervals and burrows that were judged to be wholly in the field of view (i.e. 'crossed' a 1m wide reference line viewed on the monitor) were counted (A). This was done twice and the mean count taken. Following the above count for a given minute, the section of videotape was viewed again and the burrows that were judged to extend out of the field of view (i.e. only part of the burrow visible at the reference line) were counted (B). Again, the mean of two counts was taken. Results are shown in Table 5.2.3.

Traditional counts are A+B and this results in overestimation when burrow densities are raised to be representative of the ground. A + B/2 is a crude attempt to account for edge effects.

Thus the potential overestimates due to edge effect ranges from 25-34% (excluding the low-density site that generated 50%).

Earlier work (Marrs et al., 1996) where underwater TV tracks were dived and *Nephrops* burrows within the viewing area counted by the divers showed that, whereas there was reasonable consistency between counters, the true number of burrows present was consistently slightly higher. This is because counters of video records do so conservatively; if the identity of an opening is in doubt, it is excluded. Also some burrows are almost invisible to counters since their openings are directed away from the camera.

The two approaches resulted in similar conclusions, in that edge effects for the camera configuration used in Scotland (approximately 1m width of view) lead to an approximate 30% overestimation of burrow density (for a mean burrow system diameter of 40cm). While the burrow density estimates are used as an index of animal abundance, such refinements may not have great influence, but as more reliance is put onto stock biomass estimates generated from TV abundance, it will be important to take such effects into account.

5.3 Trawl surveys

Icelandic *Nephrops* survey 1985-1999

Annual *Nephrops* cruises were initiated in the early 1970´s. Since 1985, a standard survey has been carried out on the research vessel Dröfn, a 25 m and 150 GRT stern trawler, during the period of May 5 - 25 each year. A standard 150 foot headline *Nephrops* trawl has been used with an 80 mm mesh size, i.e. in accordance with regulations for the *Nephrops* fishery.

The survey includes 55 fixed stations, distributed in relation to the size and historical catches of the fishing areas of *Nephrops* at Iceland.

As a rule, survey indices for small individual fishing units vary considerably from year to year, correlating insignificantly to other parameters like LPUE from the fishery or VPA assessments. However, when looking at the average indices separately for SW or SE Iceland over the period, a certain trend is observed. Also, a much better relationship is observed when looking at the overall May survey index and the LPUE from the log-book fishery data during the main fishing season May-August (Figure 5.3.1). Therefore, VPA (XSA) for the total stock in FU1 generates rather similar results whether tuned with CPUE or survey data.

Republic of Ireland time series of research vessel data

Over the years 1987 to 1999, nine research vessel hauls were carried out stretching across the Irish *Nephrops* grounds on an west-east transect from 6^o 00’ W to5^o 20’W at intervals of 5’ (2.98 nautical miles or 5.515km) at 53^o 40’ during summer between the dates of 15 June and 14 July, (except 1999, 28-30 July), when females were most numerous in the catches.

Of the potential 117 hauls covering nine stations over thirteen years, 102 (87% of the total) were actually completed. To complete the series for statistical purposes, missing values were supplied by interpolation, using a mean of the values of neighbouring stations multiplied by the mean of the factor by which the equivalent value differed from its western and eastern neighbours in the preceding and succeeding years, as follows:

$N_{xy} = (N_w + N_e)/2 * [(N_{wy}/((N_{wy-1}+N_{wy+1})/2)) + (N_{ey}/((N_{ey-1}+N_{ey+1})/2))]/2$

Where:	N = Number of *Nephrops*
With subscript notation:	x = Station for which data sought
	w = Next station west of station x
	e = Next station east of station x
	y = year for which data sought
	y -1 = last year previous to that for which data sought
	y +1 = next year after that for which data sought

For extreme west or east stations or where a station was omitted for two years running, as much of the formula as was applicable was applied.

Numbers of *Nephrops* caught by sex and female sexual category are given in Table 5.3.1, along with official landings and *Nephrops* Working Group VPA estimates of total spawning stock biomass. Female sexual stages were routinely and simply categorised by eye (dorsal view) as pale, (indistinguishable in colour a male), dark (ovaries of darkest green observed prior to spawning), and medium (all intermediate stages); ovigerous females were classified on that characteristic alone (i.e. their ovarian condition was not considered).

In Table 5.3.1, ‘medium’, ‘dark’ and ovigerous females are classified as ‘mature’ or ‘breeding’ females; the number of mature/breeding males was simply estimated by using the assumption that immature males’ numbers equalled those of immature females and subtracting immature/pale female numbers from total male numbers to give a value for mature/breeding males.

Research vessel data were correlated against the landings and biomass data, but without any clearcut relationships being apparent. However, some interesting correlations were found when numerical ratios of mature to immature *Nephrops* were correlated with landings and VPA biomass data.

Correlation coefficients of numerical adult:immature ratios with official landings data and with spawning biomass data from *Nephrops* Working Group Reports are given in Table 5.3.2. Correlation coefficients significant at the 10% level between the numerical ratio adult:immature females (same year) and official landed weight were found, but disappeared with log transformation of the ratio. However, correlating landings with ratios of adult numbers and immature numbers for the previous year showed for females and for sexes summed, correlations significant (or in one case nearly so) at the 10% level. No approach to 10% significance was found for adult:immature male ratios.

Correlation of biomass with the adult:immature ratios, - in the same year only, - were significant at the 2% level in one case, the 5% level in seventeen cases and the 10% level in thirteen cases out of 48 cases examined including single and double log transformations. The biomass values most closely correlated with Adult:immature numerical ratios were males estimated by Multifan, followed by age-length method-calculated biomass values of male, sexes summed, and female, in descending order. Of the adult:immature ratios, females showed the highest levels of correlation, followed by sexes summed followed by males for original values. With log-transformed values on the other hand, sexes summed tended to have slightly higher correlation coefficients than females. In general, however, neither single nor double log-transformation has very much influence on the results.

Deductions indicated by this array of values include those to the effect that (1) The assumption that immature males are found in equal numbers to immature females is not entirely valid, and (2) notwithstanding this, in most cases after log-transformation, sexes summed ratios give higher values than female ratios, their greater numbers presumably outweighing the effect of the ‘inferior’ male data.

These results are of interest as indicating the relationship between the ratio adult females:immatures (previous year) and landings, and this relationship, derived from summer cruise data has some predictive value as it relates to landings for the whole of the same calendar year.

For female and 'sexes summed', numerical adult:immature ratios correlate in most cases significantly at the 5% level (in one case 2%) with male biomass generated by Multifan, and mostly at 5% or 10% levels with male or sexes summed biomasses generated by the traditional method. In these correlations, female adult:immature numerical ratios correlate noticeably better than male ones and male Multifan generated biomass data perform better than traditionally generated data, which in turn perform noticeably better than traditional female data.

That Multifan-generated spawning biomass values correlate with the research vessel adult to immature numerical ratio data in nearly all cases better than the traditionally generated values, implies that the Multifan method of generating spawning biomass values should be an improvement on the traditional method. However, the fact that male adult:immature ratios correlate less closely with landings and biomass data than do female or sexes summed values, suggests that the assumption that immature males are equal in number to immature females is not valid enough to be a reliable basis for use in calculations of this kind. Immature male numbers could probably best be estimated (albeit somewhat laboriously) by use of MIX or Multifan, even though the summer is a poor time for estimating numbers at age by normal curve separation due to the high incidence of moulting.

Western Irish Sea - Northern Ireland Surveys

A preliminary analysis of *Nephrops* trawl survey data was presented, and is summarised in a working paper for the Study Group (Appendix 4). Spring and autumn surveys have been carried out since 1994, sampling 23 stations on the *Nephrops* ground. The analysis identified spatial variability, but relative temporal stability in mean size. Variability in catch rates at individual stations appeared more related to environmental factors (state of tide) than changes in stock size. The sex ratio in catches (examined in the spring) also appeared stable over the period of the survey.

Overlap was noted between the spatial coverage of the two Irish Sea surveys (Figure 5.3.2). Catch rate data are presented for the overlapping stations in Table 5.3.3, and trends in the catch averaged over each survey are shown in Figure 5.3.3. Although catch rates were generally higher for the NI surveys, particularly in the earlier part of the time period (even allowing for the different units of measurement), fluctuations in catches over time showed generally similar patterns (Figure 5.3.3). It may be possible to use such data series as indices of abundance for tuning, or comparison with analytical assessments.

Trends in the biomass index in FUs 28 and 29 (SW and S Portugal)

Information was presented based on a series of trawl surveys carried out in FUs 28 and 29, between 1981 and 1999. The surveys were performed with 2 different research vessels and with different sampling designs. No calibration of catch rates between vessels was attempted. The biomass indices used for the surveys during 1981-94 are arithmetic means of the catch (kg) per hour of the different stations, while for the 1997-99 surveys a stratified mean was used. This information must therefore be taken as a preliminary indication of the overall trend in the biomass index for comparison with the trend of the biomass estimates obtained from other methods.

Variation in the biomass indices over time are shown for the areas Alentejo (FU28) and Algarve (FU29) (Figure 5.3.4) and for the total area (Figure 5.3.5). Both figures show the same pattern, with high variability in the 80's and a very low level of catch rate in the 90's.

Taking into consideration that part of the variability could be related to seasonal variations, only the surveys carried out in summer period (May-August) were plotted in Figure 5.3.6. The decline in the index since 1985 is clear and is in a good agreement with the VPA results of the *Nephrops* WG in 1999, which also suggests a considerable reduction in stock biomass and very low levels through the 1990's.

Recent developments in Newfoundland Snow Crab (*Chionoecetes opilio*) Assessments

In the early 1990's the snow crab fishery began to expand at a rapid rate with landings reaching 69,000 t. in 1999. In the mid-1990's the Department of Fisheries and Oceans began to use the Campelen shrimp trawl during the annual fall groundfish trawl survey conducted from October to December. It soon became evident that trawl catches contained significant quantities of snow crab of all sizes and that the Campelen trawl represented a potentially valuable assessment tool for snow crab. As a result, in 1995 data collected during the trawl survey began to be used to generate a snow crab biomass index using STRAP. While the survey is designed specifically for assessing groundfish, all strata supporting the commercial snow crab fishery are occupied during the survey and thus far predictions resulting from each year's Fall survey have been borne out by the commercial crab fishery performance the following Spring.

In addition to the offshore trawl survey, 3 trapping/trawling surveys are conducted annually in inshore areas of NAFO Division 3L. These surveys have been ongoing since 1979 and take place at roughly the same time each year. In 1996 a new approach to these surveys, which had been largely dependent on trapping was initiated. Each station, chosen on a random-stratified basis, is sampled by both traps and a modified Yankee #36 shrimp trawl. Evaluation of the efficacy of this trawl is as yet preliminary, however, it is probable that biomass estimates using STRAP will be generated for each area beginning retrospectively with 1998. It is also proposed that a trap/trawl index of commercial abundance be developed for these data.

Other tools used to assess the fishery are mandatory logbooks, dockside catch monitors and biological at-sea observers.

The study group also received information on the prevalence of Bitter Crab Disease (BCD) in snow crab. This condition is caused by the invasion of the host by a parasitic dinoflagellate *Hematodinium* sp. causing a terminal condition similar to that observed in *Nephrops* (see Section) The disease is particularly prevalent in northern areas of Newfoundland, notably NAFO Divisions 2J and 3K. Currently, the severity of the impact of the disease on the snow crab population is unknown.

5.4 Adaptive survey design methodology

In conventional stratified random sampling, the population is divided into strata and a random sample is selected in each stratum, with selections in one stratum being independent of selections in every other. To obtain the best estimate of the population total with a given total sample size, optimal allocation of sample size among the strata involves using larger sample sizes in strata that are larger or more variable.

Often one does not have prior knowledge of the stratum variances. It is therefore natural to consider computing sample variances from an initial part of a stratified survey and to use these estimates to adaptively allocate the remaining samples among the strata. Designs such as these are referred to as adaptive designs. Secondary sample allocation can also be based on sample means, rather than variances, since with many natural populations high means are associated with high variances.

Adaptive approaches were adopted for the underwater TV surveys carried out in the Firth of Forth and Moray Firth in 1999. The overall survey areas for each of the grounds was divided into a grid of sub-units, and two stations were allocated on a random basis within each sub-unit. Where the stations were located on unsuitable ground for *Nephrops* (i.e. patches of hard ground in the middle of the Firth of Forth), a suitable site was randomly selected. The first sweep of the survey was then carried out, with burrow densities estimated "live", and the survey route planned to finish at one end of the survey area.

Burrow densities from the "live" counts on the first sweep were used to allocate stations for the second sweep. Additional stations were allocated to sub-units on the basis of mean density, using an in-house program based on Francis (1984). For each of the strata, the relative gain *G* from adding an additional station was estimated

$$G = A^2 . M^2 \big/ (n(n+1))$$

where *A* is the area of the strata, *M* is the mean burrow density within the strata, and *n* is the number of samples from the strata. M^2 is commonly found to be proportional to variance (Barnes and Bagenal, 1951; Grosslein, 1971), and either could be included in the above equation, but Francis (1984) found M^2 to be more stable than variance when densities were highly skewed. An additional station was added to the strata with highest *G*, the value of *G* was then recalculated on the basis of the additional sample (*n*), and allocation of extra stations continued on the same basis until all additional stations were allocated.

For the surveys carried out in 1999, 40 and 34 stations were surveyed in the initial stage for the Firth of Forth and Moray Firth, respectively, with 15 stations added to both for the secondary stage. In both areas, one of the additional stations was found to be on unsuitable sediment, and excluded from final analysis.

Plots of the burrow densities observed in each stage of the surveys are shown in Figures 5.4.1-5.4.4. It can be seen that in both stocks the additional stations were located in the areas of highest density from the initial surveys. A summary of the sum of strata variances for the initial and full surveys for each stock are shown in Table 5.4.1.

The variance was reduced for the Moray Firth, but the additional stations had little effect on the Firth of Forth survey variance. For simplicity, the algorithm used to allocate additional stations on the basis of relative gain assumed uniform strata area, and did not take any account of different sediment types within strata. This may well have led to allocation of stations to incorrect strata to reduce the overall variance, particularly for the Firth of Forth, where the sediment is spatially heterogeneous. Since *Nephrops* is limited in its distribution to appropriate sediment types (which often occur in irregular patches), and density varies with sediment type, it may be more appropriate to use strata based on sediment information. This could be done either using a single patch as a stratum, or splitting larger patches into a number of strata, and take the exact area of the strata into account in calculating the relative gain.

6 EXAMINATION OF THE LIKELY FORM OF THE STOCK RECRUITMENT RELATIONSHIP IN *NEPHROPS*

6.1 Earlier approaches taken by the Study Group

In 1994, the Study Group examined biological information which could provide some guidance on the most likely shape of the SRR in *Nephrops*. At the time, the data series of female spawning stock biomass (SSB) and recruitment (R) estimates (as provided by the VPA) were generally too short to allow an in-depth empirical approach, and hence the issue was tackled in a largely assumptive and speculative way (ICES, 1994).

Elements taken into account in the discussion included:

- The fact that *Nephrops* is associated with particular sediments, which physically constrains the expansion of *Nephrops* populations to areas where these sediments prevail.

- The likely dependence of newly settled pre-recruits on the presence of burrows inhabited by larger *Nephrops* in the first months/years of their life.

- The pronounced territorial behaviour of *Nephrops* – especially of the larger animals – which constrains the number of inhabitants per unit of seabed surface.

- The possible density-dependence of predation and cannibalism, which may provoke relatively higher levels of predation mortality (particularly amongst the smaller size classes) at higher stock densities of *Nephrops*.

- The possibility that density-dependent slower growth might increase mortality of the pre-recruits, by maintaining *Nephrops* at smaller sizes which may be more vulnerable to predation.

Except for the second, all these elements suggest the existence of compensatory mechanisms. Therefore, the 1994 Study Group concluded that “one might expect the SRR to be asymptotic, showing compensation at higher biomass levels” (ICES, 1994). Again however, it should be stressed that the approach taken by the Study Group was largely assumptive, and that, at the time, the available evidence was insufficient to eliminate any of the Stock-Recruitment curves (SR-curves) showing even stronger levels of compensation than the asymptotic one (such as curves C and D in Figure 6.1.1).

At its 1994 meeting, the Study Group also examined the effect of different SR-curves on the outcome of the Y/R predictions by Length Cohort Analysis (LCA) – till then the method used most widely to assess the state of exploitation of *Nephrops* stocks. The conclusion was that the choice of the SRR does make a critical difference. In the example given (Irish Sea West – ICES, 1994, Figure 3.6.5.), an apparently optimally exploited stock (under the assumption of constant recruitment, which is part of the *status quo* conditions of LCA) turned into either an under-exploited or a heavily over-exploited stock, depending on whether a SRR was used with or without compensation at higher biomass levels.

Since 1994, new information has been collected on the recruitment processes in *Nephrops*, most importantly on the processes governing the dispersion of larvae. Studies in the Irish Sea (Brown et al., 1995) have shown that tidal gyres confine the dispersion of the *Nephrops* larvae to an area roughly corresponding to that of the parent stock, and that settlement primarily occurs in the area inhabited by the parent stock. Although these processes have not (or not yet) been investigated in other areas, from a management point of view it seems prudent to assume that they generally apply to all *Nephrops* populations, and not to count upon an influx of larvae from neighbouring stocks for replenishing stocks that suffer from over-exploitation.

6.2 Empirical analysis of SSB and R data

At its present meeting, the Study Group examined several data sets, in an attempt to find numerical and corroborative evidence for any of the possible SRRs. The data sets used were derived from the existing time series of fishery dependent data (particularly CPUEs of selected size groups) and from the VPAs performed at last year's Working Group meeting (ICES, 1999). From the very beginning however, it was agreed to restrict the analyses to those Functional Units for which actual discard data (i.e. length frequency distributions (LFDs) obtained through regular sampling of the discards) were available. For several stocks (e.g. Botney Gut - Silver Pit, Celtic Sea, Bay of Biscay) the discard LFDs are estimated by extrapolating the discard pattern in one or two particular years to the next and/or previous years in the time series. This technique bears the risk of under-representing the natural variability in the numbers-at-length of the smallest size classes, and hence of giving unrealistically stable estimates of annual recruitment.

The first approach taken was that of plotting the XSA-estimates of R against the XSA-estimates of male (for Iceland) or female SSB (for the other stocks), with time lags of 6 years for the Icelandic stock (because of their long egg-bearing stage and their slow growth rate), and of 2 and 3 years for the others. Except for Iceland and – to a lesser extent – for the Clyde and for SW and S Portugal (where the plots showed a positive relationship between R and female SSB), this approach failed to give conclusive evidence on the shape of the SRR (Figure 6.2.2). There are two main reasons for this. First, the XSA-estimates of stock biomass (either total or spawning) and R for females are usually much less reliable than those for males, the consequence being that possible patterns in the data are likely to be clouded by the XSA-related uncertainty in the plotted data. Second, for most stocks the range of estimated female SSB-values is very narrow (probably narrower than in reality, owing to mismatch between year-classes and nominal age-classes from sliced length distributions), and values at the lower end of the scale are usually missing. This results in the R-values clustering over a narrow range of values on the SSB-axis, making it difficult to distinguish particular patterns in the data.

In an attempt to refine the indices of R and female SSB, and to skirt the problem of XSA-related computational uncertainty, plots were then made of the CPUEs of males and females at 'nominal age' 2 (which can be seen as an index of R) against the CPUEs of females > 35 mm CL in the period of maximum emergence from the burrows (which can be seen as an index of female SSB). The time lag used was 2 years for the fastest growing stocks (Clyde, SW and S Portugal) and 3 years for the others (Firth of Forth, Farn Deeps, Moray Firth, and Irish Sea West) (Figure 6.2.1). For some stocks (Clyde, Irish Sea West, and SW and S Portugal) either the range of SSB-values was too narrow or the degree of scattering in the data too high to produce conclusive plots, but for three stocks (Firth of Forth, Farn Deeps and Moray Firth) the plots showed a clear negative relationship between R and female SSB (Figure 6.2.3). The shape of the plots suggests the existence of compensatory mechanisms at higher female stock biomasses, and a SR-curve similar to type D in Figure 6.1.1

The idea of density-dependence in the SRR was further explored by plotting the CPUEs of males and females at 'nominal age' 2 against the CPUEs of males > 35 mm CL (averaged over the duration of the pre-recruit phase). Since males – and particularly adult males – are even more territorial, belligerent and cannibalistic than females (Mcquaid, pers. comm.), it could be assumed that the adult male component of the population too might have a compensatory impact on recruitment, and this for the whole duration of the pre-recruit phase (hence the averaging of the male CPUE-figures). None of these plots, however, showed evidence of such a density-dependent effect (Figure 6.2.4).

The difference between the male and the female component in the compensatory effects of stock densities is somewhat puzzling. Unless the compensatory mechanisms are strictly connected to the (female) reproduction process itself, there is no *a priori* reason why male and female densities would affect recruitment in a different way or, even stronger, why adult female stock densities would and male densities would not affect recruitment. Yet, this seems to be the case, at least in a number of stocks. Several hypotheses could be advanced to explain these differences, but they all need further investigation before anything definite can be said on the issue.

As a final step in the analyses performed by the Study Group, the curves in Figure 6.2.4. were re-scaled (to total female SSB in the X-axis and total number of recruits in the Y-axis), and the corresponding type D (Shepherd) SR-curves were calculated (Figure 6.2.5). In this procedure, the a-values (slope at the origin) were chosen such that all data-points were to the right of the line R = a * SSB.

With a SRR of the type found for the Firth of Forth or the Farn Deeps, one would expect stock biomass and recruitment to show cyclic fluctuations. As SSB increases, R would decrease, which, in time, would result in a decline in SSB. In turn, this would be followed by R going up again, which, in time, would result in an increase in SSB. The time series data presented in Section 3. show clear evidence of such multi-annual cyclic fluctuations in stock biomass (as reflected by the fluctuations in CPUE and/or LPUE). It is tempting to see this as corroborative evidence for the SRR that are presented here, but it should be borne in mind that the two data-sets (i.e. the data-set of CPUE or LPUE values used in the time series analysis, and the data-set of CPUE values for selected size groups used in the SRR analysis) are not independent.

6.3 Conclusions

The new approach taken by the Study Group yielded promising results, but nevertheless many questions remain unanswered.

For some stocks (Firth of Forth, Farn Deeps and Moray Firth) the data suggest a density-dependent SRR, but for others (Iceland) the SRR appears to be strictly linear, without even the slightest hint of compensatory effects at high biomass levels. And a third group (Irish Sea West, Clyde) shows no SRR at all. At present, however, the reasons for these differences are unclear.

For the stocks where the data do show evidence of compensatory effects, it looks as if the male and female population components play a completely different part in generating these effects. Here too, the possible underlying biological mechanisms are unclear, and further in-depth investigations are required (including studies on the density-dependence of the female reproductive potential, the differences in behaviour between males and females, and the importance of cannibalism) before definite conclusions can be drawn.

7 LOGISTICAL PLANS FOR COOPERATIVE WORK ON *HEMATODINIUM*

For some time there has been concern about the distribution and significance of *Hematodinium* infection in *Nephrops* populations. Some populations, such as that in the Clyde have received some attention and are presently monitored. For others there is limited information while for some, no data exist at all. The ICES Study Group has, for some time, monitored progress on the understanding of and diagnostic methods for this disease and has suggested that a more widespread study is desirable. The term of reference (e) invited the Study Group to develop logistical plans for a co-ordinated piece of work along these lines. To assist in the discussion at this meeting, the Group was joined by Grant Stentiford of Glasgow University – a student whose work concentrates on some of the effects the disease and who was able to bring a wealth of background knowledge.

7.1 Background

Stocks of *Nephrops* from the coastal waters of Scotland and Sweden are known to become seasonally infected by a parasitic dinoflagellate of the genus *Hematodinium* (Field & Appleton, 1995). Similar infections have also been described in a number of crab species around the world, but this is the first time that the infection has been reported in a lobster. The parasite has been isolated and cultured for a number of years and a tentative life-cycle has been established *in vitro* (Appleton & Vickerman, 1998). Parasitic infection in *Nephrops* leads to severe changes in blood physiology (Taylor et al., 1996) and biochemistry (Stentiford et al., 1999), histological and biochemical changes in body tissues and organs (Field & Appleton, 1995, Stentiford et al., 2000a) and a drastically reduced swimming performance (Stentiford et al, 2000b). Changes in swimming performance and possible changes in the burrow emergence behaviour (Stentiford, unpublished) may lead to an altered catchability of infected lobsters (Stentiford et al., 2000b).

7.2 Disease diagnosis

Field methods for the diagnosis of patent infection (parasites present in the blood) involve a visual assessment of external changes in the body colour (hyperpigmentation, loss of shell translucency) and the presence of agglutinated parasite and hemocyte material within the pleopods (see Field & Appleton, 1995). The pleopod method has been used systematically for the past decade in the Scottish west coast *Nephrops* fishery (Field et al., 1998) and monthly data has identified a seasonal pattern in infection prevalence which peaks in March or April of each year (Stentiford, unpublished). Similar assessment of infection in Swedish *Nephrops* caught from the Skagerrak has also identified a seasonal increase in disease prevalence, but here, the peak occurs during late summer/early autumn (Ulmestrand, unpublished).

A recent collaboration between laboratories in Sweden and Scotland attempted to compare the relative merits of the body colour and pleopod diagnostic methods for objective, reproducible estimation of *Hematodinium* infection in *Nephrops*. It was found that the body colour method, while being rapid, portable and non-invasive, failed to consistently identify lobsters with light infections and identified approximately 50% of those diagnosed as infected by the pleopod method. It was also found, that using the body colour method, the diagnostic accuracy did not improve with the experience of the scorer. The pleopod method is less subjective and diagnostic ability did improve with the experience of the scorer. However, it was found that the naïve scorer tended to overestimate the prevalence of infection, mainly by diagnosing animals at Stage 1 (lightly infected) when the experienced scorer diagnosed as Stage 0 (uninfected). This over-scoring was mainly attributed to degradation of the sample during the 4-5h following capture, when bacterial proliferation tends to occur in the blood, making assessment of *Hematodinium* infection more difficult. A fresh sample is therefore required if this method is to be employed accurately.

The results from the Swedish-Scottish collaboration have shown that, while the pleopod method is clearly superior in terms of between-scorer and overall diagnostic accuracy, this method is also open to a certain degree of subjectivity, with a possibility of results differing between scorers and with the experience of individual scorers over time.

7.3 Antibody-based diagnostics

Field & Appleton (1996) described the production of a polyclonal antibody raised against a lysate of cultured *Nephrops* isolate, *Hematodinium* trophonts, and the application of an indirect fluorescent antibody (IFAT) test to identify parasite cells in blood and tissue smears from *Nephrops* of unknown infection status. The method proved highly accurate, but was time consuming and not applicable to mass-diagnosis at field level. More recently, this technology has been advanced by the establishment of a western blotting assay for detection of parasite proteins in blood and tissue (Stentiford, unpublished). The method has been used to show that the levels of infection predicted from the pleopod assessment method considerably underestimate the true levels of infection in the field. This has been attributed to the increased sensitivity of the method, which allows the user to detect patent, sub-patent and latent (tissue based) infections. Further development of the technology into a rapid, multi-sampling technique is currently being pursued at the University of Glasgow, Scotland, UK.

7.4 Pan-European study – discussions and recommendations

The Study Group has at several occasions discussed the desirability of a pan-European project to describe importance of mortality caused by *Hematodinium* infection, and its potential impact on management measures.

The possibility of a co-operative work was discussed. It was concluded that, except for some minor areas, the knowledge is very limited about the presence and distribution of *Hematodinium* in the various *Nephrops* stocks. In order to compare distributions and prevalence between areas it is strongly desirable to standardise the diagnosing method

A pan-European study of *Hematodinium* infection in *Nephrops* will require an objective, reproducible diagnostic method which allows for the reliable comparison of data from different regions. The body colour method is not recommended due to its between-scorer subjectivity and its inability to diagnose early infections. The pleopod method is quick, relatively reliable and reproducible and can be carried out using minimal equipment (light microscope, basic dissection tools). The pleopod method can be used to study changes in seasonal infection prevalence, but because it scores animals displaying only patent (visible in blood) infection, prevalence scores may be biased by the changes in behaviour which may accompany such infections. Even though molecular diagnostic methods may require a considerably increased financial commitment, the development of an antibody-antigen based technique will provide accurate data for animals showing patent and latent infections. Data may also be used to identify principle infection periods as well as predicting the level of patent infection that will be seen in the following season. The pursuance of such methods is strongly recommended. Data will need to be collected from monthly samples for at least a 12-month period to allow any seasonal pattern to be observed.

One important question is whether changes in behaviour of infected *Nephrops* affect the catchability. Estimated prevalence may be either over- or underestimated depending on its activity and following availability to fishing gears. (Preliminary results indicate that infected *Nephrops* are more frequently emerged from their burrows compared to healthy ones, indicating a possible overestimation in prevalence.)

The behaviour of fishers in relation to areas with high prevalence was discussed. Commercial fishers may avoid local areas with high prevalence and trends in e.g. CPUE may be difficult to use as indicators of effects caused by *Hematodinium*.

Another important question is what appropriate action to take if infection rate is increasing and have significant impact on the population. Closing the fishery in affected areas and adjusting the TAC according to the increased mortality might need to be considered.

It was suggested that a future study might go in two steps. Firstly, to describe how important an outbreak of *Hematodinium* infection may be on a *Nephrops* population, and secondly if it has a significant impact, describe prevalence and distributions in the different Functional Units. The two steps (documentation of impact on population and a monitoring program) might also go parallel.

In order to document spatial and temporal variations in distribution, transfer of *Hematodinium* between species and possibly explain seasonal differences between areas etc., a monthly monitoring should last for at least 12 months.

As most members of the study group were of the opinion that additional funding would be required in order to include *Hematodinium* monitoring in their regular *Nephrops* sampling program, it was suggested that an application for funding be put to the EU. It was decided to approach Glasgow University with a view to their co-ordinating such an EU funded project. Preliminary contact with Dr Douglas Neil of Glasgow University indicated that he was willing to consider such an undertaking.

8 NEW DISCARD DATA AND INFORMATION ON THE FATE OF DISCARDED *NEPHROPS* AND BYCATCH

8.1 Fish discards from *Nephrops* vessels in the Farn Deeps

Discards of cod, haddock and whiting have been sampled on vessels targeting *Nephrops* in the Farn Deeps since 1994 (Table 8.1.1 Figure 8.1.1). Whiting make up the largest portion of the fish by-catch. Proportions discarded have declined from 95% by weight in 1994 to 65% in 1999. Catches of haddock are small and around half the animals are discarded. Cod are a more important by-catch species. Discards vary from 8% to 57% of the catch of this species.

8.2 *Nephrops* discards in Spanish trawl fisheries

See Working Document (Pérez & Fariña), Appendix 5. The main conclusions from 1994, 1997 and 1999 data are that the numbers and biomass of *Nephrops* discards are low in proportion to the catch, and that there is no clear size-related pattern to *Nephrops* discards.

8.3 Swedish discard and by-catch projects in the *Nephrops* trawl fishery

Kattegat (part of SD IIIa).

The Kattegat area is included in an EU funded discard project, ‘International Baltic Sea Sampling Project (IBSSP II)’, with objectives to provide basis for calculation of discard rates and generate biological information as input for stock assessment. All relevant measures for both discarded and retained fish/shellfish are collected. The project started in 1995 and is funded until July 2001. Details are given in Anon (2000).

Skagerrak (part of SD IIIa).

The Skagerrak area is included in an EU funded discard project, ‘Monitoring discarding and retention on fishing vessels towing demersal gears in the North Sea and Skagerrak’. The objective in this project is to monitor numbers-at-age of main commercial species discarded and retained by demersal gear fisheries, and when possible estimate non-commercial species discarded. The project started in 1998 and is funded until March 2001. Details are given in Anon (2000).

8.4 The composition and fate of discards from *Nephrops* trawling

This work comprises two studies. The first is EU-funded research carried out in Scottish (Clyde) and Italian (Central Adriatic) waters from 1997-1999 (Wieczorek et al., 1999). The Scottish component of the work gave particular attention to the fate of the *Nephrops* component of the discarded catch. The main conclusions from Wieczorek et al. (1999) as they relate to the Clyde Sea area are given as a Working Paper, Appendix 6.

The second study is Clyde-based and comprises the on-going Ph.D. studies of M. Bergmann (supervised by P.G. Moore). This concentrates on the fate of the non-*Nephrops* component of the invertebrate discard from *Nephrops* trawling in the Clyde Sea area, Scotland. The main conclusions of M. Bergmann’s studies are given in the following summary.

Catch composition

Monthly trips on commercial fishing boats revealed that only a mean of 18% of the total catch is landed and 82% is discarded from Clyde Sea *Nephrops* trawlers. Invertebrates accounted for up to 90% of the discards, decapod crustaceans (*Liocarcinus depurator* and *Munida rugosa*) and echinoderms (*Asterias rubens* and *Ophiura ophiura*) being the most important groups discarded. More than 90 invertebrate species were recorded.

Damage

The degree of damage will inevitably affect the survival of an individual. In order to assess the damage caused by the trawling and handling process, invertebrate discards were collected from commercial boats and *RV Aora* every month over one year. On each trawl the visible damage (*i.e*. missing appendages, carapace damage, broken and missing arms in starfish and brittlestars) to the most commonly caught invertebrates was assessed. The study showed that some invertebrates were more prone to damage than other groups: almost 100% of the brittlestars *O. ophiura* sustained damage and 40-50% of the crustaceans incurred some degree of damage. In contrast, damage was low in more flexible invertebrates such as *A. rubens* (ca 30%) or hard-shelled animals such as hermit crabs *Pagurus bernhardus* (15%) and queen scallops *Aequipecten opercularis* (2%).

The probability of damage as a function of various likely predictor variables was modelled fitting general linear models. Body size, catch size and vessel type were the most important predictor variables, *i.e.* being caught by a twin rigger increased the probability of damage to *P. bernhardus, M. rugosa, P. prideaux* and *Buccinum undatum*.

Survival

Longer-term survival experiments showed that the mortality of trawled or experimentally damaged animals increased with the severity of damage, as might be expected, but that even apparently healthy animals sustained significant mortality. Post-trawling mortality was 100% for *O. ophiura* two weeks after trawling; in contrast, almost all hermit crabs and whelks survived trawling and exposure to air. Experimental removal of two appendages and induced autotomy increased post-trawling mortality of swimming crabs significantly (78% and 27% respectively) compared with creel-caught controls (8%). Post-trawling mortality was lower in squat lobsters although those with forcefully removed appendages had a significant lower median survival time than controls. *A. rubens*, traditionally thought to survive damage well and with the capacity for arm regeneration, were nevertheless vulnerable and those with multiple arm loss showed > 90% mortality three weeks after trawling and damage. All previous studies on the survival of discarded non-target invertebrates covered a monitoring period of only 3-5 d and therefore have underestimated discard mortality considerably. The mortality figures for most species investigated here, doubled over the last two weeks of the experiment, implying a much higher overall benthos mortality than previously suggested.

8.5 Summary of sources of discard data

The Study Group decided that it would be helpful if summaries were provided of the sources of discard data used by the Working Group. A pro forma template was drawn up and members were asked to complete these for stocks on which they gathered discard data. Details of the type of project, (whether long term or short contract), nature of data gathered etc. were provided. Information was received for a number of stocks and is shown in Tables 8.5.1- 8.5.9. A cursory examination of these tables reveals that some discards are collected routinely while others are only collected during special studies. Given the effect that inclusion of discards has on assessments it is suggested that efforts should be made to collect discard data routinely from rather more stocks. Further details of sampling levels and numbers of *Nephrops* measured are included in the Working Group reports prepared biennially.

9 NEW DATA ON THE BIOLOGY OF *NEPHROPS* AND ON PARAMETER VALUES

9.1 New growth parameters for *Nephrops* in Skagerrak, estimated from tagging experiment and length frequency data

New estimates of von Bertalanffys growth parameters for *Nephrops norvegicus* in Skagerrak along the Swedish West Coast were presented. They have been estimated using both analysis of length frequency distributions from commercial catches and tag-recapture data ('Growth parameters for Norway lobster, *Nephrops norvegicus* (Linneaus 1758), in Skagerrak, estimated from tagging experiment and length frequency data' Ulmestrand & Eggert, in prep.). The asymptotic lengths (L_∞) for males and females are estimated from size distribution using a modified Powell-Wetherall plot. The tagging experiment was conducted with Floy streamer tags and the data was analysed in a “forced” Gulland-Holt plot for estimation of the growth coefficient K for males. L_∞ and K are also estimated using Munro’s method. The estimates of L_∞ differ slightly from what is currently used in the ICES assessment for this area, while the estimated value of K for males is notably lower.

Even minor changes in values of either L_∞ or K is shown to lead to drastic changes in the biological reference point (Fmax) applying LCA. Depending on which growth parameters are used, the current or the new ones, management advice could either advocate increased or reduced fishing effort.

9.2 Preliminary analyses of growth data for ovigerous females and fecundity estimates for Irish Sea stocks of *Nephrops*

A working paper, ‘Reproduction, development and growth in Irish Sea *Nephrops*’, was presented to the SG, see Appendix 7.

Potential and realised fecundity were estimated for Irish Sea stocks in 1999 using techniques similar to those used in an EU biomass project in 1997 (see Appendix 7). Potential fecundity was estimated by counting the number of eggs extruded by females while in captivity at the start of the incubation period (August) while realised fecundity was calculated by counting the number of eggs on trawled berried females just prior to hatch (April). These values were then converted to specific fecundity eggs g^{-1}. Overall specific potential and realised fecundity estimates (107.7 eggs g^{-1} and 46.5 eggs g^{-1} respectively) were similar to those from the earlier EU biomass project (104.3 eggs g^{-1} and 55.1 eggs g^{-1} respectively) which used similar techniques on the same stocks.

Growth data are being gathered for a range of different individuals, males, ovigerous females and non-ovigerous females. A preliminary analysis of data for ovigerous females was carried out, using “forced” Gulland-Holt plot with a fixed L_∞ of 56 (taken from the last *Nephrops* working group report, ICES, 1999). The new K value estimated, (0.0811) was approximately 20% lower than the currently used value (0.100) in the stock assessment for this area.

9.3 Geographical patterns in the life histories of the Norway lobster

New information on patterns in the geographical variation of biological characteristics of *Nephrops* was presented to the SG, see Appendix 8 ‘Geographical patterns in the life history of the Norway lobster (*Nephrops norvegicus*): environmental and density-dependent effects’.

Nephrops constitutes a useful species for analysis of the geographical variability in the life history tactics due to its wide geographical distribution, sedentary post-larval phases and the high volume of information available because of its importance to commercial fisheries. Biological parameters are used as descriptors of overall trends or patterns in life history of *Nephrops* along its distribution range. In the NE Atlantic *Nephrops* stocks, female size at onset of maturity decrease towards the North, but age at onset of maturity remains relatively constant in the whole distribution range. Southern stocks show a lower fecundity but its breeding cycle is annual, whereas it is biennial in northern stocks. The lifetime reproductive output (LRO) decreases towards northern latitudes. LPUE, used as a density index, increase towards the North in *Nephrops* populations located to the north of Bay of Biscay at is at low level in southern ones. LRO and densities are inversely related, with LRO showing low levels in stocks with high densities. Taking into account the previous information, two areas could be characterised in the NE Atlantic *Nephrops* populations: northern areas with relatively high densities and low LRO, and southern ones with low densities and high LRO values.

Two explanations of the latitudinal pattern of *Nephrops* populations are proposed: i) density-dependent effects (density, growth, LRO), operating mainly in northern stocks and ii) environmental factors (sediment, larval retention) with major relevance in the southern.

9.4 Changes in size of females and males with increasing depths and latitude.

Mean size (CL) of male and female *Nephrops* from samples taken at SE Iceland during pristine years of the fishery in 1963 was presented to the SG and compared to similar more recent data from 1991. In 1963 mean size of both sexes showed a decreasing size with depth. In 1991 this still holds for trends in female size with depth but males, however, show a similar mean size over the whole depth range as a result of higher fishing mortality on the male component of the stock (Eiríksson 1999).

A comparison of maximum size of males vs. females over the whole geographical range of *Nephrops* was presented to the SG (Eiríksson, unpublished data). Iceland and Faroe *Nephrops* stocks show a much lower female/male CL ratio than

Scottish and Irish stocks and an even greater difference when compared to the most southern stocks in the Mediterranean Sea. As an example the size ratio of females/males averages around 0,70 at Iceland, 0,77 at Scotland and Ireland and up to 0,85 in the Adriatic Sea. Thus, the trend shows an increasing size of females vs. males with decreasing latitudes. The smaller relative size of females in Iceland and the Faroes can be described by the inhibition of female growth by the biennial breeding cycle (Eiríksson, 1993). Therefore, the relative size of females to males seems to be highly correlated with the decreasing length of the incubation period from north to south over the geographical range of *Nephrops* distribution.

9.5 Overview and update of the biological and assessment input parameters.

The SG decided to present an overview of the most recent estimates of the various biological parameters and other relevant biological information. This information is shown in Table 9.5.1, which essentially is a modified version of Table 4.1 of the 1999 *Nephrops* WG Report. Note that for many stocks basic data are still missing.

10 SUMMARY OF RECOMMENDATIONS

The following list of recommendations were drawn from the suggestions made throughout the report. There is potential for some of these recommendations to be implemented at the next Working Group, while others will require significant additional research to be undertaken in individual institutions (or as part of coordinated research projects) prior to any future Study Group meeting.

Comparison of assessment and fishery data trends – use of time series analysis

The group recommends that the Dynamic factor Analysis approach is utilised to investigate in more detail the observed trends in CPUE and LPUE. Preliminary results suggest some similarities in trend across quite wide geographic areas (particularly if time lags are incorporated)

The above analysis could be further enhanced by provision of environmental or other potentially explanatory variables and the Group considers that incorporation of such data would be very worthwhile.

***Nephrops* specific assessment methodologies**

Amongst a number of potentially useful methods requiring fewer data than standard assessment methods such as VPA, the use of Leslie depletion method based approaches offer the most promise. The Group considered that for a number of Functional Units with limited data, these methods should be investigated well in advance of the next WG meeting with a view to implementing the approach at the meeting.

Stratified methods incorporating spatial data are also worth pursuing, particularly since they may help to establish the extent to which standard methods (which rely on dynamic pool assumptions) may be giving misleading results. These methods generally require considerably more data than is normally available and should not be prioritised for stocks where fishery data are in short supply.

Fishery Independent Methods

The Study Group endorses the findings of the Lowestoft Workshop on Underwater Television methods and suggests that recommendations coming from that meeting are adopted.

In particular there is a need to fully examine the implications of edge effects for the estimation of biomass using this TV method.

The Group considers that fishery independent assessments for stocks is a key requirement and recommends that longer term commitments to such surveys for *Nephrops* should be made.

Stock recruitment relationship

The findings on stock recruitment relationships for *Nephrops* remain inconclusive but the Group feels that contradictions in some stock recruitment plot elements should prompt Working Group members to re-examine some of the raw data for these stocks.

For a number of stocks, working up existing data in more detail could provide tools for examining stock/recruitment relationships.

Logistical plans for cooperative work on *Hematodinium*

The Group would like to encourage existing programmes of underpinning research and monitoring to be continued. Particularly those elements which help to evaluate the effect of this disease on population dynamics of *Nephrops* stocks.

A pan-European project to look at the distribution of this parasitic organism is proposed although it is recognised that significant funding for this may have to come from outside normal budgets of individual institutes. In the first instance, a proposal will be put together for EU funding at the first opportunity provided by funding programmes. Glasgow University agreed in principle to act as co-ordinators of this project.

In addition to the need to look at distribution of the organism it was felt that a wider consideration of the ecological aspects would be worthwhile, in particular the vectors of disease transmission and the role which might be played by discarded material.

Discard data and fate of discarded material

The Study Group reiterates the Working Group view that additional collection of discard data is required, particularly since this helps to contribute to a much more reliable idea of recruitment.

There is a need to examine the implications of discarding on *Nephrops* population energetics.

The Group draws attention to the high levels of bycatch in some *Nephrops* fisheries and to the need to investigate the implications of such high levels on other elements of the ecosystem. This work cannot be undertaken by *Nephrops* biologists in isolation and will require co-operative studies involving other groups of workers.

Biological Parameters

In common with the recommendations of numerous previous meetings of this Study Group, the members again emphasise the need for biological parameter data to be gathered for *Nephrops*.

Recommendation on a new chair for the ICES *Nephrops* Study Group

Following the announcement by the present Chair of the Study Group, Nick Bailey, of his decision to stand down after 8 years of carrying out this role, the Group considered who might take on the chairmanship in the future. Time was also given to discussing the likely future need for the Group to meet on a basis as regular as the current biennial arrangement. It was decided to defer making a recommendation on a new chair for the Study Group until after the ICES *Nephrops* Working Group meeting in 2001. At that time it will be possible to judge the need for another Study Group based on whether recommendations contained in this report have been successfully implemented by the Working Group and on whether there are new questions to be addressed.

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Table 3.1.1 AIC for dynamic factor models applied on Icelandic CPUE series containing 1, 2 and 3 common trends.

Number of common trends	AIC
1	747.28
2	***725.82***
3	731.11

Table 3.1.2 Maximum cross-correlation between Iceland CPUE time series significantly different from 0

Stocks	Correlation	Time lag (years)
373 & 366	0.65	-1
373 & 365	0.57	-1
321 & 367	0.46	2
321 & 365	0.39	1
319 & 365	0.43	1

Table 3.1.3 AIC for dynamic factor models containing 1, 2 and 3 common trends.

Number of common trends	AIC
1	594.03
2	587.95
3	593.68

Table 3.1.4 Maximum cross-correlation (upper diagonal elements) and time lags (lower diagonal elements) between common trends of Iceland, Scotland and Europe. The numbers 1 to 6 refer to the first common trend of Iceland, the second common trend of Iceland, the first common trend of Scotland, the second common trend of Scotland, the first common trend of Europe and the second common trend of Europe respectively.

	1	2	3	4	5	6
1	-	0.50	0.49	-0.08	**0.64**	**0.71**
2	0	-	0.29	-0.03	0.28	0.47
3	0	0	-	-0.55	**0.72**	0.46
4	0	0	-2	-	0.34	0.53
5	3	0	1	-1	-	0.32
6	2	-1	3	1	0	-

Table 3.2.1 Overall trends in exploitation indices and outputs of analytical assessments for a range of Functional Units

FU	T.Biom	Fbar	CPUE	CPUE<35	CPUE>35	Recruits	TV surveys	Mean CL
Farn Deeps 6	→	↘	→			→	↘	→
Firth of Forth 8	→	→		↗	→	↗	↘	↘
Moray Firth 9	↘	↘		→	→	→	↘↗	→
North Minch 11	↘	↗		↘	↗	↘	↘↗	→
Clyde 13	↗	↗		↗	→	↗	↗	→
Irish Sea West 15	↗	→	↗			→		↗
Celtic Sea 21-22	→	↗	↘			↘		↗
Biscay 23-24	↘	↗				↗		→
S-SW Portugal 28	→	→				↘		

Table 5.2.1 Analysis of Variance table for effect of width of view and burrow density on proportional error of the density estimates from the first simulation.

Term	d.f.	Sum of squares	Mean square	***F***	Pr(*F*)
width	2	378.32	189.16	11454.77	<0.0001
density	1	0.0832	0.0832	5.04	<0.05
residual	44996	743.05	0.0165		

Table 5.2.2. Analysis of Variance table for effect of burrow diameter, density and width of view on proportional error of the density estimates from the second simulation.

	d.f.	Sum of squares	Mean square	***F***	Pr(*F*)
diameter	2	2190.302	1095.151	38215.37	<0.0001
density	3	0.242	0.081	2.82	<0.05
width	2	498.384	249.192	8695.57	<0.0001
diameter:width	4	28.459	7.115	248.27	<0.0001
residuals	35988	1031.32	0.029		

Table 5.2.3. Summary of burrow counts wholly within (A) and only partly within (B) the field of view. See text for further explanation.

Site	A	B	A+B	A+B/2	**% difference**
23	130	134	264	197	25
24	141	207	348	244.5	30
25	30	62	92	61	34
49	0	8	8	4	50
29	72	96	168	120	29
32	99	97	196	147.5	25
36	98	107	205	151.5	26
43	78	96	174	126	28
21	122	147	269	195.5	27
22	169	185	354	261.5	26
34	115	131	246	180.5	27
15	118	133	251	184.5	26
14	99	107	206	152.5	26
9	71	79	150	110.5	26
46	70	71	141	105.5	25
48	75	86	161	118	27
13	105	144	249	177	29
4	90	148	238	164	31
44	41	62	103	72	30
45	47	98	145	96	34
47	42	76	118	80	32

Table 5.3.1 Numbers of males and females by sexual category in research vessel hauls on standard transect, with landings and biomass data, 1987 -1999

Year	Males		Females, by ovarian colour/external eggs						Both Sexes				Official	Spawning biomass (VPA)			
	All	(Adult)*	Pale*	Med-ium	Dark	Ext. Eggs	All Adult	All	All Adult	All	Total Wt	Mean Wt	Land-ings	Males Multifan	Males Traditional VPA	Females Traditional VPA	All Traditional VPA
1987	12,305	5,462	6,843	99	10,421	37	10,557	17,400	16,019	29,705	247.2	8.32	6466	14,557	15024	6553	21577
1988	4,421	1,182	3,239	1,387	3,006	0	4,393	7,632	5,575	12,053	60.0	4.98	4711	13,001	13689	6202	19891
1989	10,036	4,223	5,813	1,299	10,276	3	11,578	17,391	15,801	27,427	278.0	10.13	4545	12,803	13976	5726	19702
1990	2,669	1,783	886	886	2,177	1	3,064	3,950	4,847	6,619	83.2	12.568	4810	13,143	13424	5291	18715
1991	13,477	5,799	7,678	1,432	11,592	4	13,028	20,706	18,827	34,183	263.9	7.72	5566	13,152	14337	5756	20093
1992	16,701	8,457	8,245	468	18,113	19	18,600	26,845	27,056	43,546	401.3	9.22	4287	12,702	12788	6239	19027
1993	6,599	1,249	5,350	883	6,304	1	7,188	12,538	8,436	19,137	182.8	9.55	4591	13,820	15052	5837	20889
1994	3,032	1,625	1,406	1,834	640	13	2,487	3,893	4,112	6,925	84.6	12.22	4435	15,055	16142	5537	21679
1995	2,766	2,354	411	134	1,358	0	1,492	1,903	3,846	4,669	74.1	15.88	5431	16,582	18059	6540	24599
1996	2,787	1,852	935	448	1,568	0	2,016	2,951	3,868	5,738	76.8	13.38	4832	17,669	18552	7084	25636
1997	2,931	1,769	1,162	42	5,165	0	5,207	6,369	6,976	9,300	129.7	13.95	6844	18,816	19348	7512	26860
1998	7,460	5,125	2,335	512	8,582	2	9,096	11,431	14,221	18,891	213.5	11.30	6231	17,838	18293	6375	24668
1999	4,449	3,858	591	43	5,416	3	5,462	6,053	9,320	10,502	132.0	12.571					
Total	89,633	44,738	44,894	9,467	84,617	83	94,167	139,062	138,906	228,695	2,227	142	62,749	179,138	188,684	74,652	263,336
Mean	6,895	3,441	3,453	728	6,509	6	7,244	10,697	10,685	17,592	171	11	4,827	13,780	14,514	5,742	20,257

*Adult male numbers are taken as (All males - Immature females), since numnbers of immatures of both sexes are asasumed to be equal.

Table 5.3.2 Correlation of Irish landed weight (t) and of FU15 biomass with numerical ratios of adult to immature *Nephrops* in standard summer research vessel hauls, 1987 to 1999

Numerical Ratio Adult to Immature	Type Of Data	Sex	Official landings				Spawning biomass (VPA)							
			Original data		Log transformed		Original values				Log transformed			
			Same Year	Mat: yr. 0 Imm: yr.-1	Same Year	Mat: yr. 0 Imm: yr.-1	Males Multifan	Males	Fem. Traditional VPA	All	Males Multifan	Males	Fem. Traditional VPA	All
(Same	Orig-	M*	0.193	0.124	0.218	0.144	0.481	0.521	0.254	0.487	0.493	0.516	0.256	0.486
year	Inal	F	0.534	0.527	0.530	0.543	**0.661**	**0.596**	0.412	**0.585**	**0.644**	0.570	0.389	0.561
Except		M+F*	0.376	0.517	0.390	0.537	**0.619**	**0.614**	0.357	**0.586**	**0.618**	**0.598**	0.347	0.575
where	Log	M*	0.295	0.151	0.310	0.155	**0.581**	0.561	0.305	0.531	**0.584**	0.547	0.294	0.522
stated)	Trans-	F	0.465	0.569	0.463	0.572	**0.629**	0.564	0.372	0.549	**0.612**	0.537	0.348	0.525
	Formed	M+F*	0.383	0.579	0.391	0.587	**0.644**	**0.611**	0.365	**0.586**	**0.639**	**0.591**	0.348	0.570
	Degrees of Freedom		10	9	10	9	10	10	10	10	10	10	10	10

*Assuming numbers of immature males to be equal to numbers of immature females.

Table 5.3.3. Catch rates for stations in the area common in both the NI and ROI trawl surveys. Stations with similar locations are paired. Stations 200, 106, 104 and 103 are from the NI surveys. Stations H4, H7, H8 and H11 are from the ROI surveys.

	200	**H4**	**106**	**H7**	**104**	**H8**	**103**	**H11**
	kg/nm	kg/0.5hr	kg/nm	kg/0.5hr	kg/nm	kg/0.5hr	kg/nm	kg/0.5hr
Apr-94			9.1		16.3	2.1		
Oct-94			50.7	3.4	14.7	19.8	18.2	5.3
Apr-95	2.0	3.1	13.5	3.6	5.4	3.6	1.0	
Oct-95		2.7	23.0	17.5	68.2	13.6	101.4	11
Apr-96		0.4	2.0	4.2	3.4	7.5	0.4	0.9
Sep-96			45.3	40.5	4.4	14.1		9.2
Apr-97		0.0	47.2	6.6	62.8	27.2	100.9	
Aug-97	28.6	0.7	51.3	4.8	3.3	1.37	28.0	100.8
Apr-98	1.8	3.4	33.4	8.3	70.7		4.4	67.2
Aug-98	19.8	3.4	33.7	7.3	24.0	2.44	27.2	0.3
Apr-99	0.0	0.3	4.0		23	19.86	2.4	0.3
Aug-99	20.6	0.3	80.0	61.0	5.2	8.5	3.8	7.3

Table 5.4.1. Sum of strata variances for initial and full surveys for Moray Firth and Firth of Forth stocks.

Stock	Initial survey		Full survey	
	Stations	Sum of Strata variances	Stations	Sum of Strata variances
Moray Firth	34	0.63	48	0.54
Firth of Forth	40	2.39	54	2.40

Table 8.1.1. Monitored fish discards on *Nephrops* fishing vessels in the Farn Deeps (Grant Course, pers. comm.). Data are live weights in kg, estimated from raised length distributions.

		1994	1995	1996	1997	1998	1999
Nephrops trips observed		11	15	22	6	9	13
Landings	Cod	796	625	1593	271	505	671
	Haddock	86	73	206	48	56	161
	Whiting	228	833	1513	259	552	2551
Discards	Cod	334	111	438	289	675	61
	Haddock	199	129	220	29	18	169
	Whiting	4124	5967	7056	686	1349	4630
Nephrops landings				9971	1283	2656	3495

Table 8.5.1 Discard data sources: Sweden (FU 3 and 4 Skagerrak and Kattegat)

Functional Unit(s)	3.4	**Country**	Sweden	
Routine sampling programmes	**None**	**Case studies**	**FU 4 (Kattegat)**	**FU 3 (Skagerrak)**
In operation since		Year performed	1997+99	1999 - 2001
Year-round or particular season(s)		Year-round or particular season(s)	Year around	Year around
RV or commercial vessels		RV or commercial vessels	Comm. vessels	Comm. vessels
Species groups investigated		Species groups investigated		
Nephrops		*Nephrops*	Yes	Yes
Commercial fish		Commercial fish	Yes	Yes
Non-commercial fish		Non-commercial fish	Yes	Yes
Benthos		Benthos	Yes	Yes
Sampling frequency		Sampling frequency	hauls	hauls
Quarterly		Quarterly	4-14	5-20
Monthly		Monthly		
Weekly		Weekly		
Daily		Daily		
Areal resolution		Areal resolution		
By Functional Unit		By Functional Unit	Y	Y
By statistical rectangle		By statistical rectangle		
By part of statistical rectangle		By part of statistical rectangle		
Type of data collected		Type of data collected		
Overall quantities		Overall quantities	Yes	Yes
Quantities by species		Quantities by species	Yes	Yes
Length compositions		Length compositions	Yes	Yes
No of samples collected per year		No of samples collected per year	No. hauls	No. hauls
> 100		> 100		
50 - 100		50 - 100		
25 - 50		25 - 50	x	x
< 25		< 25		

Table 8.5.2 Discard data sources: Belgium (FU 5 Botney Gut)

Functional Unit(s)	5	**Country**	Belgium		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since		Year performed	1993		
Year-round or particular season(s)		Year-round or particular season(s)	Summer		
RV or commercial vessels		RV or commercial vessels	Comm		
Species groups investigated		Species groups investigated			
Nephrops		*Nephrops*	Yes		
Commercial fish		Commercial fish	Yes		
Non-commercial fish		Non-commercial fish	No		
Benthos		Benthos	No		
Sampling frequency		Sampling frequency			
Quarterly		Quarterly	X		
Monthly		Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit		By Functional Unit	X		
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities		Overall quantities	X		
Quantities by species		Quantities by species	X		
Length compositions		Length compositions	X		
No of samples collected per year		No of samples collected per year			
> 100		> 100	X		
50 - 100		50 - 100			
25 - 50		25 - 50			
< 25		< 25			

Table 8.5.3 Discard data sources: UK England (FU 6 Farn Deeps)

Functional Unit(s)	6	**Country**	**England**		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since	1985	Year performed			
Year-round or particular season(s)	oct-mar	Year-round or particular season(s)			
RV or commercial vessels	comm	RV or commercial vessels			
Species groups investigated		Species groups investigated			
Nephrops	yes	*Nephrops*			
Commercial fish		Commercial fish			
Non-commercial fish		Non-commercial fish			
Benthos		Benthos			
Sampling frequency		Sampling frequency			
Quarterly		Quarterly			
Monthly	oct-mar	Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit	yes	By Functional Unit			
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities	yes	Overall quantities			
Quantities by species		Quantities by species			
Length compositions	yes	Length compositions			
No of samples collected per year		No of samples collected per year			
> 100		> 100			
50 - 100		50 - 100			
25 - 50	yes	25 - 50			
< 25		< 25			

Table 8.5.4 Discard data sources: Belgium (FU 7 Fladen Ground)

Functional Unit(s)	7	**Country**	Belgium		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since		Year performed	1999		
Year-round or particular season(s)		Year-round or particular season(s)	Autumn		
RV or commercial vessels		RV or commercial vessels	Comm		
Species groups investigated		Species groups investigated			
Nephrops		*Nephrops*	Yes		
Commercial fish		Commercial fish	Yes		
Non-commercial fish		Non-commercial fish	No		
Benthos		Benthos	No		
Sampling frequency		Sampling frequency			
Quarterly		Quarterly			
Monthly		Monthly			
Weekly		Weekly			
Daily		Daily	X		
Areal resolution		Areal resolution			
By Functional Unit		By Functional Unit			
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle	X		
Type of data collected		Type of data collected			
Overall quantities		Overall quantities	X		
Quantities by species		Quantities by species	X		
Length compositions		Length compositions	X		
No of samples collected per year		No of samples collected per year			
> 100		> 100	X		
50 - 100		50 - 100			
25 - 50		25 - 50			
< 25		< 25			

Table 8.5.5 Discard data sources: UK Scotland (FUs: 8 - Firth of Forth, 9 – Moray Firth, 11- North Minch, 12 – South Minch, 13 – Firth of Clyde)

Functional Unit(s)	8,9,11,12,13	**Country**	UK, Scotland		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since	1990	Year performed			
Year-round or particular season(s)	year	Year-round or particular season(s)			
RV or commercial vessels	comm	RV or commercial vessels			
Species groups investigated		Species groups investigated			
Nephrops	Y	*Nephrops*			
Commercial fish		Commercial fish			
Non-commercial fish		Non-commercial fish			
Benthos		Benthos			
Sampling frequency		Sampling frequency			
Quarterly	Y(9,11,13)	Quarterly			
Monthly	Y(8&12)	Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit	FU	By Functional Unit			
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities	Y	Overall quantities			
Quantities by species		Quantities by species			
Length compositions	Y	Length compositions			
No of samples collected per year		No of samples collected per year			
> 100		> 100			
50 - 100		50 - 100			
25 - 50	Y(occas)	25 - 50			
< 25	Y	< 25			

Table 8.5.6 Discard data sources: UK England (FU 14 Irish Sea East)

Functional Unit(s)	14	**Country**	England		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since	1999	Year performed			
Year-round or particular season(s)	year	Year-round or particular season(s)			
RV or commercial vessels	comm	RV or commercial vessels			
Species groups investigated		Species groups investigated			
Nephrops	yes	*Nephrops*			
Commercial fish		Commercial fish			
Non-commercial fish		Non-commercial fish			
Benthos		Benthos			
Sampling frequency		Sampling frequency			
Quarterly		Quarterly			
Monthly	5	Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit	yes	By Functional Unit			
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities	yes	Overall quantities			
Quantities by species		Quantities by species			
Length compositions	yes	Length compositions			
No of samples collected per year		No of samples collected per year			
> 100		> 100			
50 - 100	yes	50 - 100			
25 - 50		25 - 50			
< 25		< 25			

Table 8.5.7 Discard data sources: UK Northern Ireland (FU 15 Irish Sea West)

Functional Unit(s)	15		**Country**	**UK (Northern Ireland**		
Routine sampling programmes			**Case studies ***	**a**	**b**	**c**
In operation since	1984	1990	Year performed	1997	1998	1999
Year-round or particular season(s)	All year	Apr & Aug	Year-round or particular season(s)	All year	All year	All year
RV or commercial vessels	Comm	RV	RV or commercial vessels	Comm	Comm	Comm
Species groups investigated			Species groups investigated			
Nephrops	Yes	Yes	*Nephrops*	Yes	Yes	Yes
Commercial fish	Yes	Yes	Commercial fish	Yes	Yes	Yes
Non-commercial fish	Yes	Yes	Non-commercial fish	Yes	Yes	Yes
Benthos	Some	Yes	Benthos	some	some	some
Sampling frequency			Sampling frequency			
Quarterly		Apr & Aug	Quarterly			
Monthly	Yes		Monthly	Yes	Yes	Yes
Weekly			Weekly	sometimes	sometimes	sometimes
Daily			Daily			
Areal resolution			Areal resolution			
By Functional Unit	Yes		By Functional Unit	Yes	Yes	Yes
By statistical rectangle			By statistical rectangle			
By part of statistical rectangle		Yes	By part of statistical rectangle			
Type of data collected			Type of data collected			
Overall quantities			Overall quantities			
Quantities by species			Quantities by species			
Length compositions	Yes	Yes	Length compositions	Yes	Yes	Yes
No of samples collected per year			No of samples collected per year			
> 100			> 100			
50 - 100			50 - 100	Yes	Yes	Yes
25 - 50	40-60	45	25 - 50			
< 25			< 25			
			* EU Discard Projects			

Table 8.5.8 Discard data sources:France (FUs 20-22 Celtic Sea)

Functional Unit(s)	20-22	Country	France		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since		Year performed	1985	1991	1997
Year-round or particular season(s)		Year-round or particular season(s)	year-round for each year		
RV or commercial vessels		RV or commercial vessels	commercial vessels		
Species groups investigated		Species groups investigated			
Nephrops		*Nephrops*	Y	Y	Y
Commercial fish		Commercial fish	Y	Y	Y
Non-commercial fish		Non-commercial fish	N	N	N
Benthos		Benthos	N	N	N
Sampling frequency		Sampling frequency			
Quarterly		Quarterly	Y	Y	Y
Monthly		Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit		By Functional Unit	Y	Y	Y
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities		Overall quantities			
Quantities by species		Quantities by species	Y	Y	Y
Length compositions		Length compositions	Y	Y	Y
No of samples collected per year		No of samples collected per year			
> 100		> 100	Y	Y	Y
50 - 100		50 - 100			
25 - 50		25 - 50			
< 25		< 25			

Table 8.5.9 Discard data sources: France (FU 23 –24 Bay of Biscay)

Functional Unit(s)	23-24	**Country**	France		
Routine sampling programmes		**Case studies**	**a**	**b**	**c**
In operation since		Year performed	1985	1991	1998
Year-round or particular season(s)		Year-round or particular season(s)	Year-round for each year		
RV or commercial vessels		RV or commercial vessels	commercial vessels		
Species groups investigated		Species groups investigated			
Nephrops		*Nephrops*	Y	Y	Y
Commercial fish		Commercial fish	Y	Y	Y
Non-commercial fish		Non-commercial fish	N	N	N
Benthos		Benthos	N	N	N
Sampling frequency		Sampling frequency			
Quarterly		Quarterly	Y	Y	Y
Monthly		Monthly			
Weekly		Weekly			
Daily		Daily			
Areal resolution		Areal resolution			
By Functional Unit		By Functional Unit	Y	Y	Y
By statistical rectangle		By statistical rectangle			
By part of statistical rectangle		By part of statistical rectangle			
Type of data collected		Type of data collected			
Overall quantities		Overall quantities			
Quantities by species		Quantities by species	Y	Y	Y
Length compositions		Length compositions	Y	Y	Y
No of samples collected per year		No of samples collected per year			
> 100		> 100	Y	Y	Y
50 - 100		50 - 100			
25 - 50		25 - 50			
< 25		< 25			

Table 9.5.1 Overview of biological parameters used in assessments.

FU (Stock)	Geographical Area	ICES Area (Division)	Management area	Sex	Growth parameters L8 (CL, mm)	K ($year^{-1}$)	Length -weight ($W = a * L^b$) a	b	Size at maturity CL, mm	Mortality parameters M	Z
1	Iceland waters	V a		Males	80	0.110	0,00113	2867		0.2	
			A	Females - immature					29-30		
				Females - mature	58	0.110				0.2	
				Males							
2	Faroe waters	V b	B	Females - immature							
				Females - mature							
				Males	73 a)	0.113 a)	0.00045 (	3.113 c)		0.3	
				Males	76 b)	0.16 b)	0.00045 (	3.113 c)		0.3	
				Females - immature	73 a)	0.113 a)					
				Females - immature	76 b)	0.16 b)					
3	Skagerrak	III a	E	Females - mature	67 b)	0.10 b)	0.00108 (	2.847 c)	28.5 c)	0.2	
				Females - mature	66 a)	0.04? a)	0.00108 (	2.847 c)	28.5 c)	0.2	
				Males			0.0003	3.22		0.3	
4	Kattegat	III a	E	Females - immature							
				Females - mature			0.0011	2.84		0.2	
				Males	62	0.165				0.3	
5	Botney Gut	IV b,c	H	Females - immature	62	0.165				0.3	
				Females - mature	60	0.080				0.2	
				Males	66	0.160	0.00038	3.17		0.3	0.826
6	Farn Deeps	IV b,c	I	Females - immature	66	0.160	0.00091	2.89	24	0.3	
				Females - mature	58	0.060	0.00091	2.89		0.2	0.381
				Males	66	0.160	0.00028	3.24		0.3	
7	Fladen	IV a	G	Females - immature	66	0.160	0.00085	2.91	25	0.3	
				Females - mature	56	0.100	0.00085	2.91		0.2	
				Males	66	0.163	0.00028	3.24		0.3	
8	Firth of Forth	IV b,c	I	Females - immature	66	0.163	0.00085	2.91	26	0.3	
				Females - mature	58	0.065	0.00085	2.91		0.2	
				Males	62	0.165	0.00028	3.24		0.3	
9	Moray Firth	IV a	F	Females - immature	62	0.165	0.00085	2.91	25	0.3	
				Females - mature	56	0.060	0.00085	2.91		0.2	
				Males							
10	Noup	IV a	F	Females - immature							
				Females - mature							
				Males	70	0.160	0.00028	3.24		0.3	
11	North Minch	VI a	C	Females - immature	70	0.160	0.00085	2.91	27	0.3	
				Females - mature	60	0.060	0.00085	2.91		0.2	
				Males	68	0.161	0.00028	3.24		0.3	
12	South Minch	VI a	C	Females - immature	68	0.161	0.00085	2.91	25	0.3	
				Females - mature	59	0.060	0.00085	2.91		0.2	
				Males	73	0.160	0.00028	3.24		0.3	
13	Clyde	VI a	C	Females - immature	73	0.160	0.00085	2.91	27	0.3	
				Females - mature	62	0.060	0.00085	2.91		0.2	
				Males	60	0.160	0.00022	3.348		0.3	
14	Irish Sea east	VII a	J	Females - immature	60	0.160	0.00114	2.82		0.3	
				Females - mature	56	0.100	0.00114	2.82	24	0.2	

Table 9.5.1 (continued) Overview of biological parameters used in assessments.

FU (Stock)	Geographical Area	ICES Area (Division)	Management area	Sex	Growth parameters L8 (CL, mm)	K (year^{-1})	Length -weight (W = a * L^{b}) a	b	Size at maturity CL, mm	Mortality parameters M	Z
15	Irish Sea west	VII a	J	Males	60	0.160	0.00032	3.21		0.3	?
				Females - immature	60	0.160	0.00032	3.21		0.3	?
				Females - mature	56	0.100	0.00068	2.96	24	0.2	?
16	Porcupine Bank	VII b,c,j,k	L	Males	75	0.140	0.00009	3.55		0.2	
				Females - immature							
				Females - mature	60	0.100	0.00009	3.55	24	0.2	
17	Aran Grounds	VII b,c,j,k	L	Males	60	0.150	0.00032	3.21			
				Females - immature	60	0.150	0.00068	2.96			
				Females - mature	50	0.100	0.00068	2.96			
18-19	Irish W & SE coasts	VII b,c,j,k	L	Males							
				Females - immature							
				Females - mature							
20-22	Celtic Sea	VII a,f,g,h	M	Males	68	0.170	0.00009	3.55		0.3	
				Females - immature	68	0.170	0.00009	3.55		0.3	
				Females - mature	49	0.100	0.00009	3.55	31	0.2	
23-24	Bay of Biscay	VIII a,b	N	Males	76	0.140	0.00039	3.18		0.3	
				Females - immature	76	0.140			25	0.3	
				Females - mature	56	0.110	0.00081	2.97		0.2	
25	North Galicia	VIII c	O	Males	70	0.160	0.00043	3.16		0.2	
				Females - immature	70	0.160				0.2	
				Females - mature	60	0.080	0.00043	3.16	28	0.2	
26-27	W. Galicia & N. Portugal	IX a	Q	Males	85	0.150	0.00043	3.16		0.2	
				Females - immature	85	0.150				0.2	
				Females - mature	65	0.100	0.00043	3.16	26	0.2	
28-29	SW & S Portugal	IX a	Q	Males	70	0.200	0.00028	3.22		0.3	
				Females - immature	70	0.200	0.00056	3.03		0.3	
				Females - mature	65	0.065	0.00056	3.03	30	0.2	
30	Gulf of Cadiz	IX a	Q	Males							
				Females - immature							
				Females - mature							
31	Cantabrian Sea	VIII c	O	Males	90	0.150	0.00043	3.16		0.2	
				Females - immature							
				Females - mature	70	0.100	0.00043	3.16		0.2	
32	Norwegian Deeps	IV a	S	Males							
				Females - immature							
				Females - mature							
33	Off Horns Reef	IV b	H	Males							
				Females - immature							
				Females - mature							

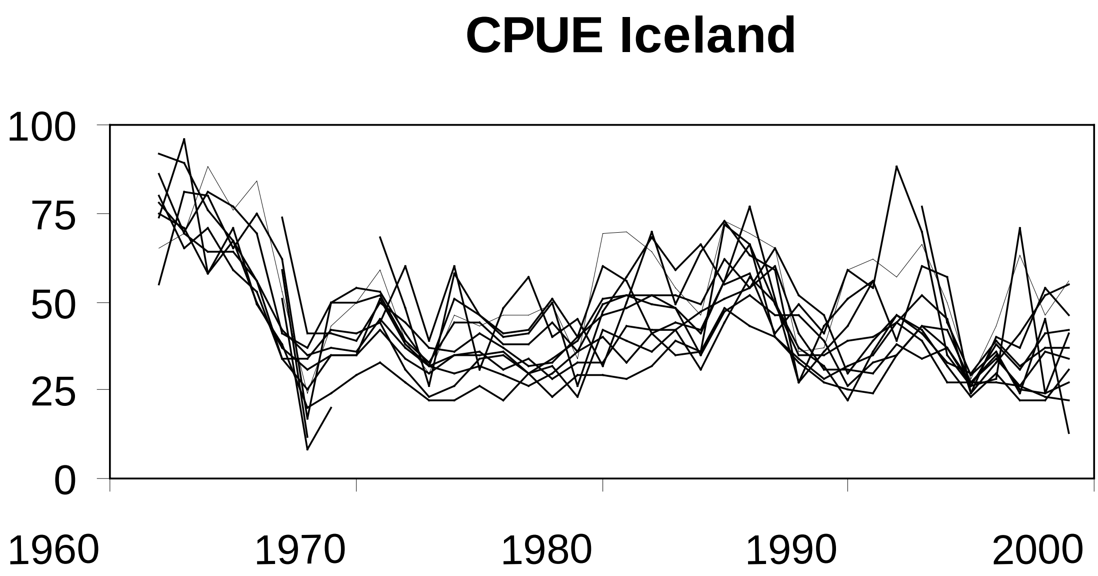
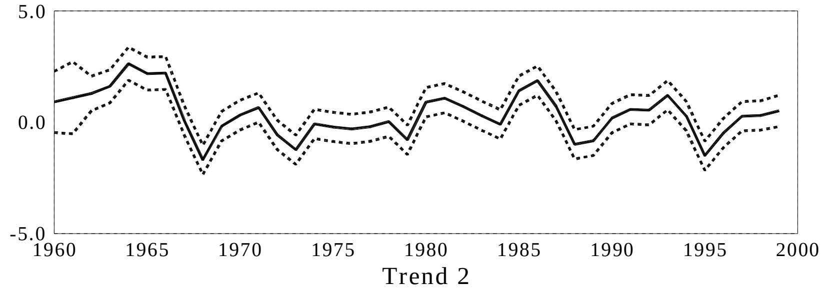
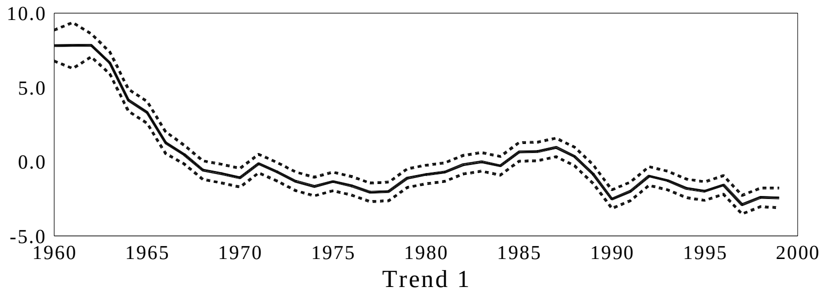


Figure 3.1.1 *Nephrops* CPUE time series of 11 stocks from Iceland.





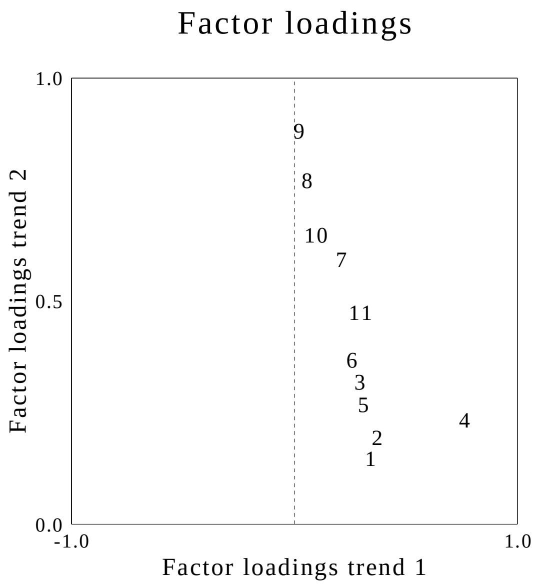


Figure 3.1.2 Estimated common trends and factor loadings for Iceland CPUE data obtained by a 2-common trend dynamic factor model. The numbers 1 to 11 refer to the stocks 373, 372, 371, 321, 320, 319, 367, 366, 365, 364 and 414.

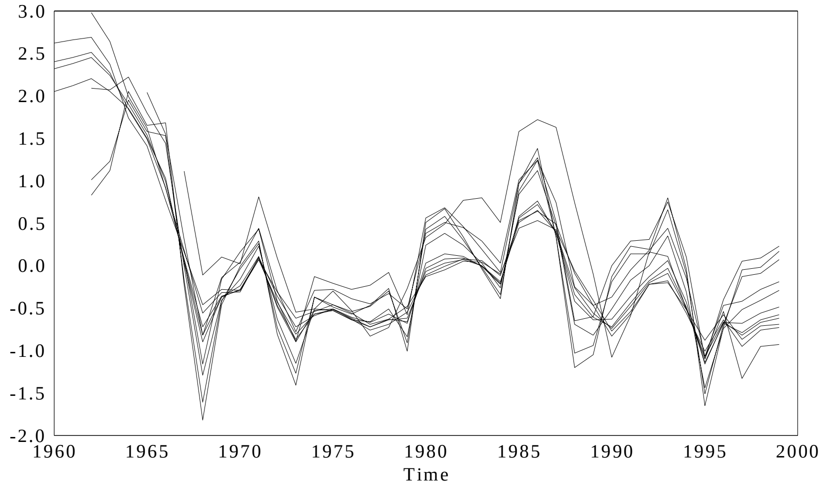


Figure 3.1.3 Fitted values for Iceland CPUE data obtained by the 2-common trend dynamic factor analysis model.

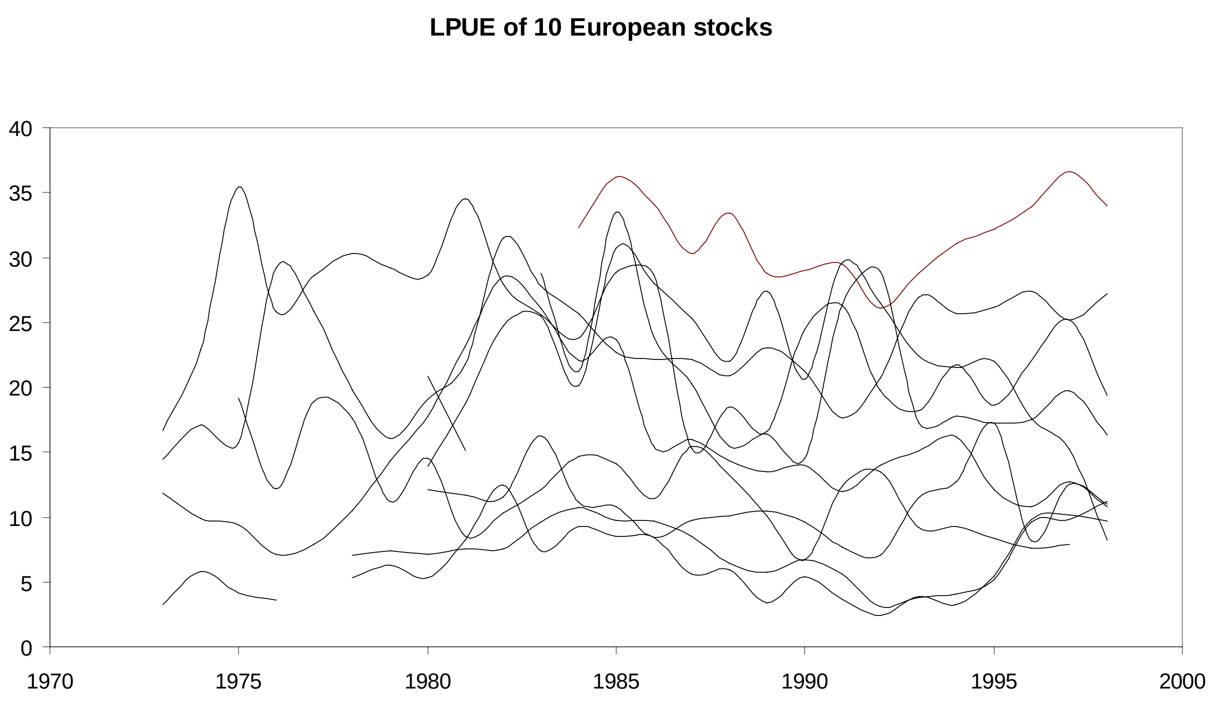
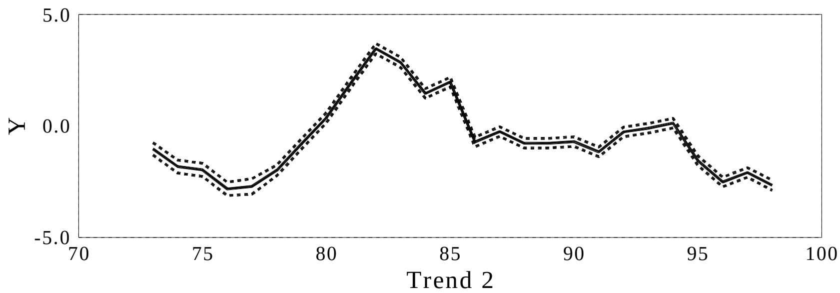
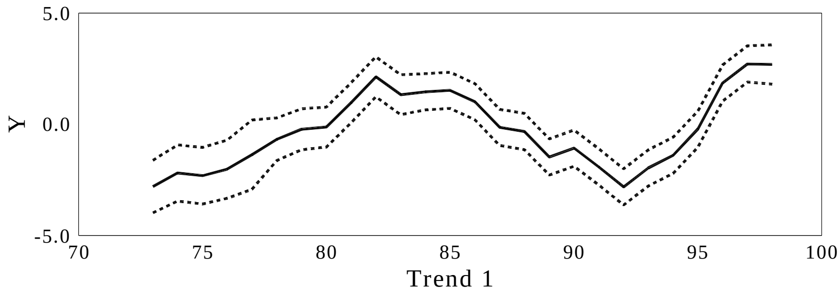


Figure 3.1.4 LPUE series of FU3, FU4, FU5, FU6, FU14, FU15, FU16, FU25, FU26 and FU26.





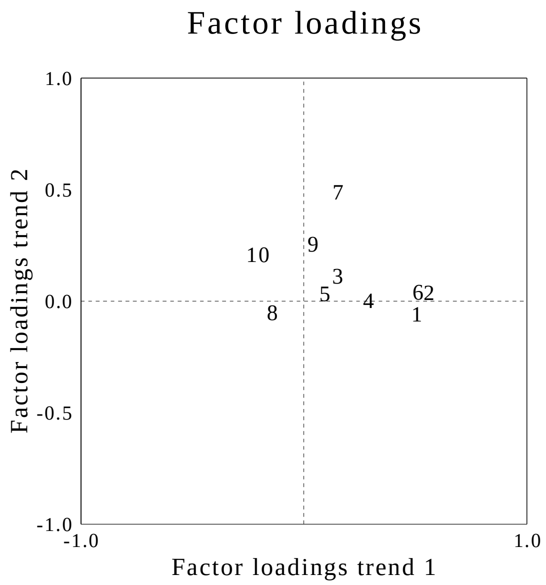


Figure 3.1.5 Estimated common trends and factor loadings for 10 LPUE series obtained by a 2-common trend dynamic factor model. The numbers 1 to 11 correspond to the stocks FU3, FU4, FU5, FU6, FU14, FU15, FU16, FU25, FU26 and FU26.

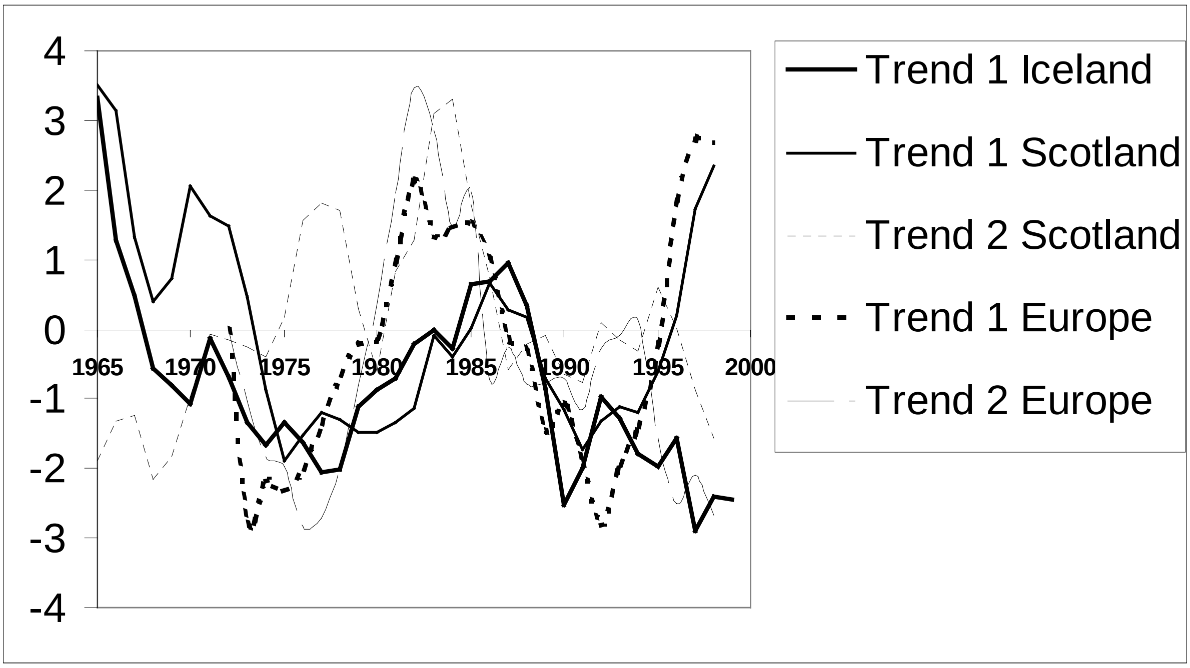


Figure 3.1.6 Estimated common trends for Iceland CPUE series, Scottish LPUE series and European LPUE series.

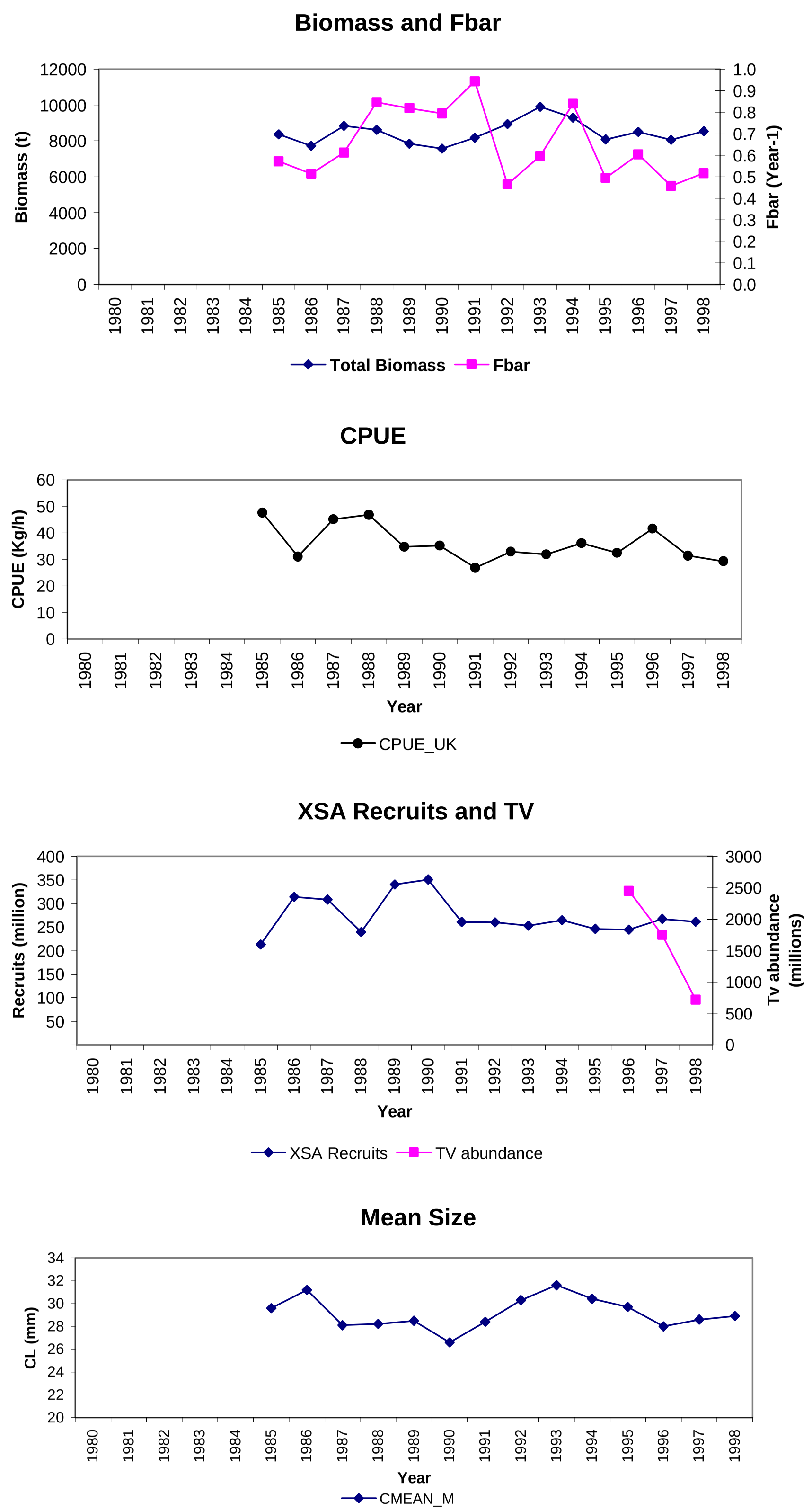


Figure 3.2.1. Farn deeps (FU 6): Correspondence between indices of state of exploitation

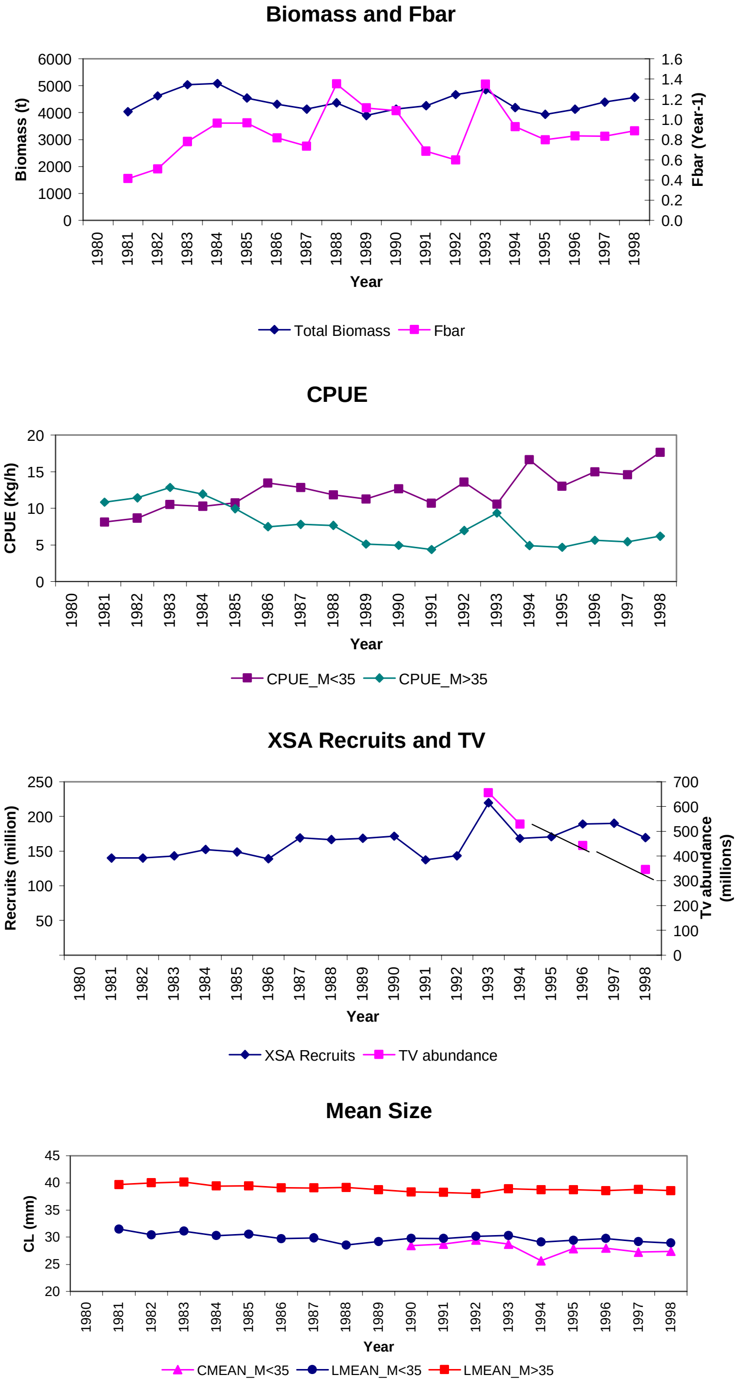


Figure 3.2.2. Firth of Forth (FU 8): Correspondence between indices of state of exploitation

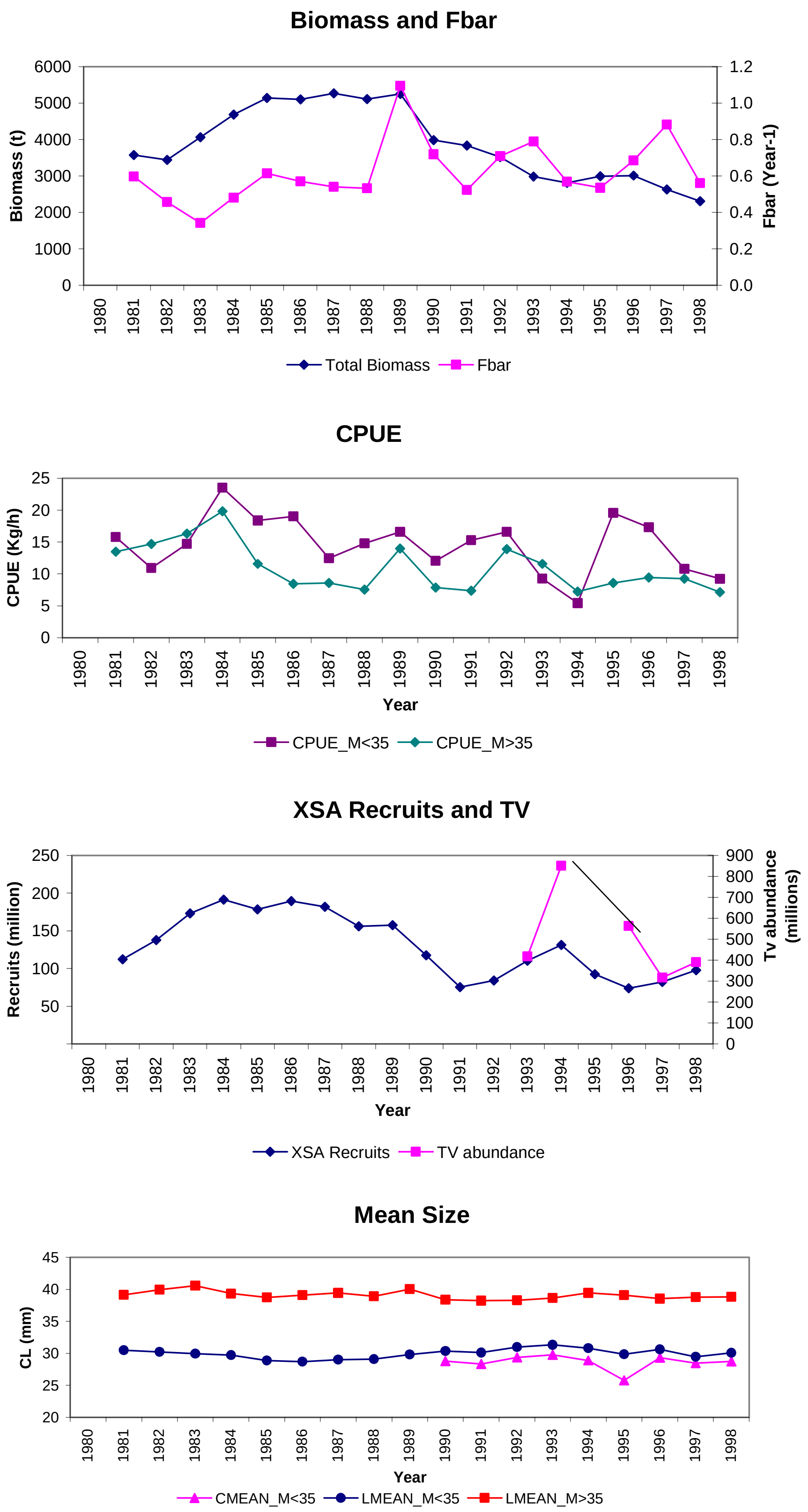


Figure 3.2.3 Moray of Forth (FU 9): Correspondence between indices of state of exploitation

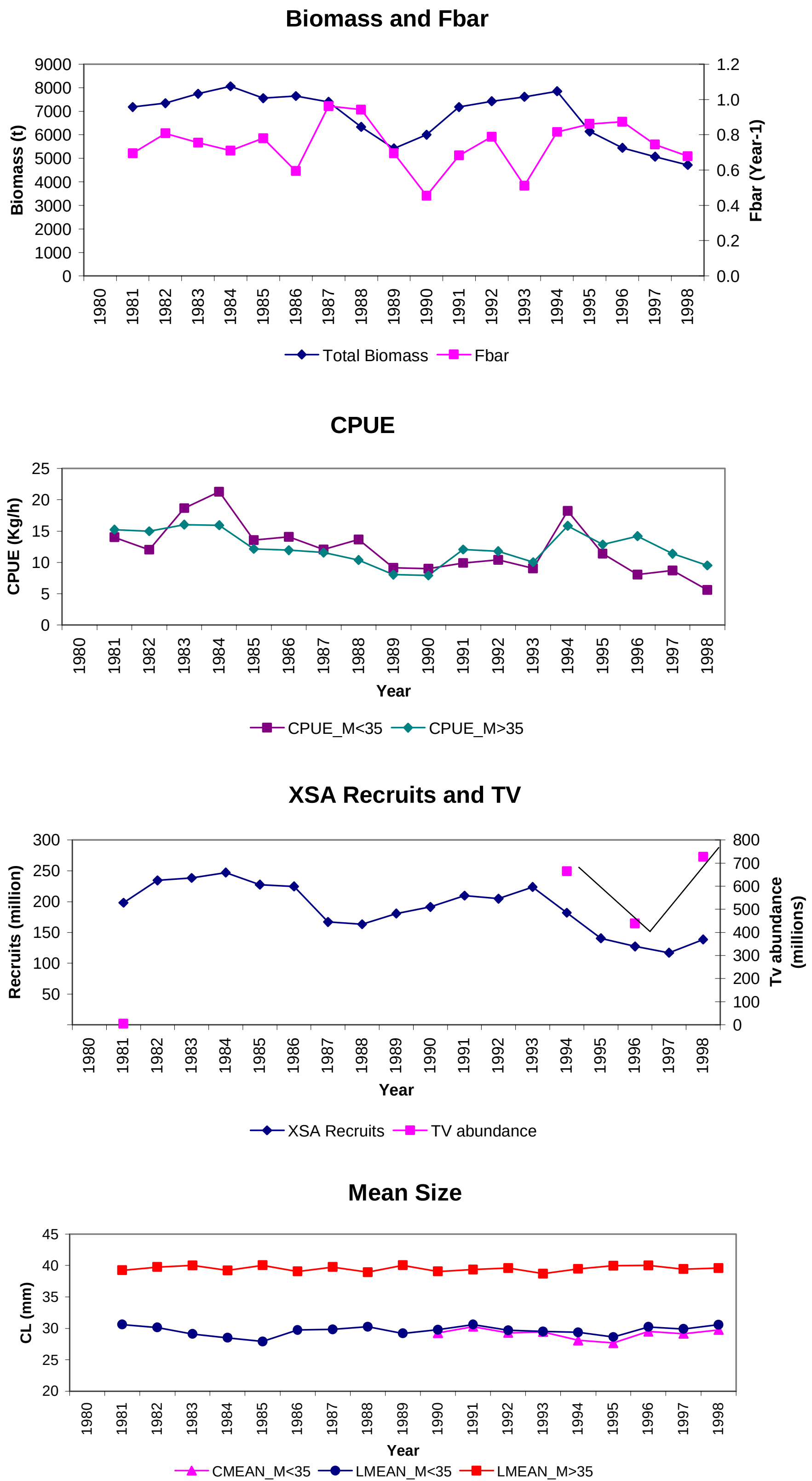


Figure 3.2.4. North Minch (FU 11): Correspondence between indices of state of exploitation

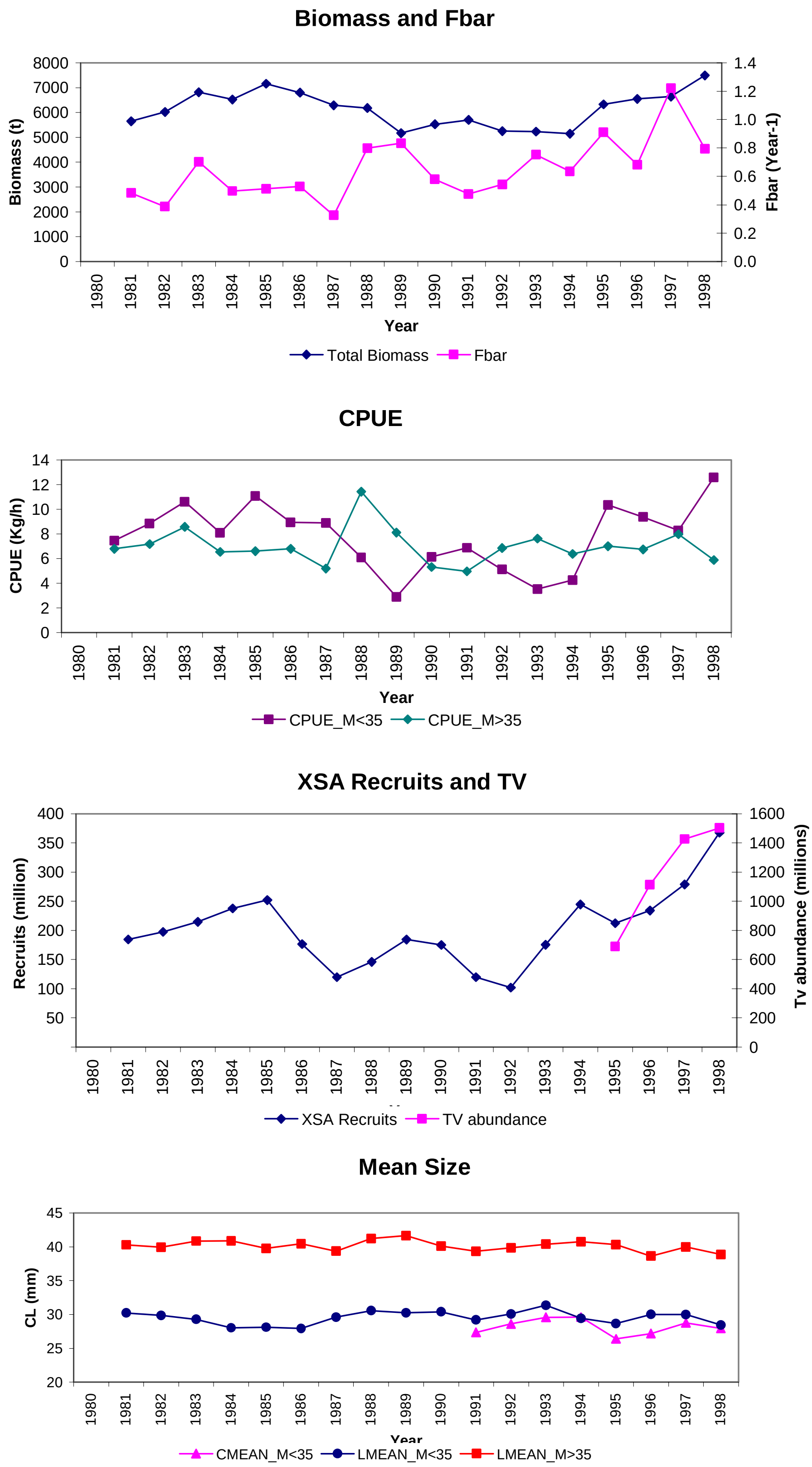


Figure 3.2.5. Firth of Clyde (FU 13): Correspondence between indices of state of exploitation

Figure 3.2.6. Irish Sea West (FU 15): Correspondence between indices of state of exploitation

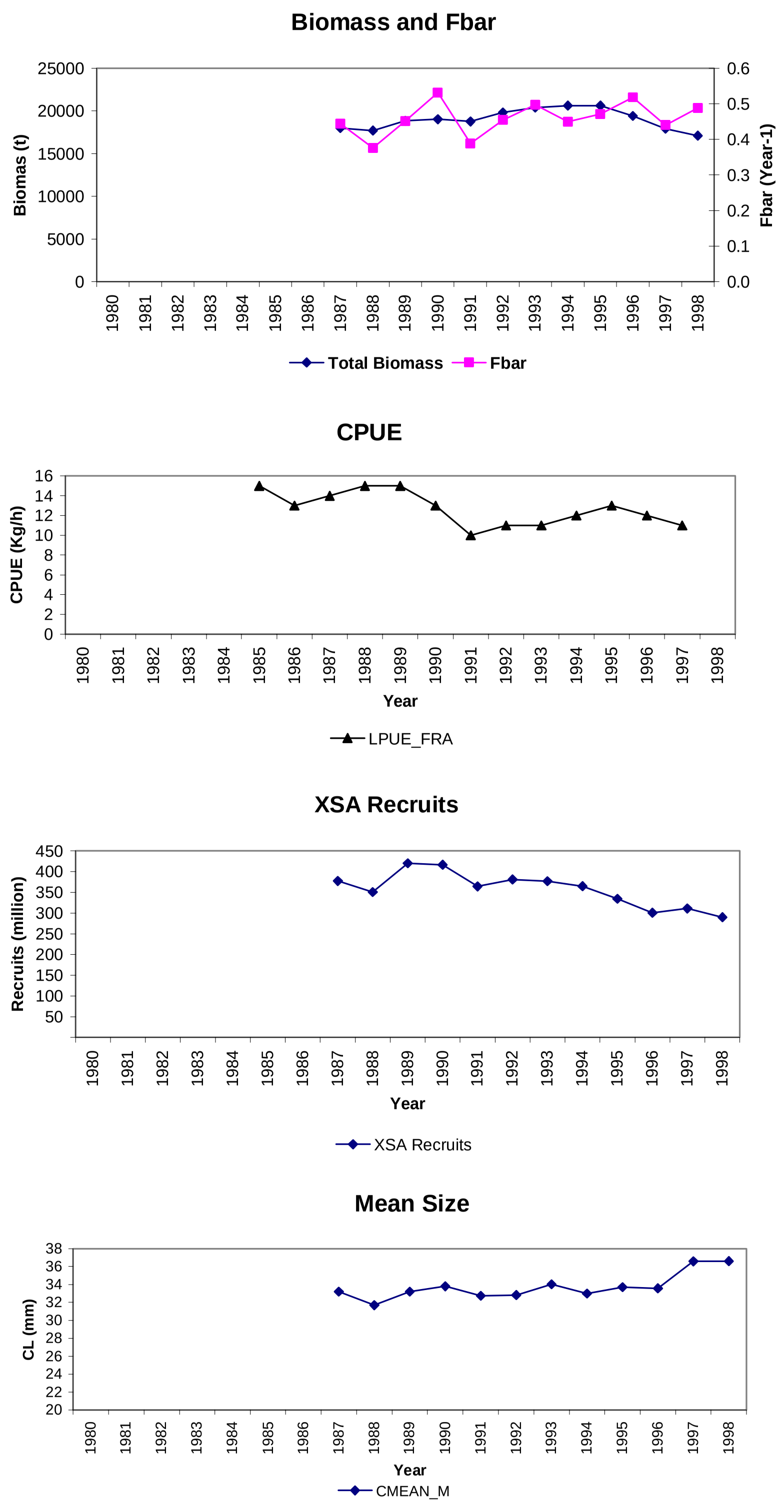


Figure 3.2.7. Celtic Sea West (FU 21-22): Correspondence between indices of state of exploitation

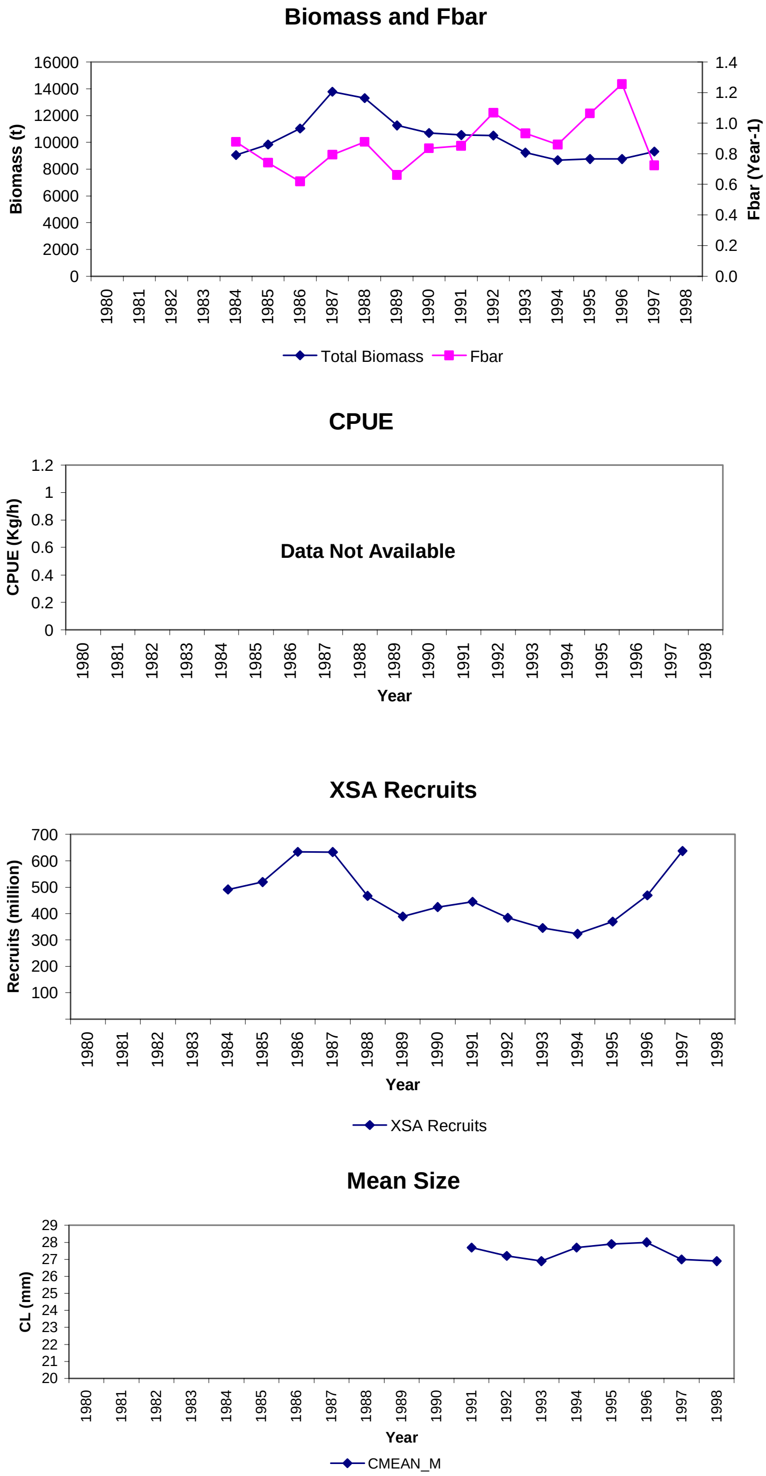
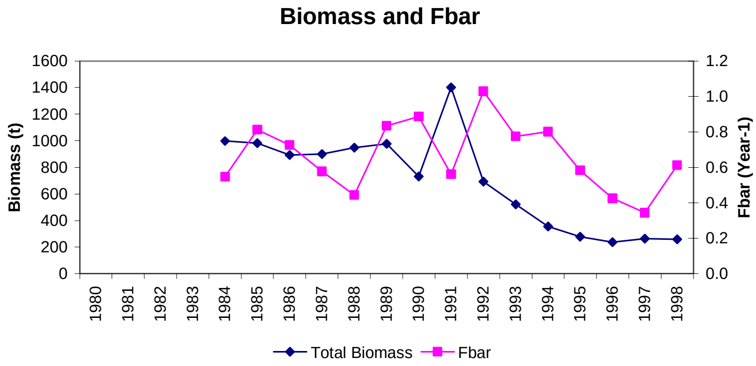
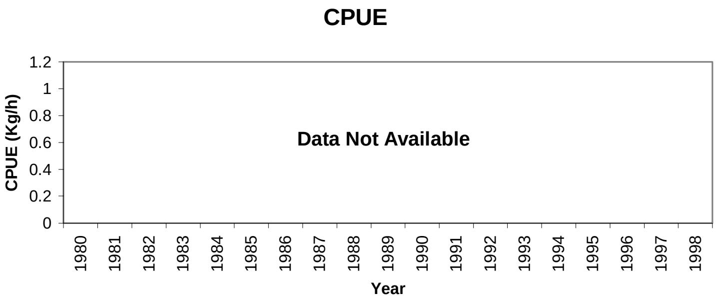
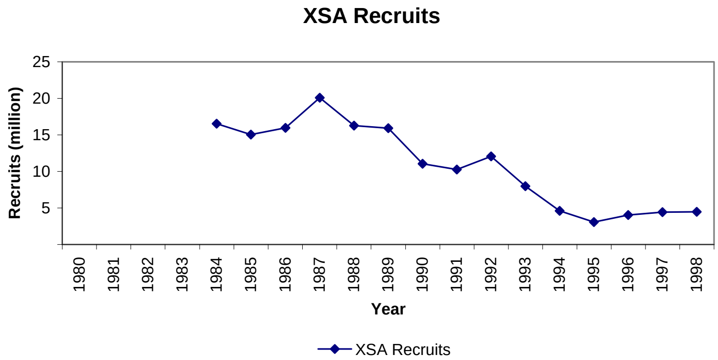


Figure 3.2.8 Bay of Biscay (FU 23-24): Correspondence between indices of state of exploitation







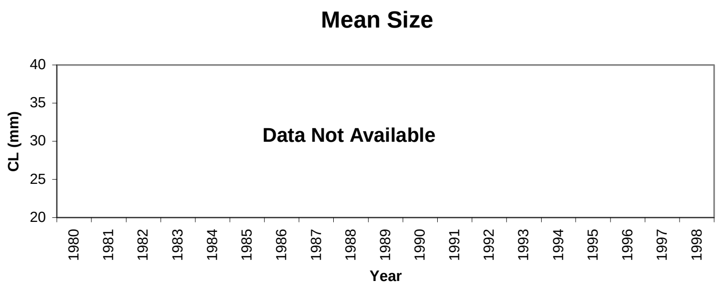


Figure 3.2.9. South and SW Portugal (FU 28): Correspondence be indices of state of exploitation

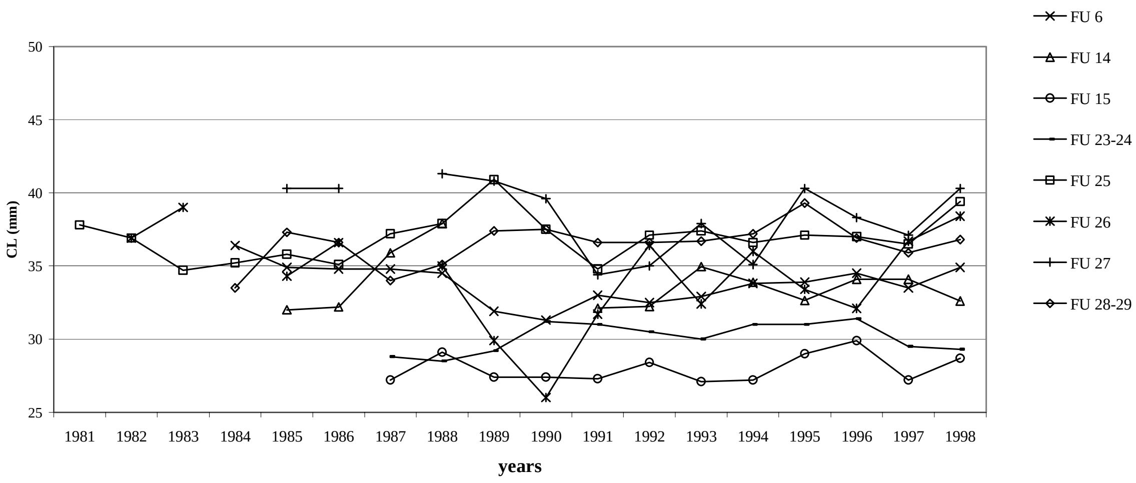


Figure 3.3.1: Mean sizes of males (<40mm CL)

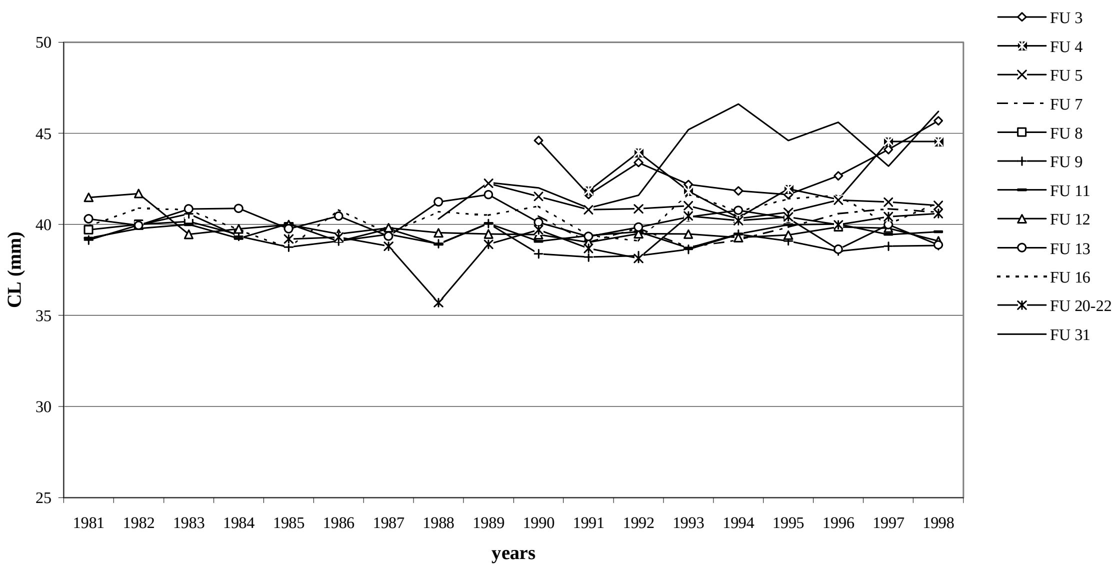


Figure 3.3.2: Mean sizes of males (>40mm CL)

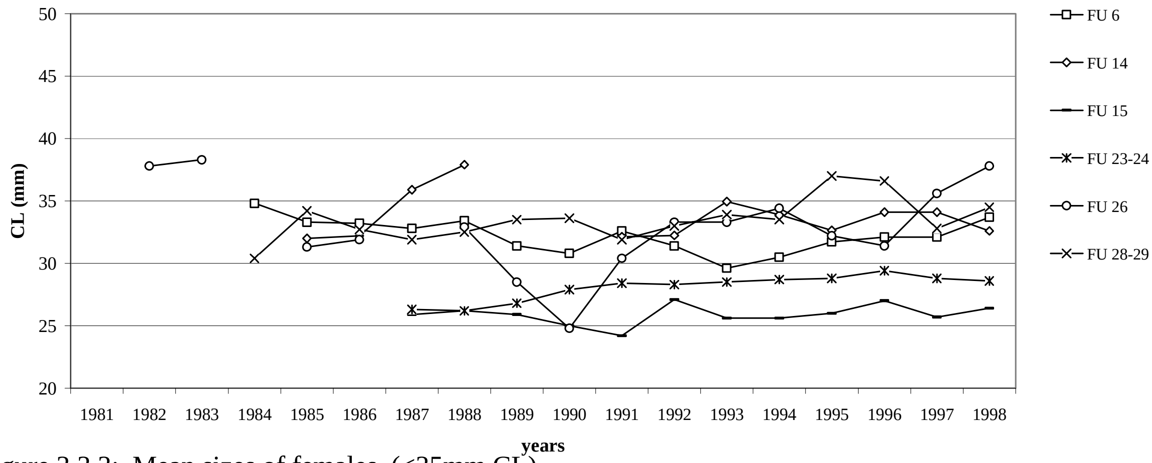


Figure 3.3.3: Mean sizes of females (<35mm CL)

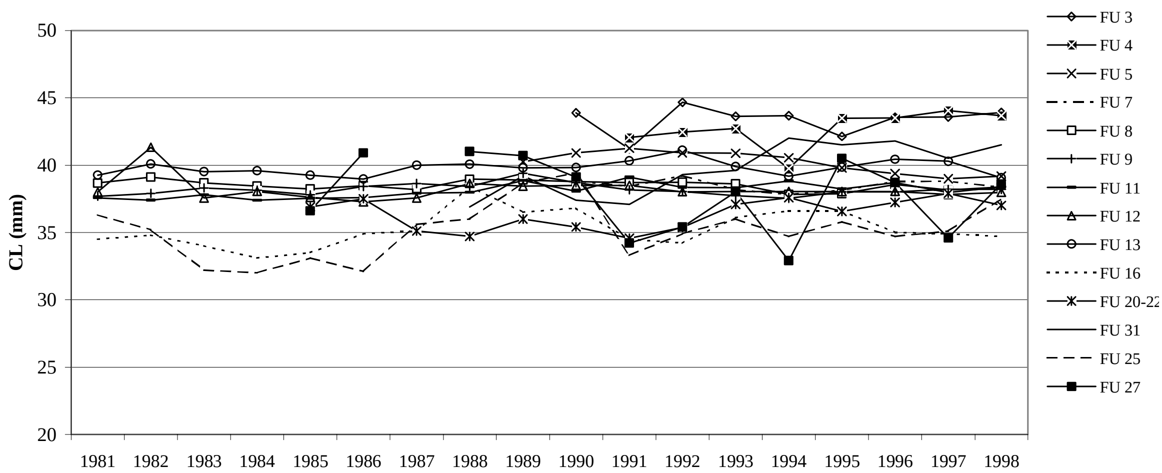


Figure 3.3.4: Mean sizes of females (>35mm CL)

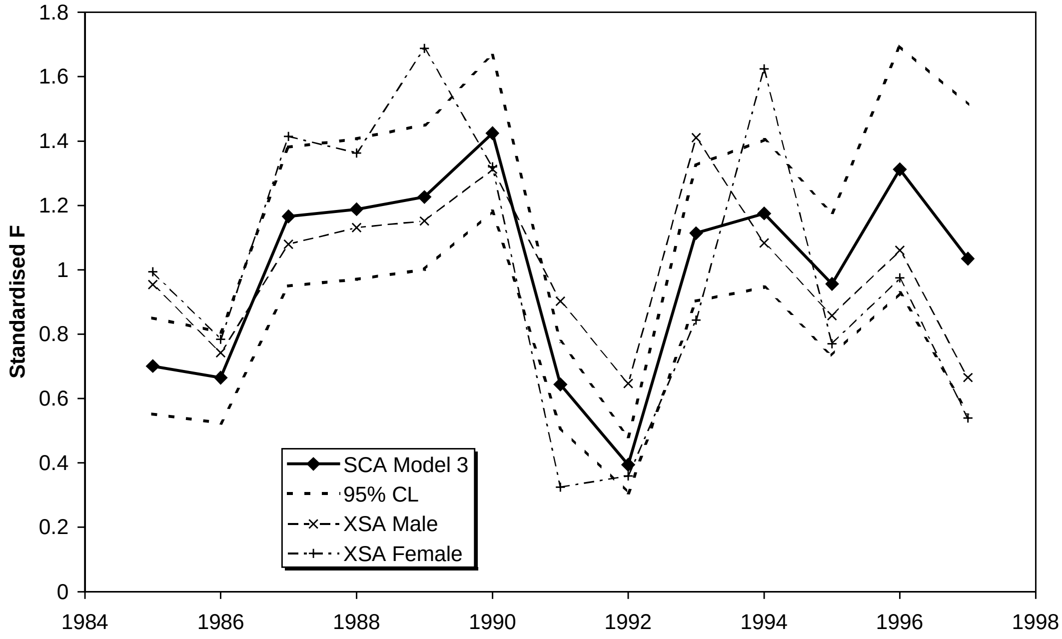


Figure 4.1.1 Standardised F from Farn Deeps Model 3 compared to XSA assessment.

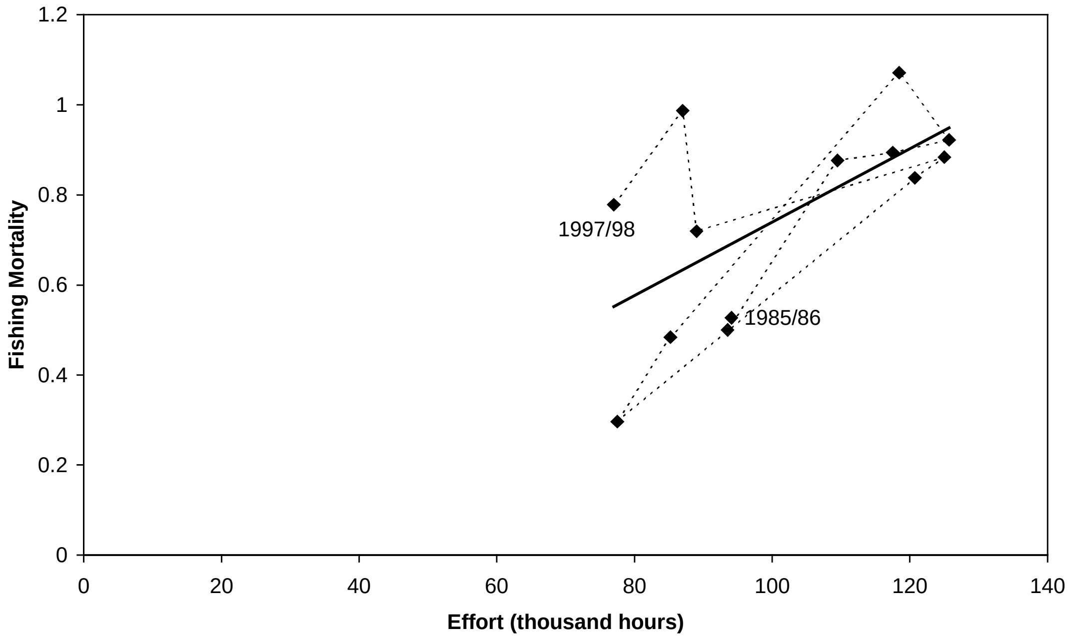


Figure 4.1.2 Relationship between Fishing Mortality and Effort for the Farn Deeps

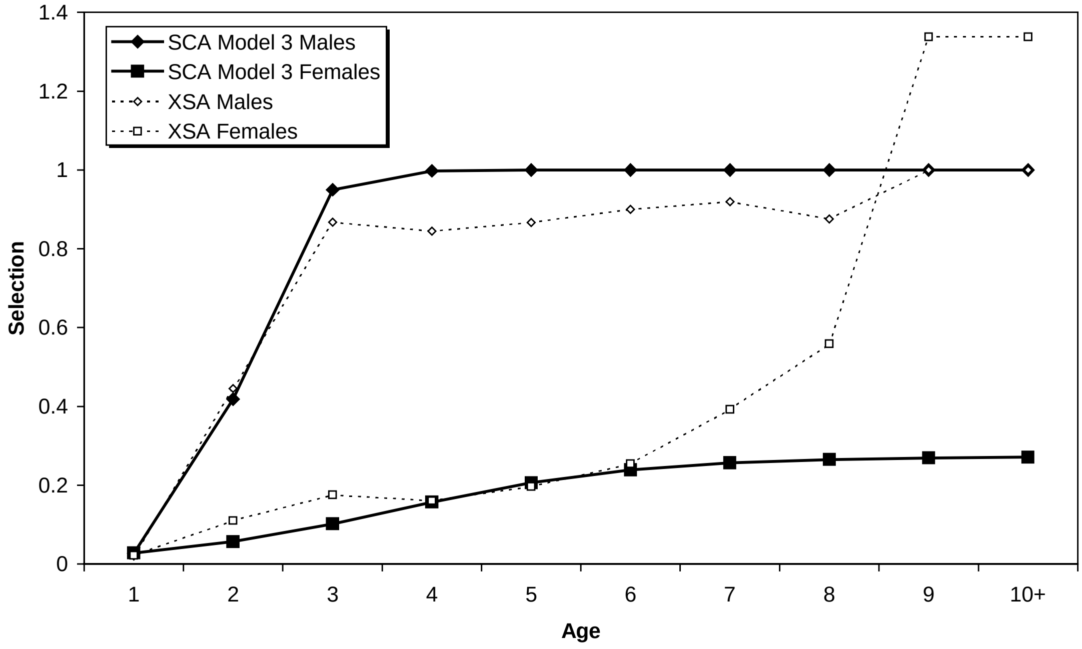


Figure 4.1.3 Relative selection at age for Farn Deeps Model 3 and XSA assessment.

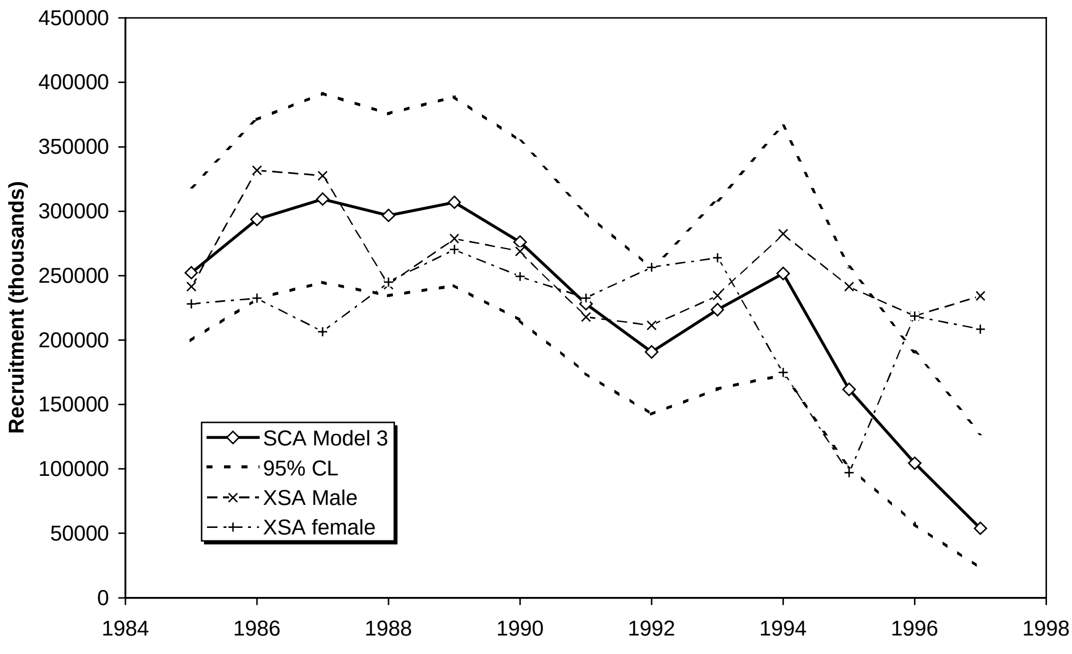


Figure 4.1.4 Recruitment estimates for Farn Deeps Model 3 and XSA assessments.

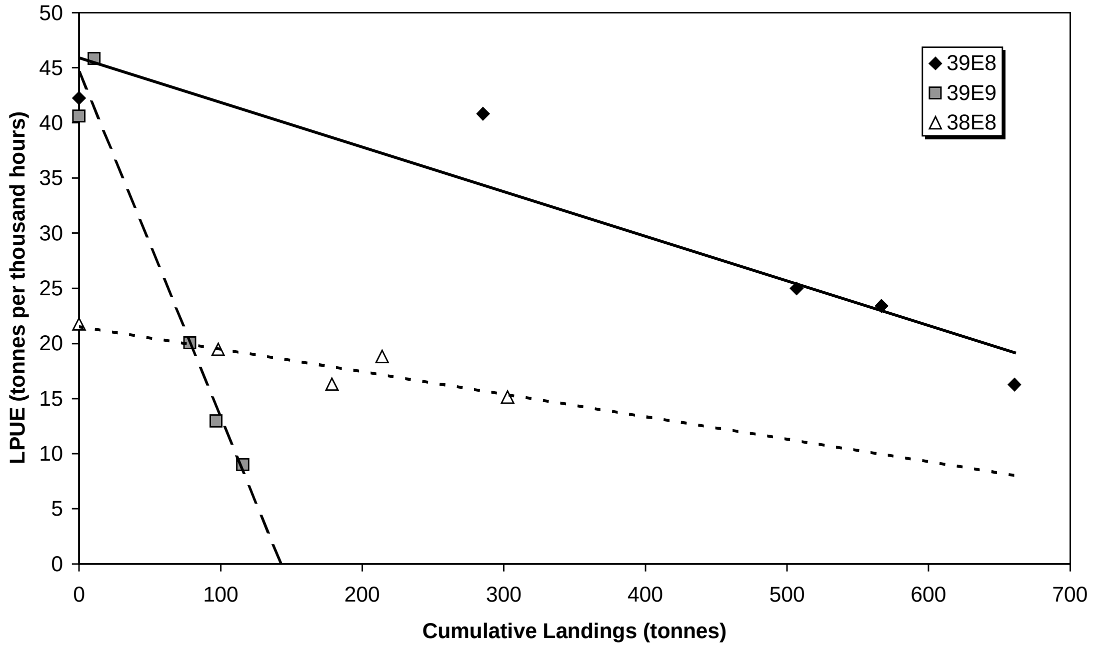


Figure 4.1.5 Depletion plots for three main rectangles of the Farn Deep *Nephrops* fishery in 1992.

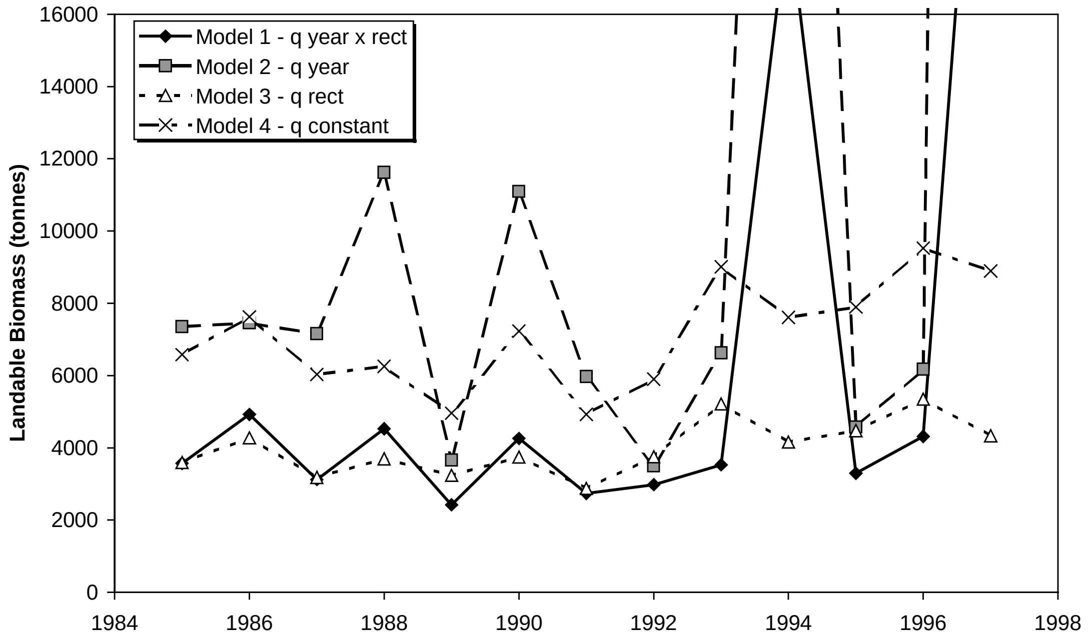


Figure 4.1.6 Farn deeps landable biomass estimates for Model 1 to 4.

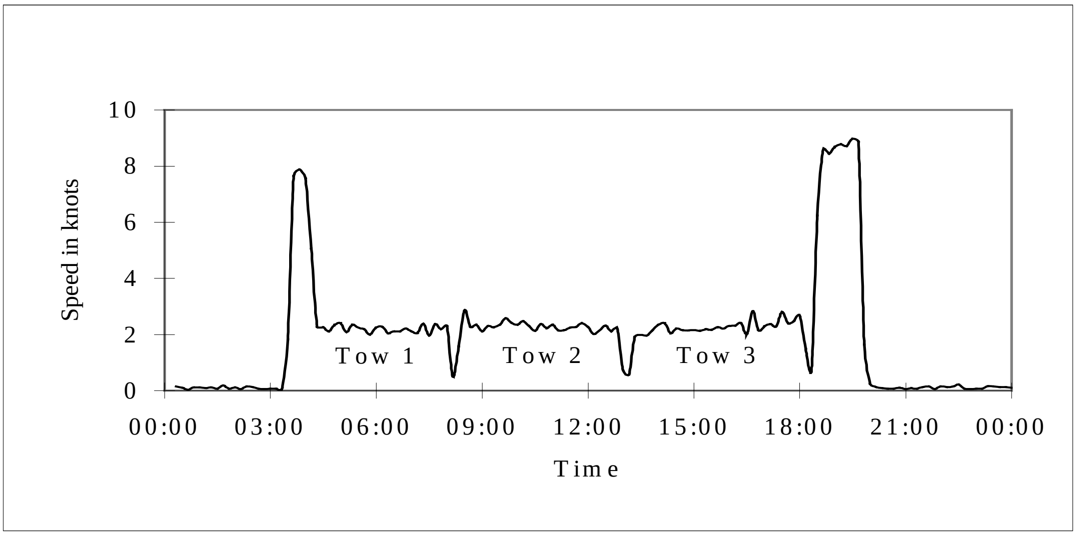


Figure 4.2.1 A typical example of one day's trawling activity for one of the sampled vessels showing three distinct tows.

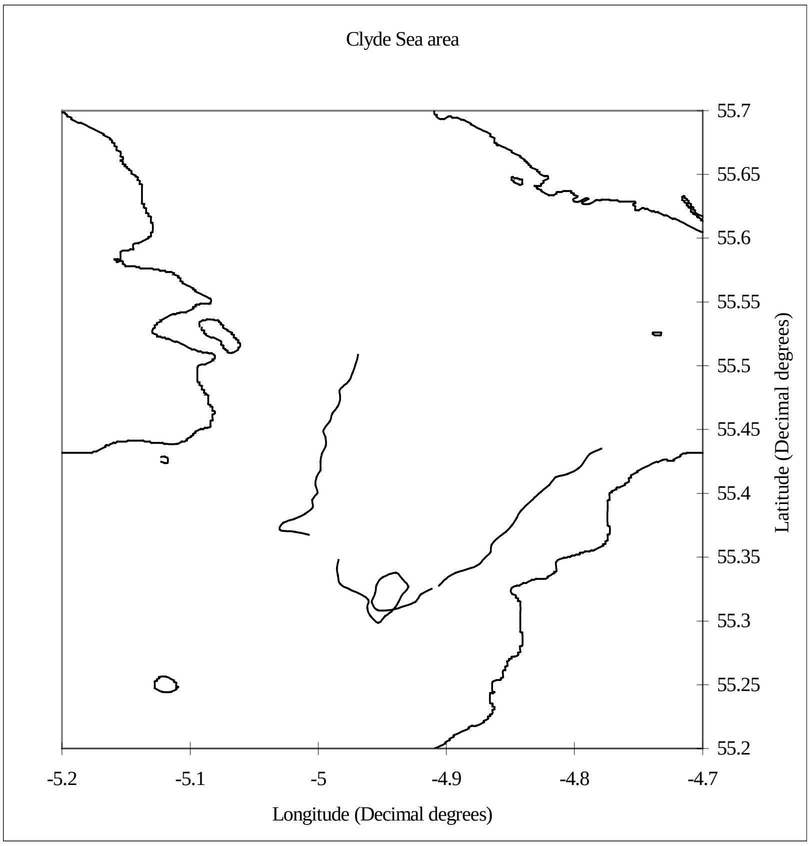


Figure 4.2.2 Location of the trawl tracks from the above example on a digitised map of the SE Clyde. The Isle of Arran is located in the upper left hand corner.

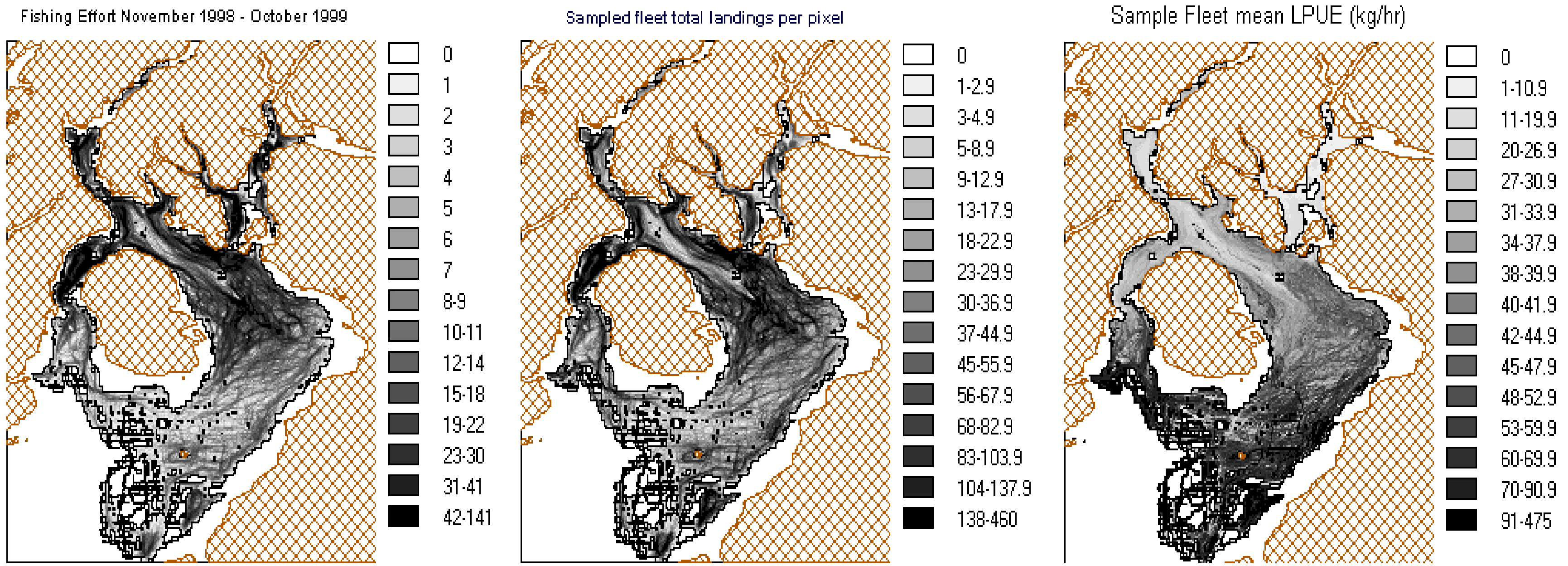


Figure 4.2.3 Fishing effort (number of times a pixel was fished), total landings per pixel (kg per pixel) and mean LPUE (kg per hour) for the sampled fleet over the 12-month study period in the Firth of Clyde

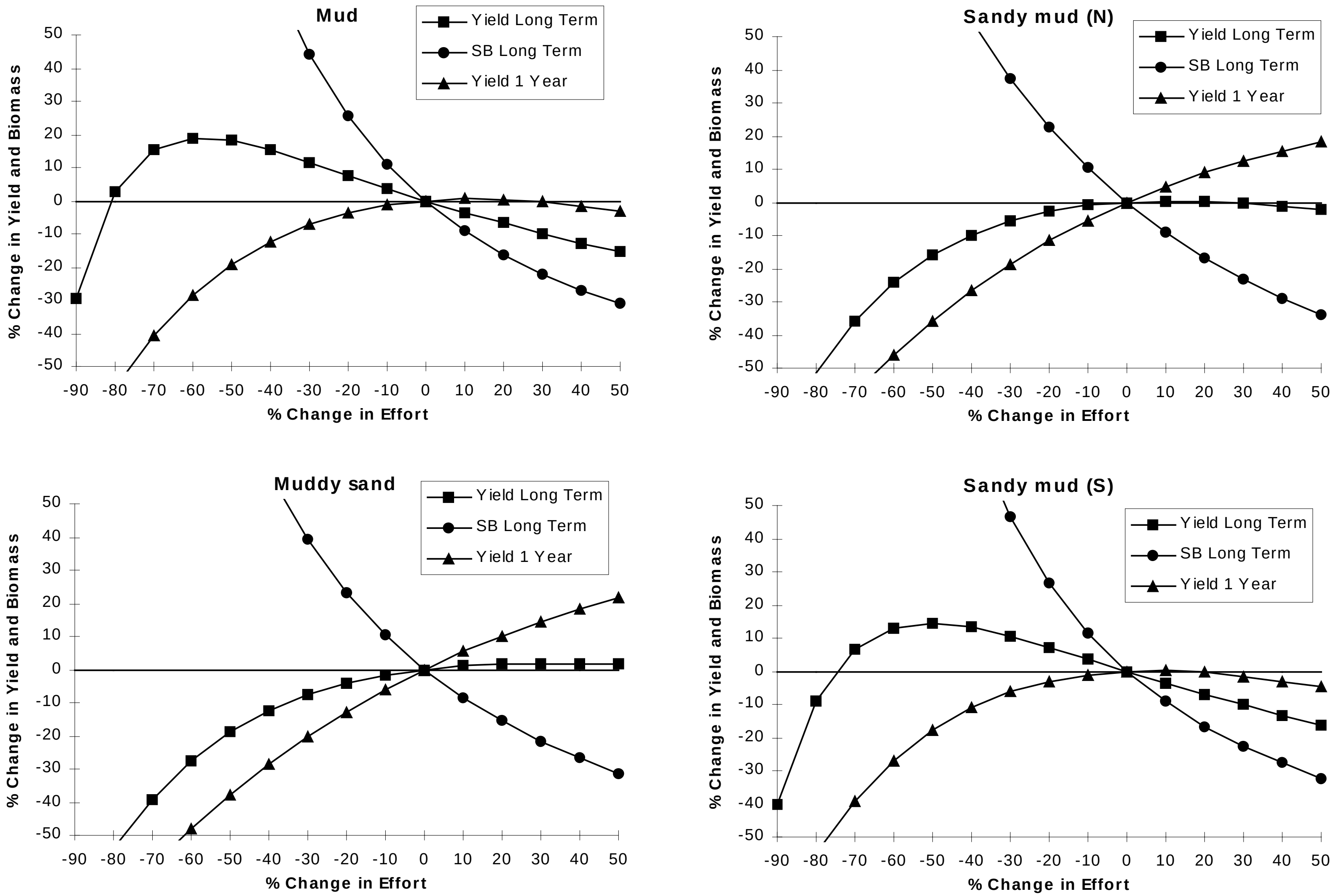


Figure 4.2.4. Firth of Clyde: Percentage changes in long term landings and stock biomass and short term landings following various changes in fishing effort for males. BGS sediment derived strata shown separately.

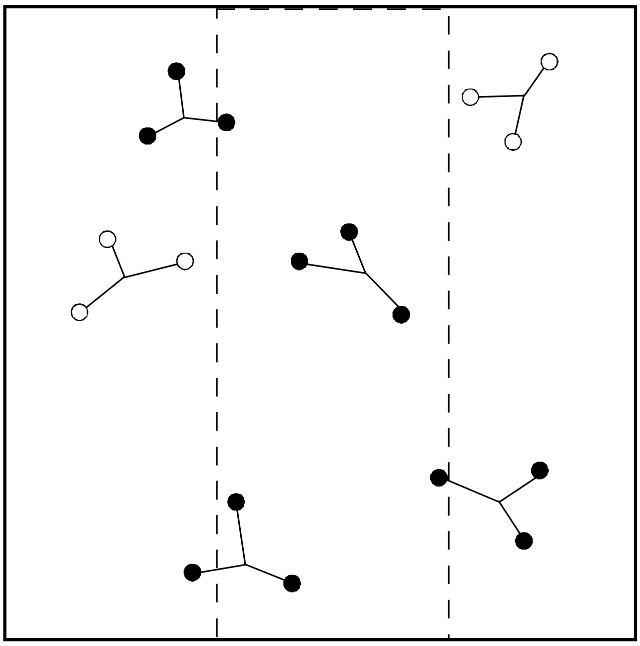


Figure 5.2.1 Pictorial simplification of the burrow counting methodology. The extent of the area of seabed viewed at a station is indicated by the dashed rectangle. Burrow systems with an opening within this area, which therefore would be counted, are indicated as solid circles. Burrow systems without an opening in the viewed area are indicated as hollow circles. Figure shows all burrows with three openings, but simulation allows number of openings to vary.

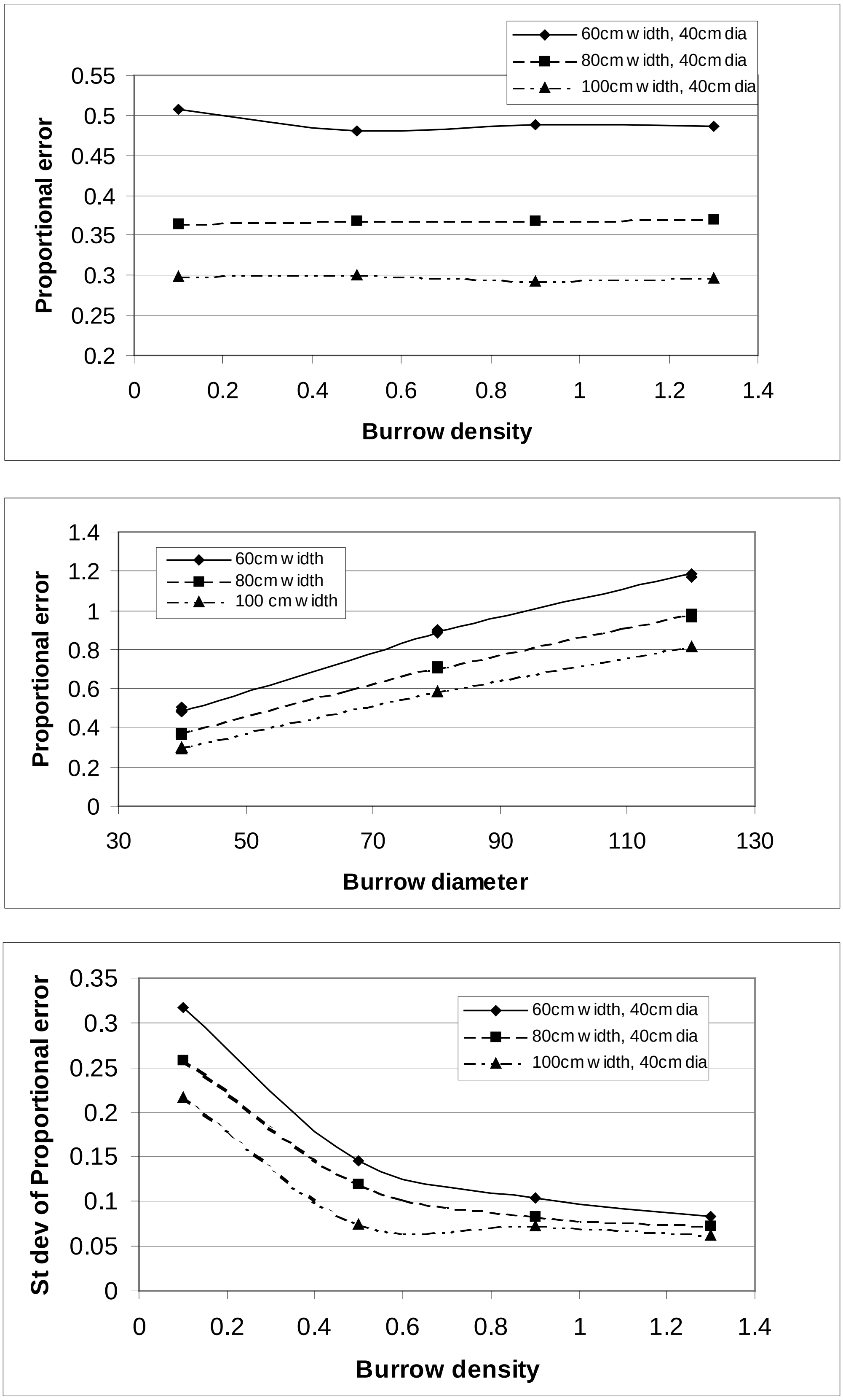


Figure 5.2.2 Plots of Proportional error in relation to Burrow density and Burrow diameter, and Standard deviation of Proportional error in relation to burrow density, from the second simulation.

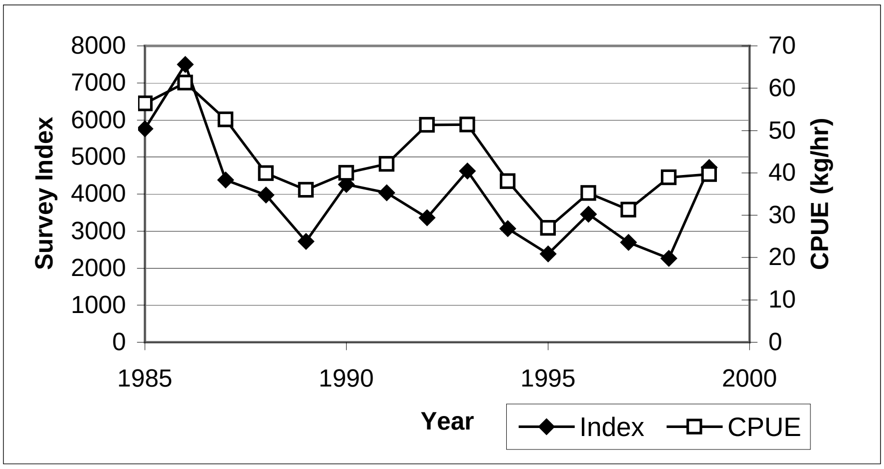


Figure 5.3.1 Long term trends in commercial CPUE and survey indices for the Icelandic FU.

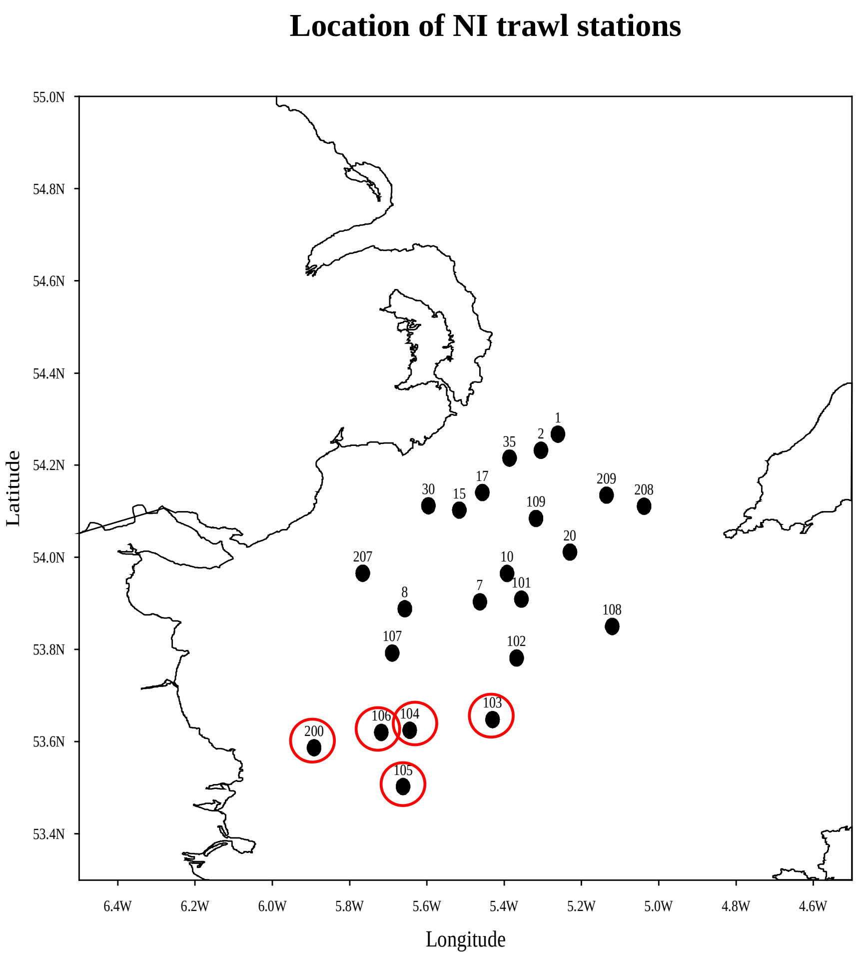


Figure 5.3.2 NI trawl stations sampled since 1994, with those included in the comparison with the ROI survey data circled.

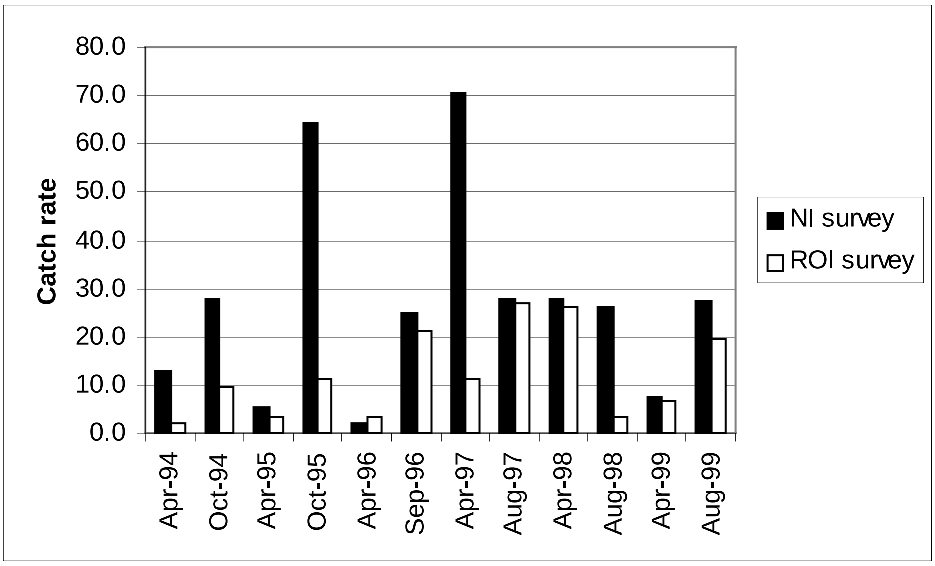


Figure 5.3.3 Trends in NI and ROI surveys for overlapping stations.

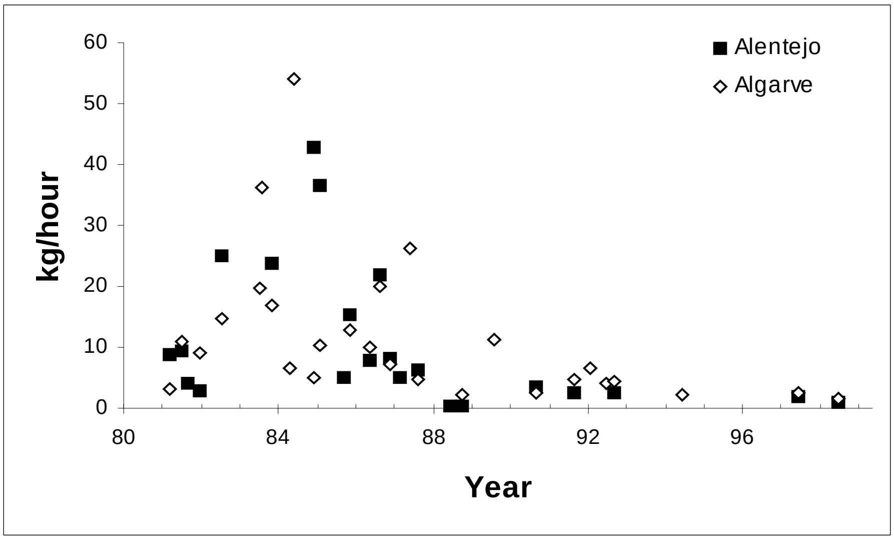


Figure 5.3.4 Variations in Research Vessel survey catch rates for the Alentejo (FU28) and Algarve (FU29) stocks.

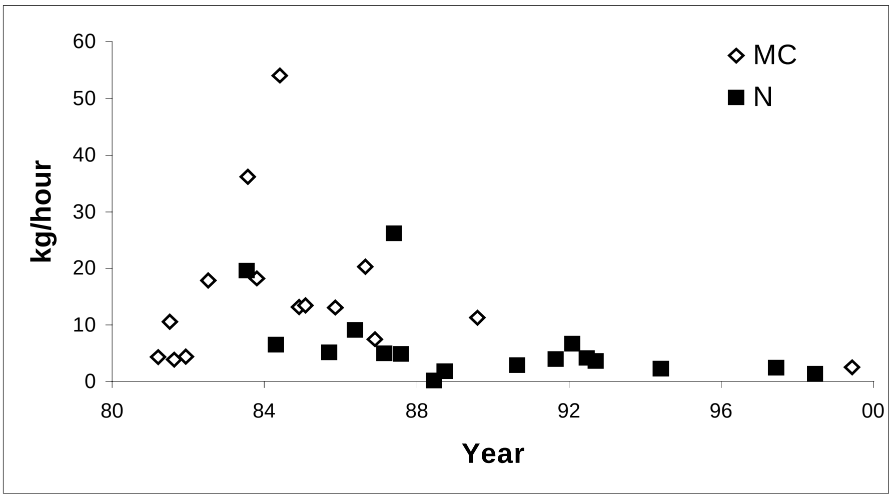


Figure 5.3.5 Variations in RV catch rate for whole Portuguese survey area.

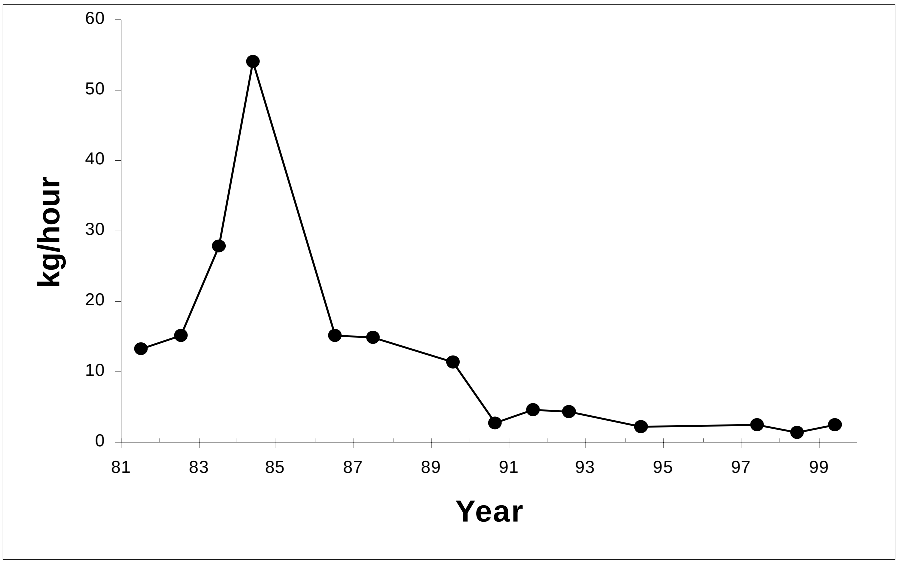


Figure 5.3.6 Trend in catch rate from Portuguese surveys carried out during summer months (May – August).

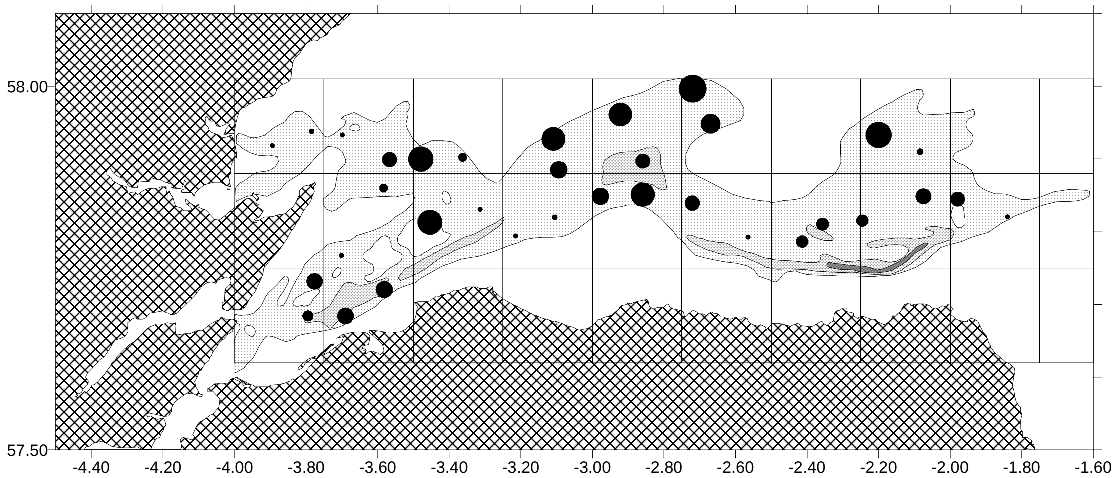


Figure 5.4.1 Map of TV stations for initial Moray Firth survey (size of dot scaled to burrow density).

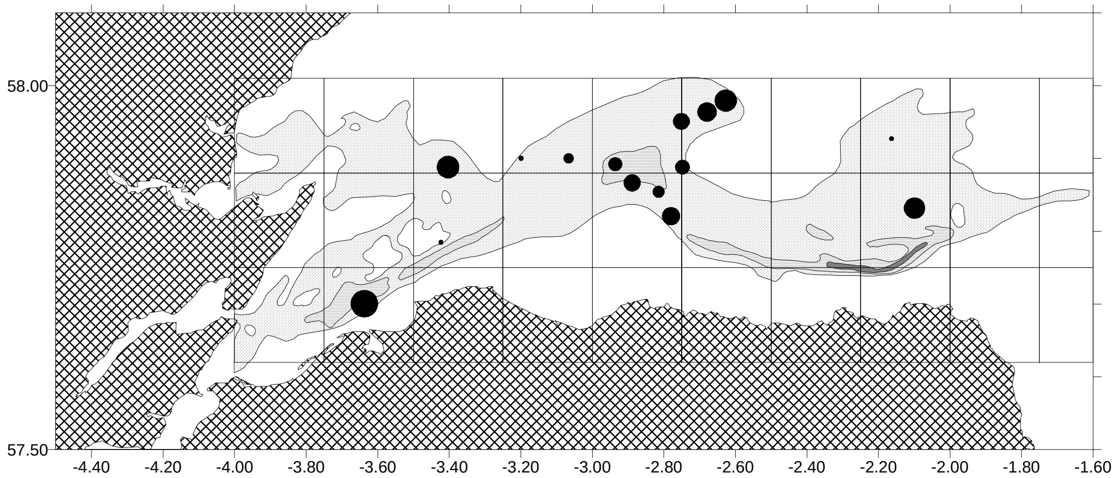


Figure 5.4.2 Map of additional TV stations for second stage of Moray Firth survey (size of dot scaled to burrow density).

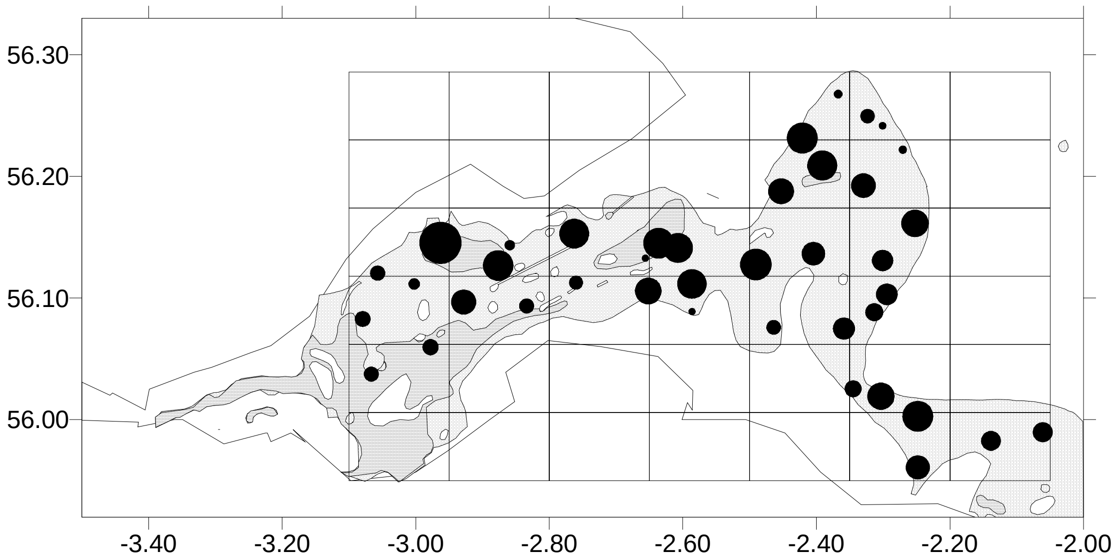


Figure 5.4.3 Map of TV stations for initial Firth of Forth survey (size of dot scaled to burrow density).

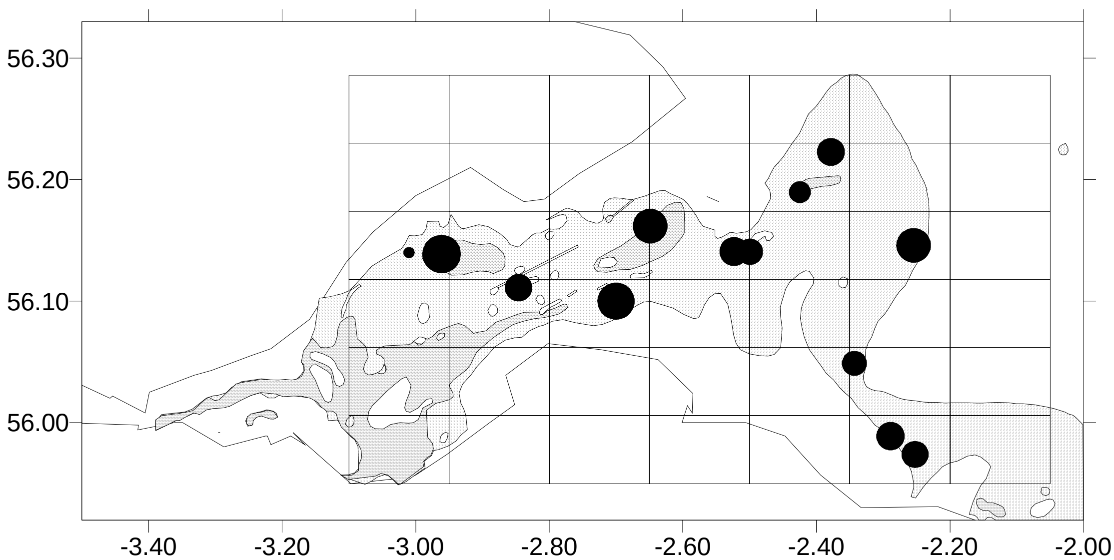
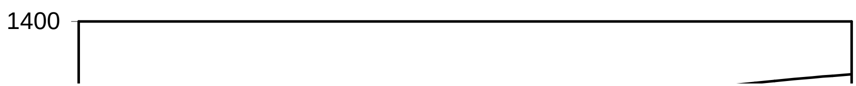
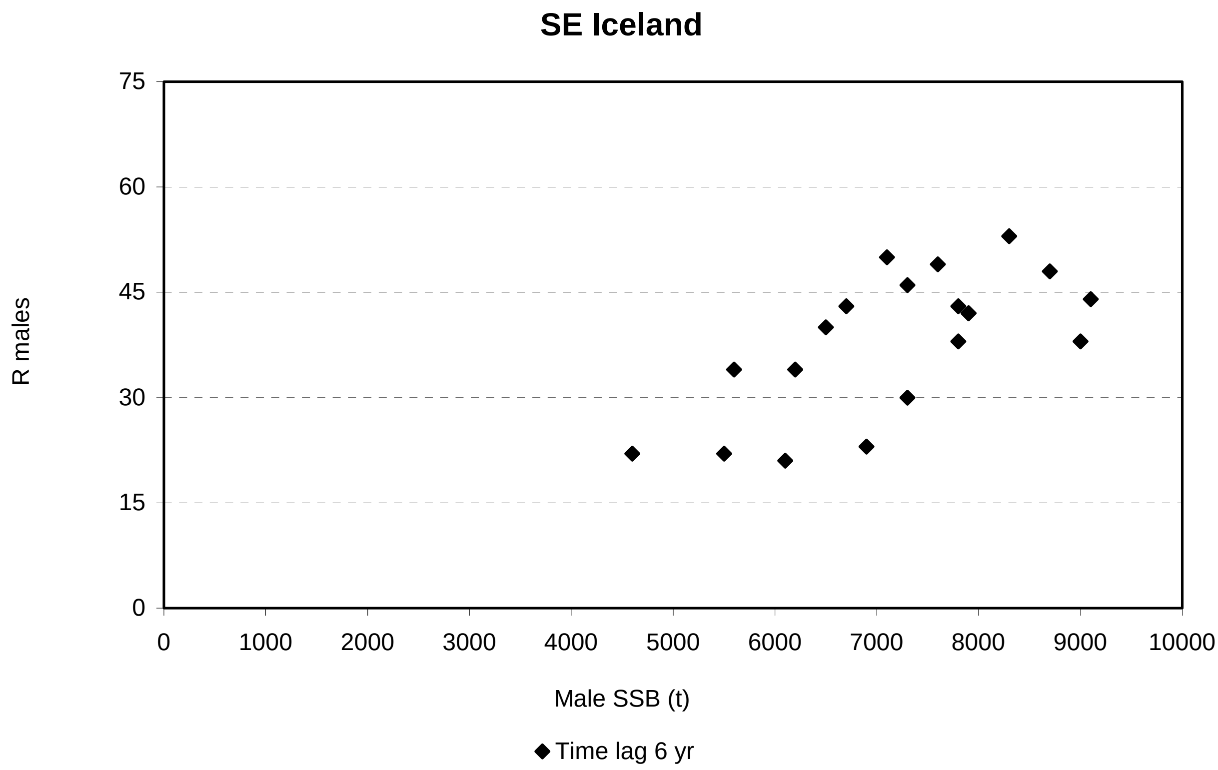


Figure 5.4.4 Map of additional TV stations for second stage of Firth of Forth survey (size of dot scaled to burrow density).





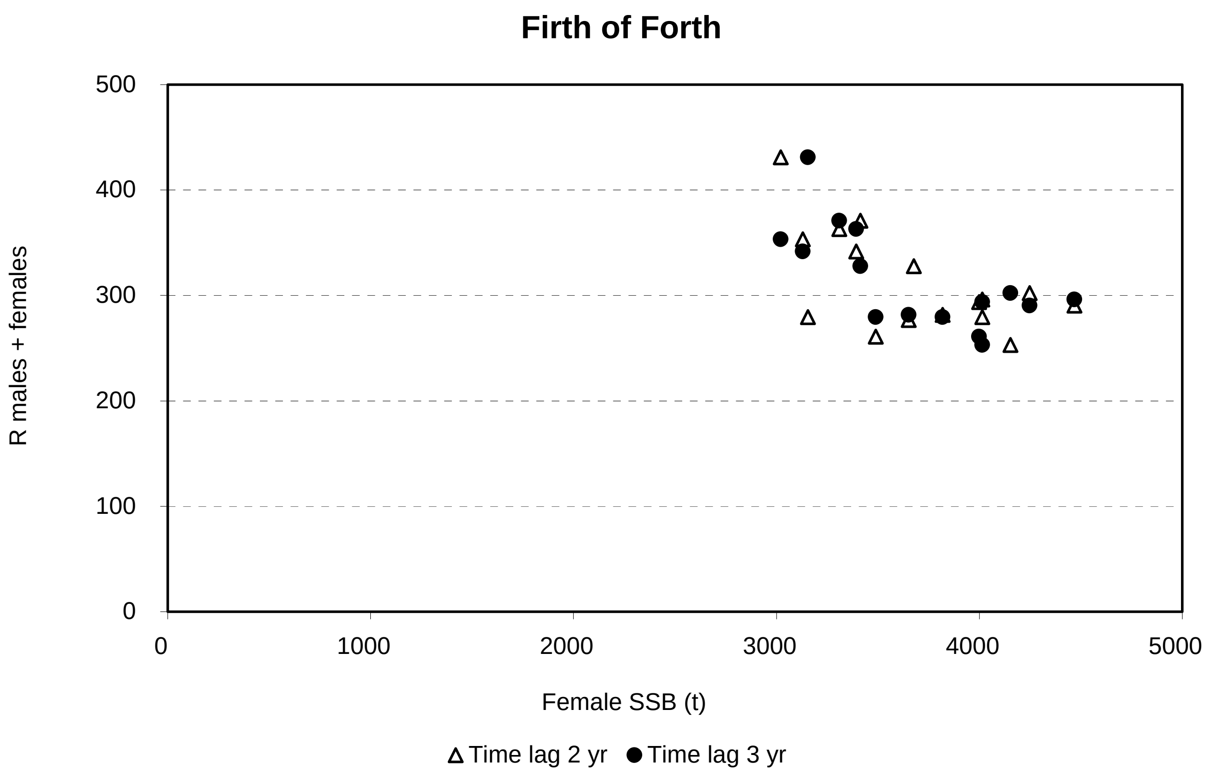
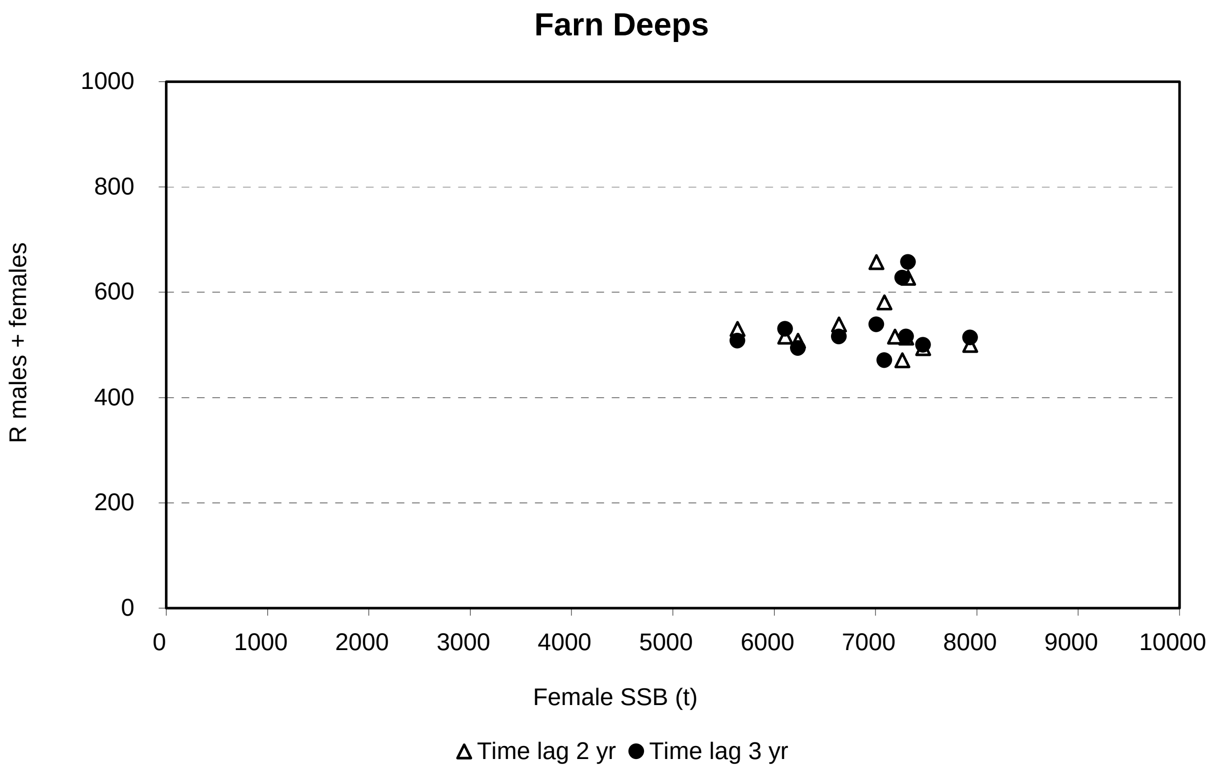


Figure 6.2.2.A. - Relationships between recruitment and SSB, as estimated by XSA.



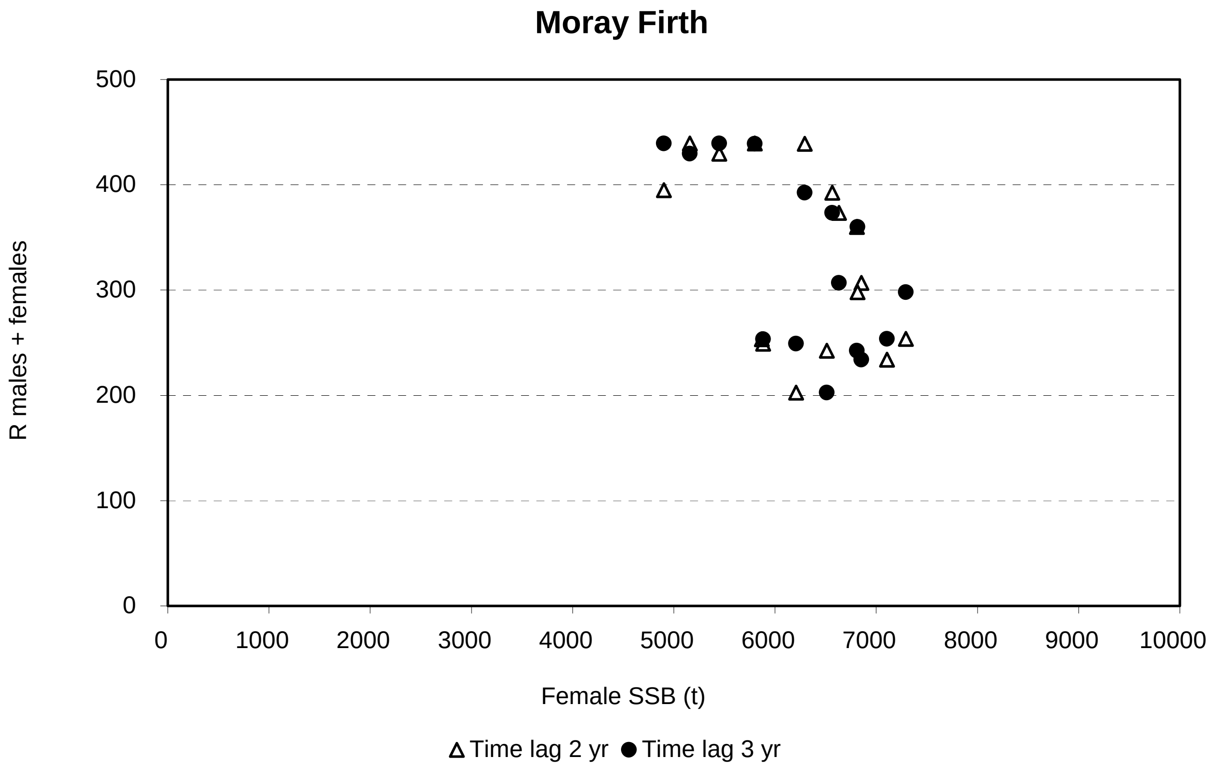


Figure 6.2.2.B. - Relationships between recruitment and SSB, as estimated by XSA.

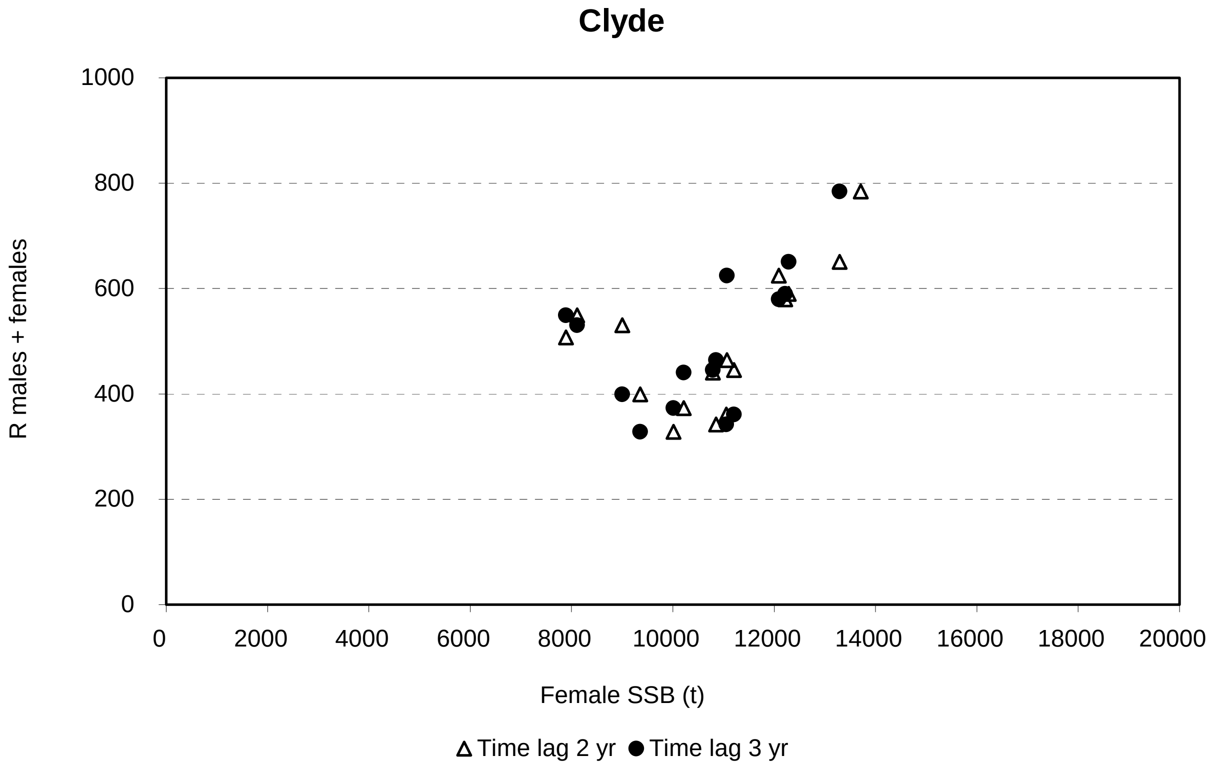


Figure 6.2.2.C. - Relationships between recruitment and SSB, as estimated by XSA.

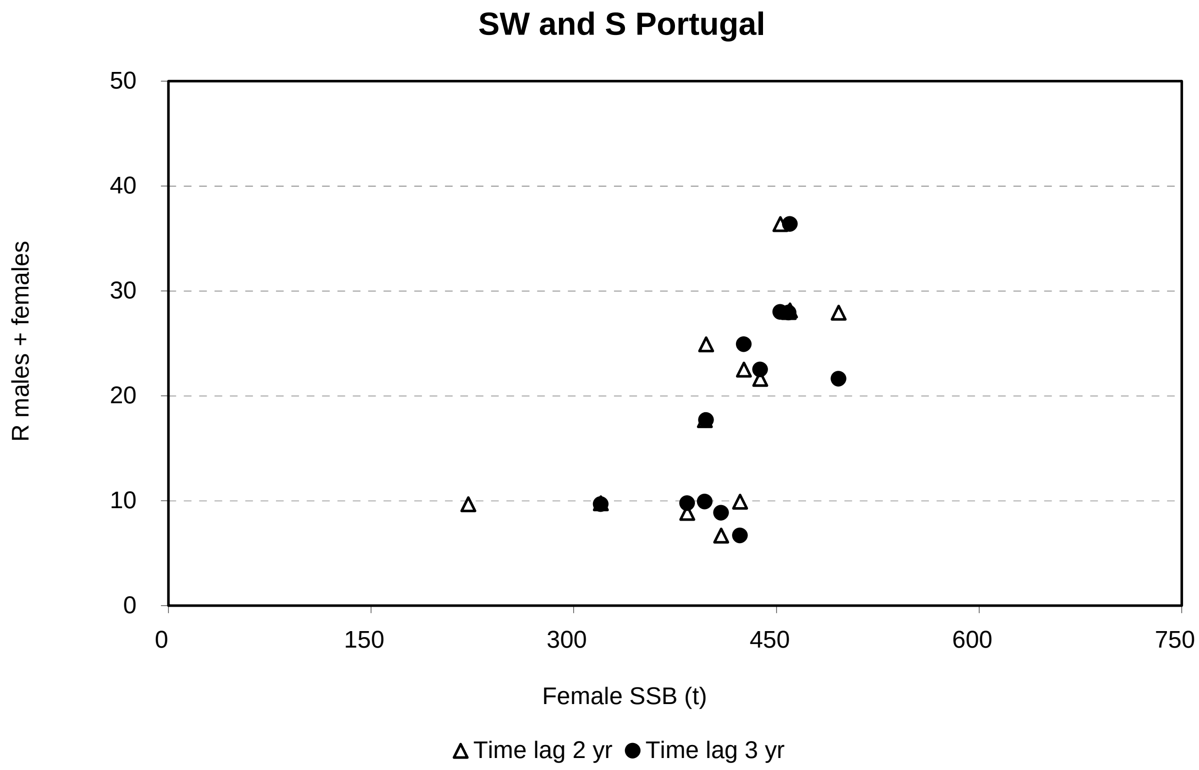
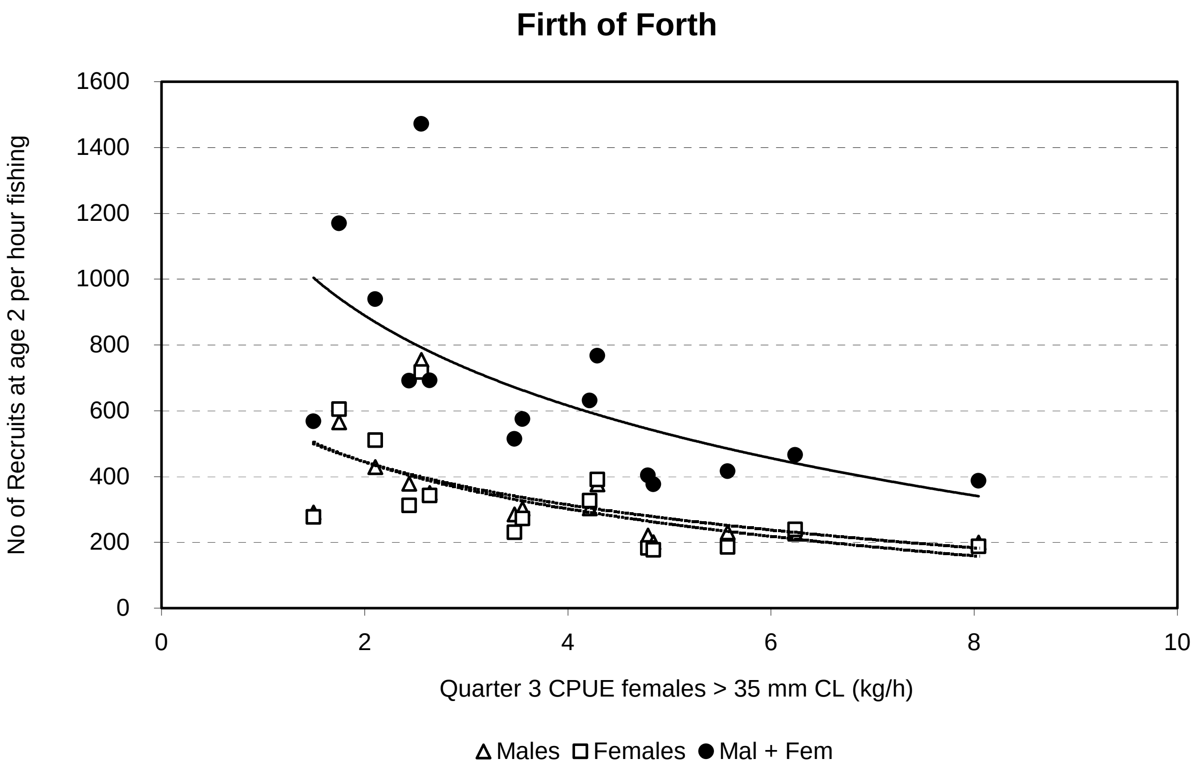


Figure 6.2.2.D. - Relationships between recruitment and SSB, as estimated by XSA.



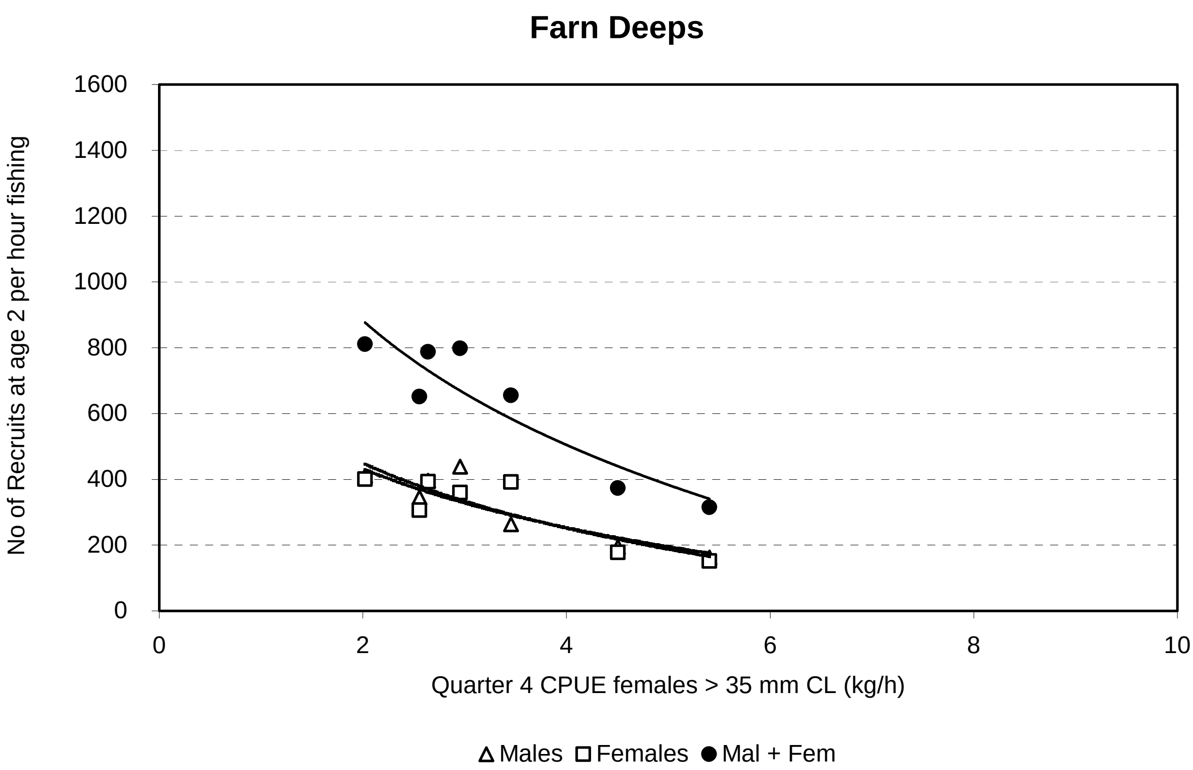
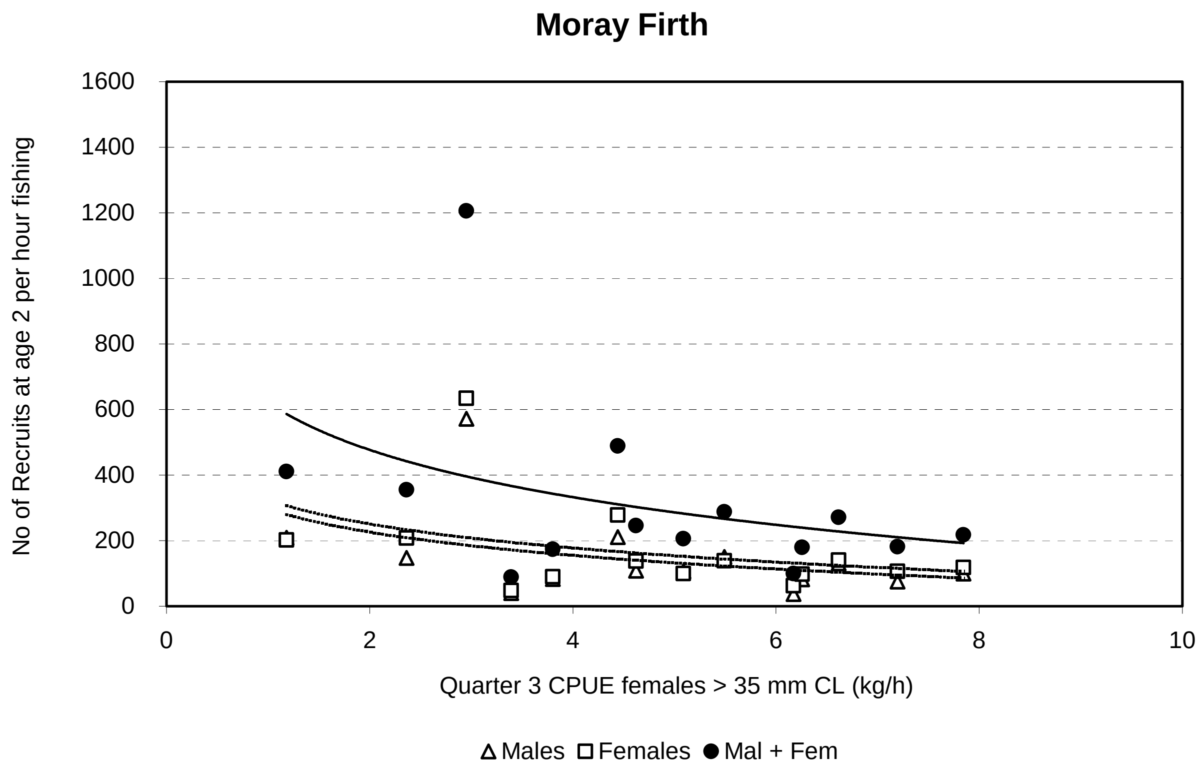


Figure 6.2.3.A. - Relationships between recruitment and index of mature female stock size.



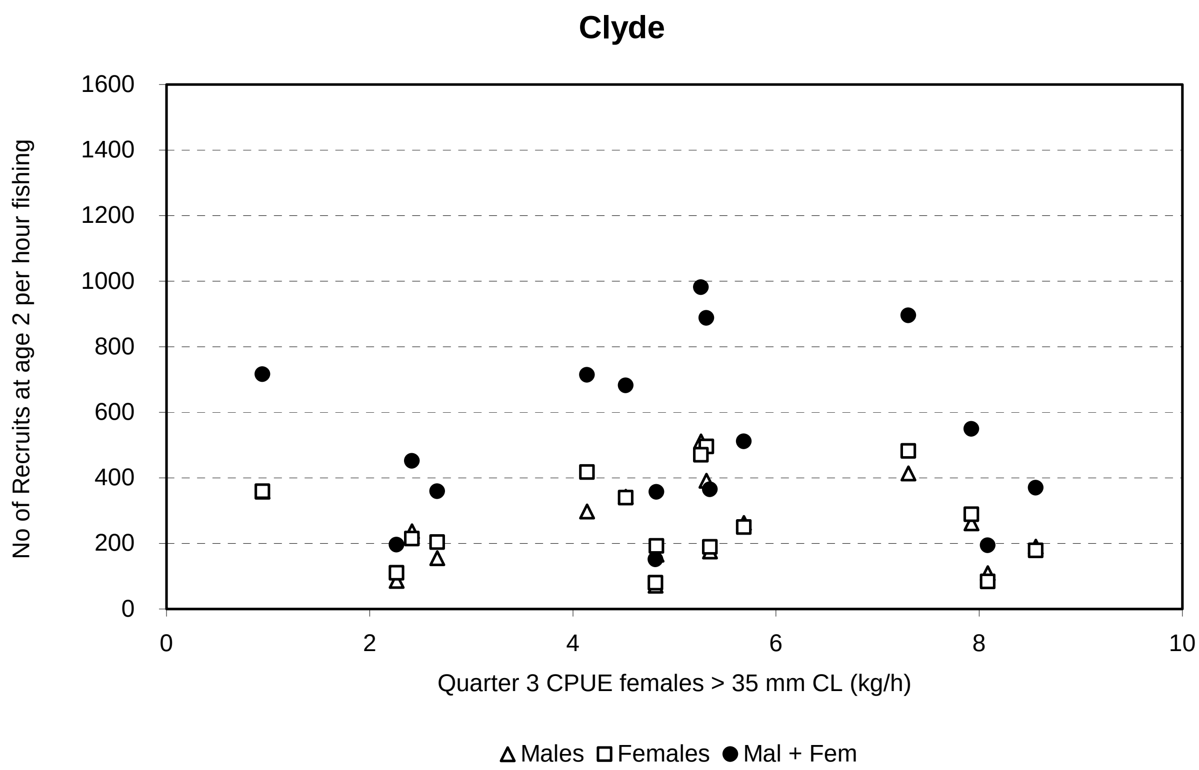
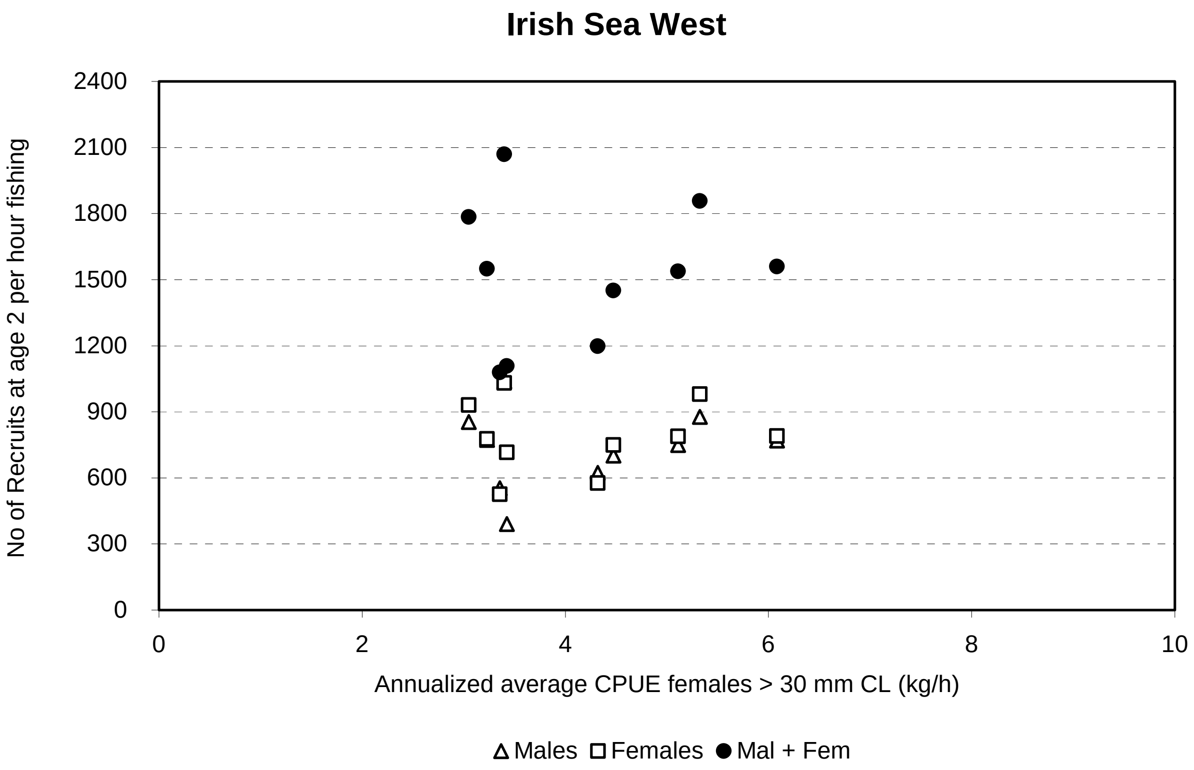


Figure 6.2.3.B. - Relationships between recruitment and index of mature female stock size.



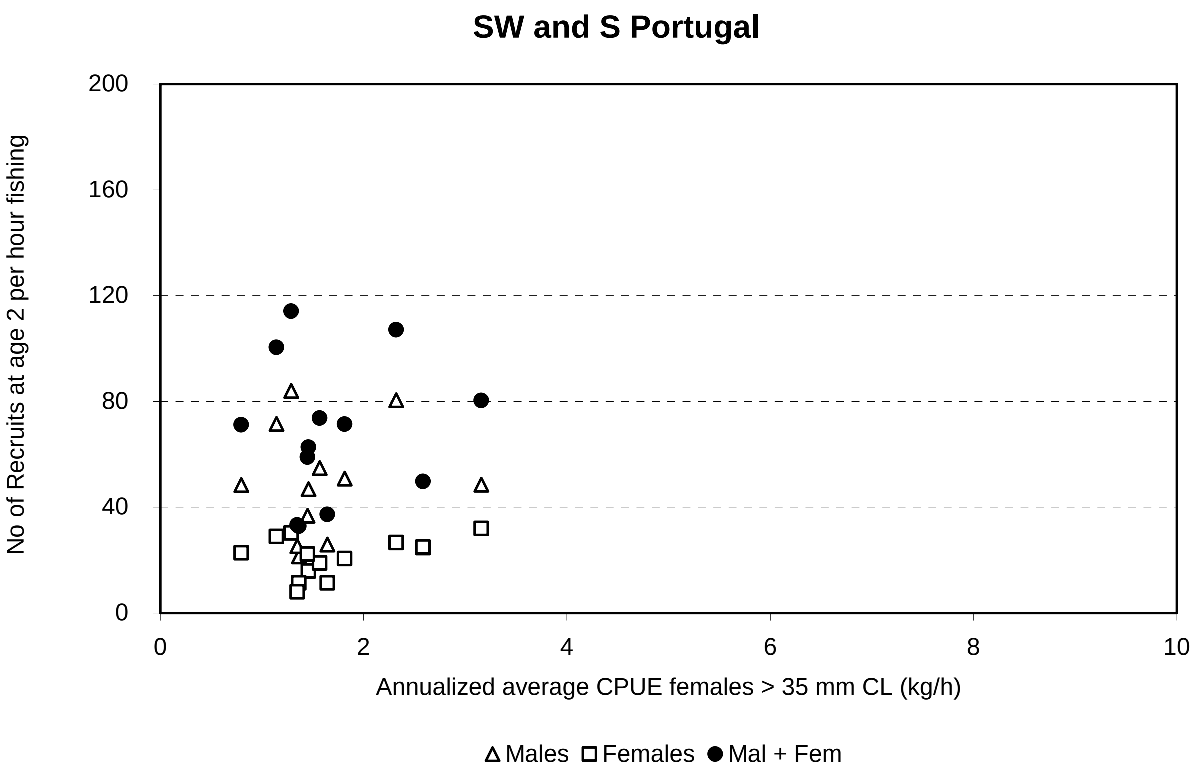
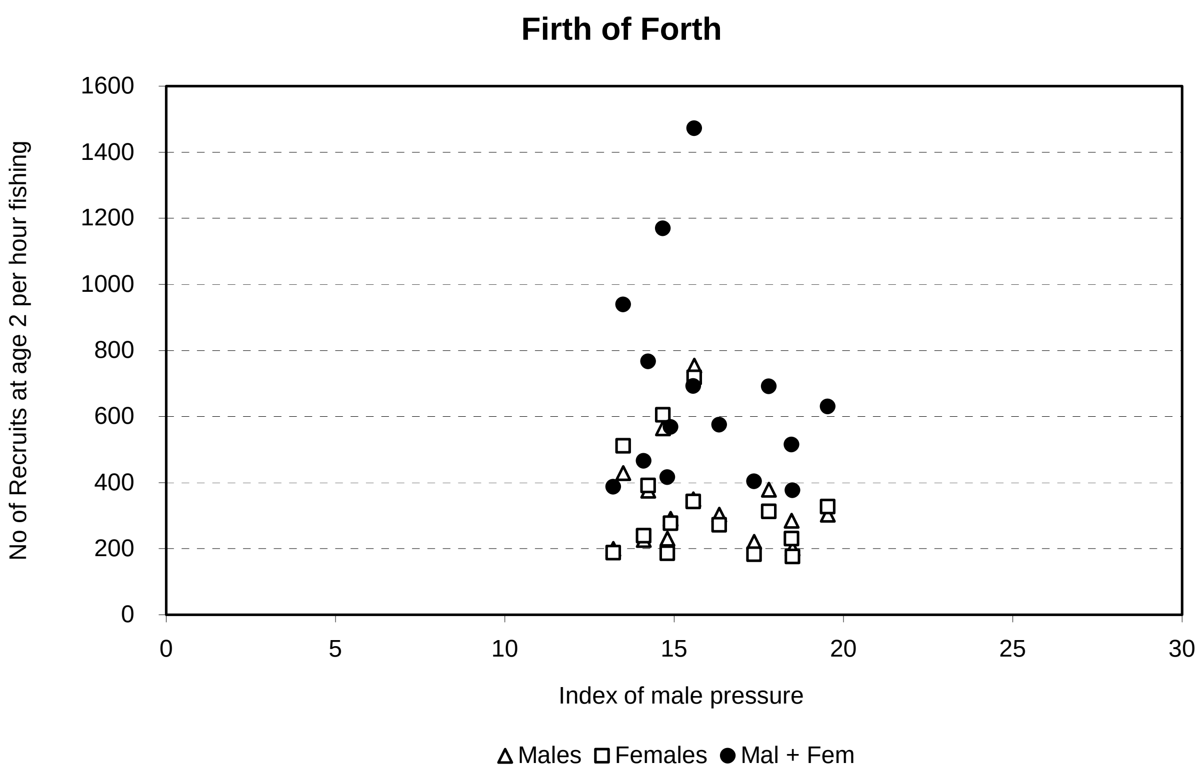


Figure 6.2.3.C. - Relationships between recruitment and index of mature female stock size.



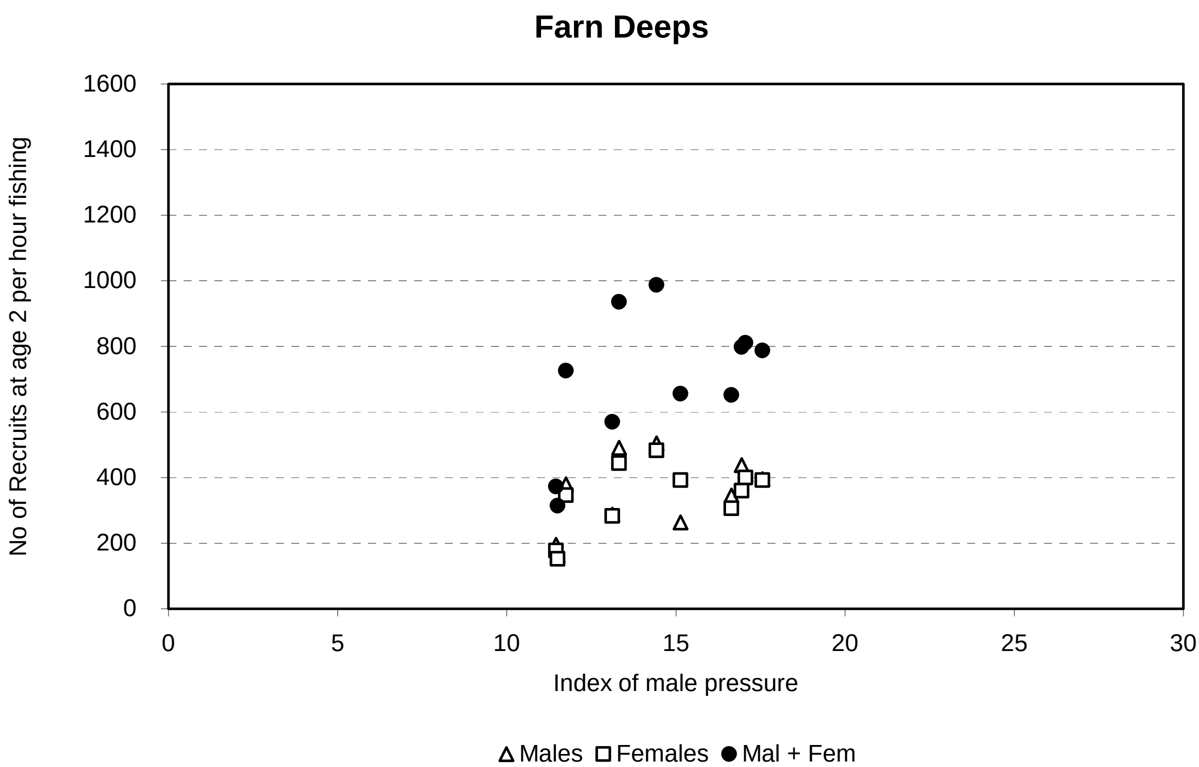
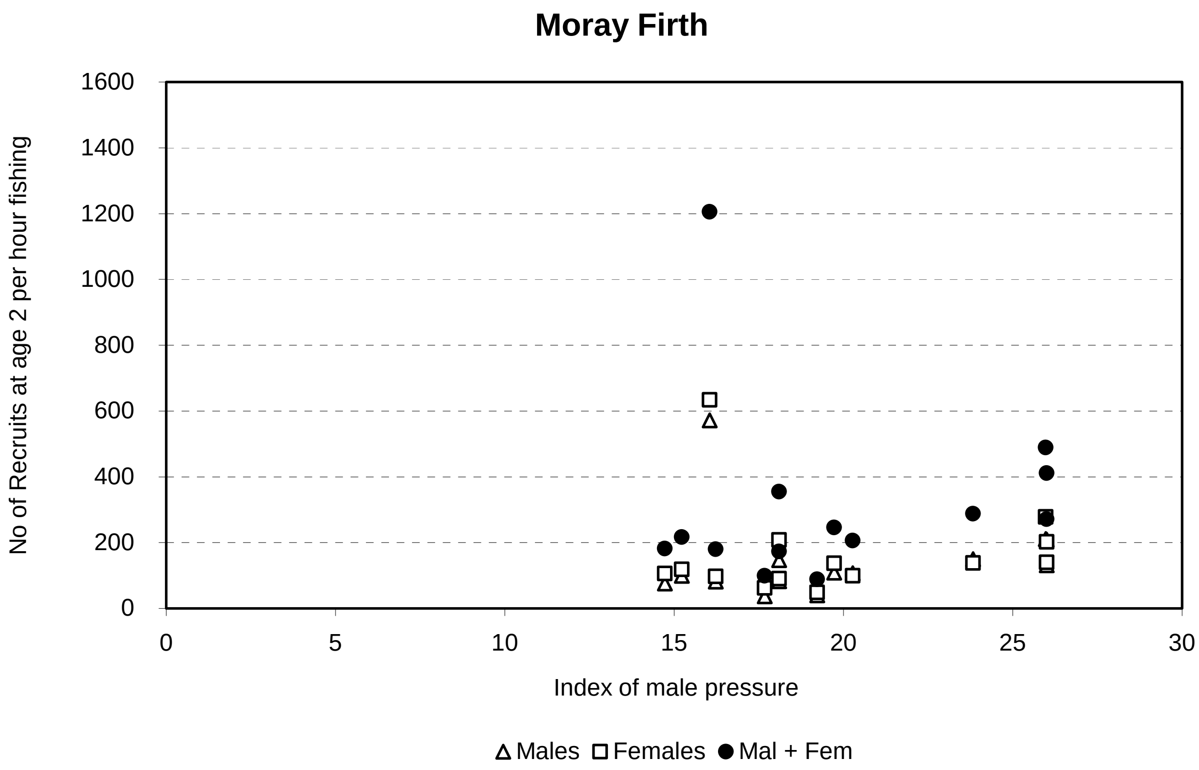


Figure 6.2.4.A. - Relationships between recruitment and index of predation and competition pressure exerted by adult male population component.



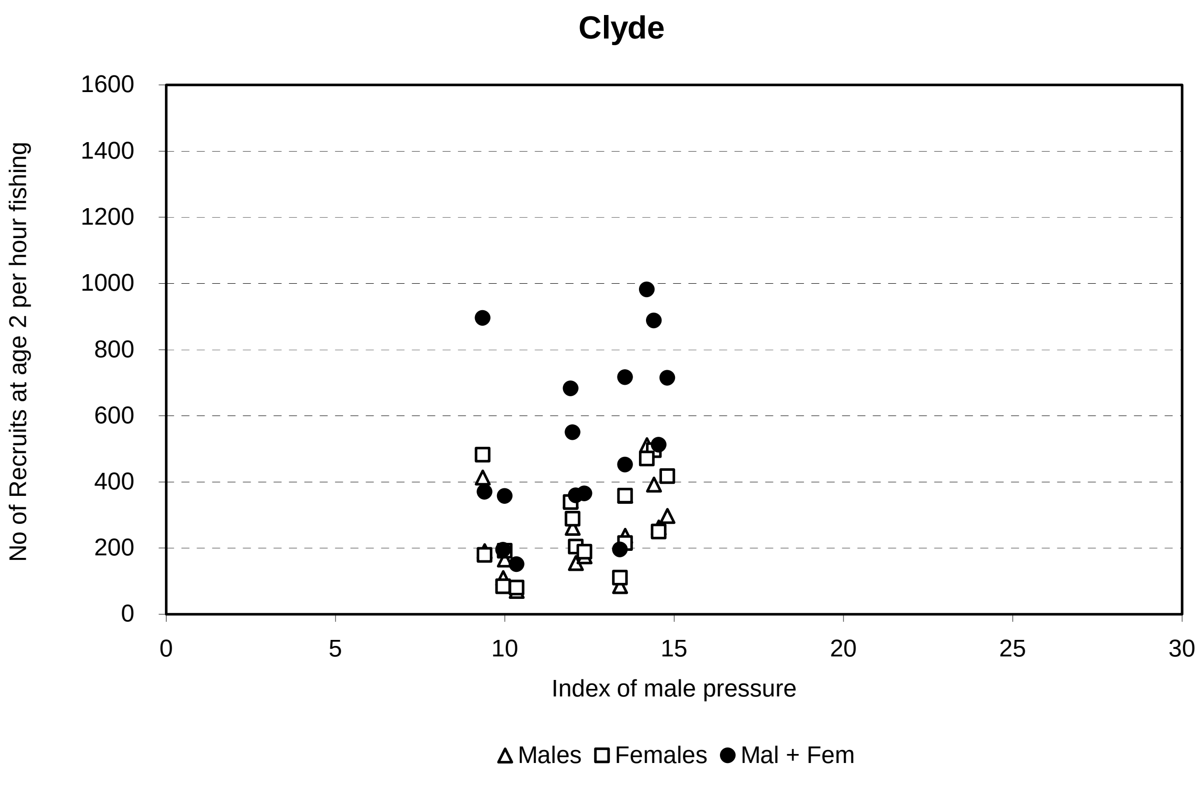
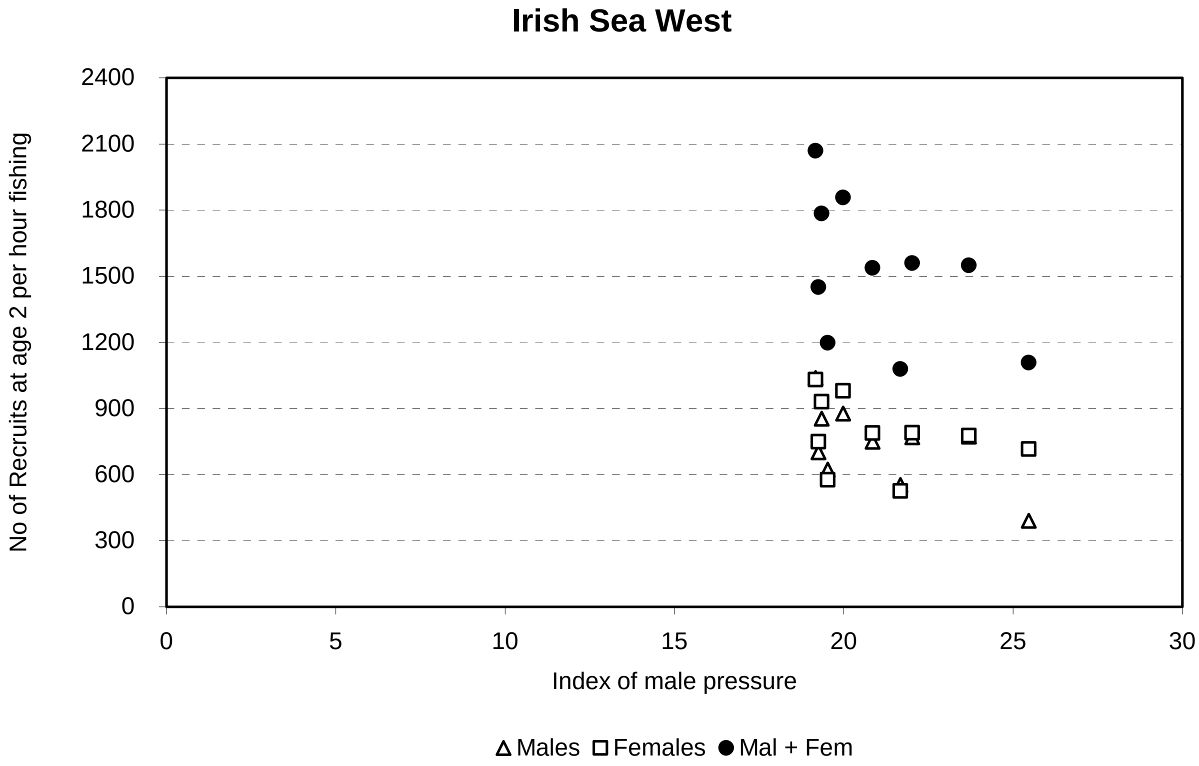


Figure 6.2.4.B. - Relationships between recruitment and index of predation and competition pressure exerted by adult male population component.



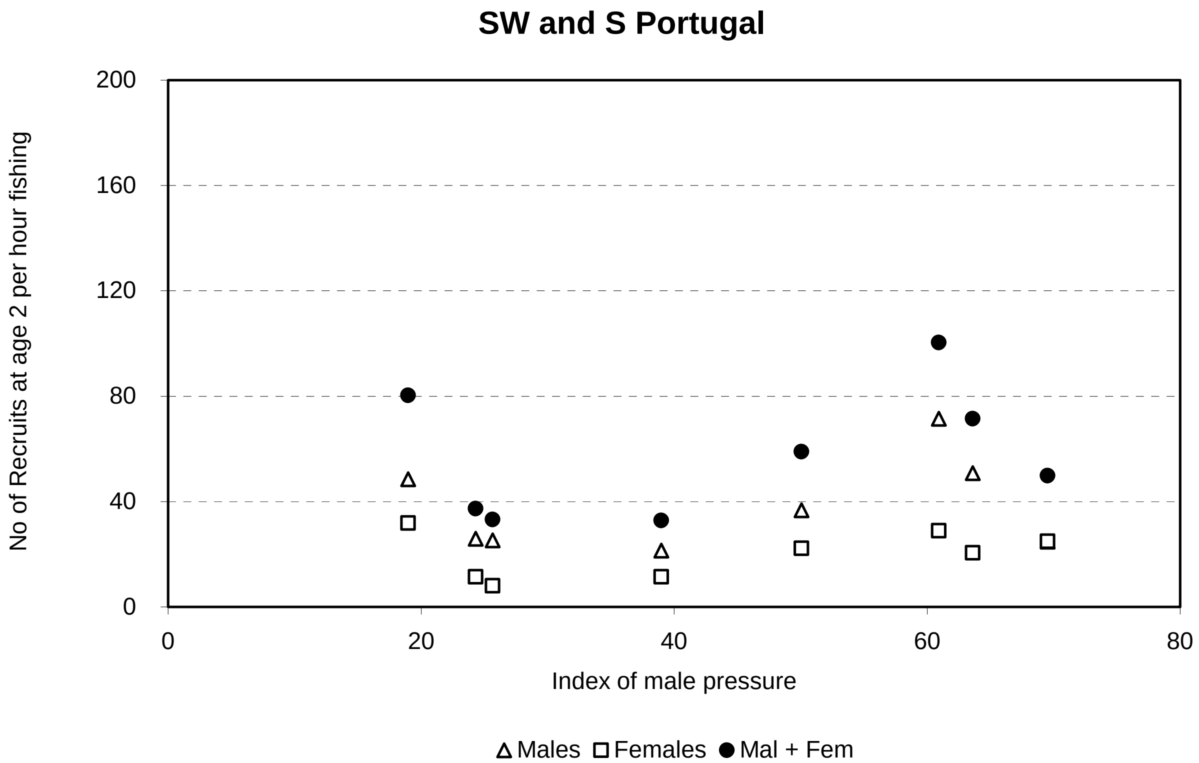


Figure 6.2.4.C. - Relationships between recruitment and index of predation and competition pressure exerted by adult male population component.

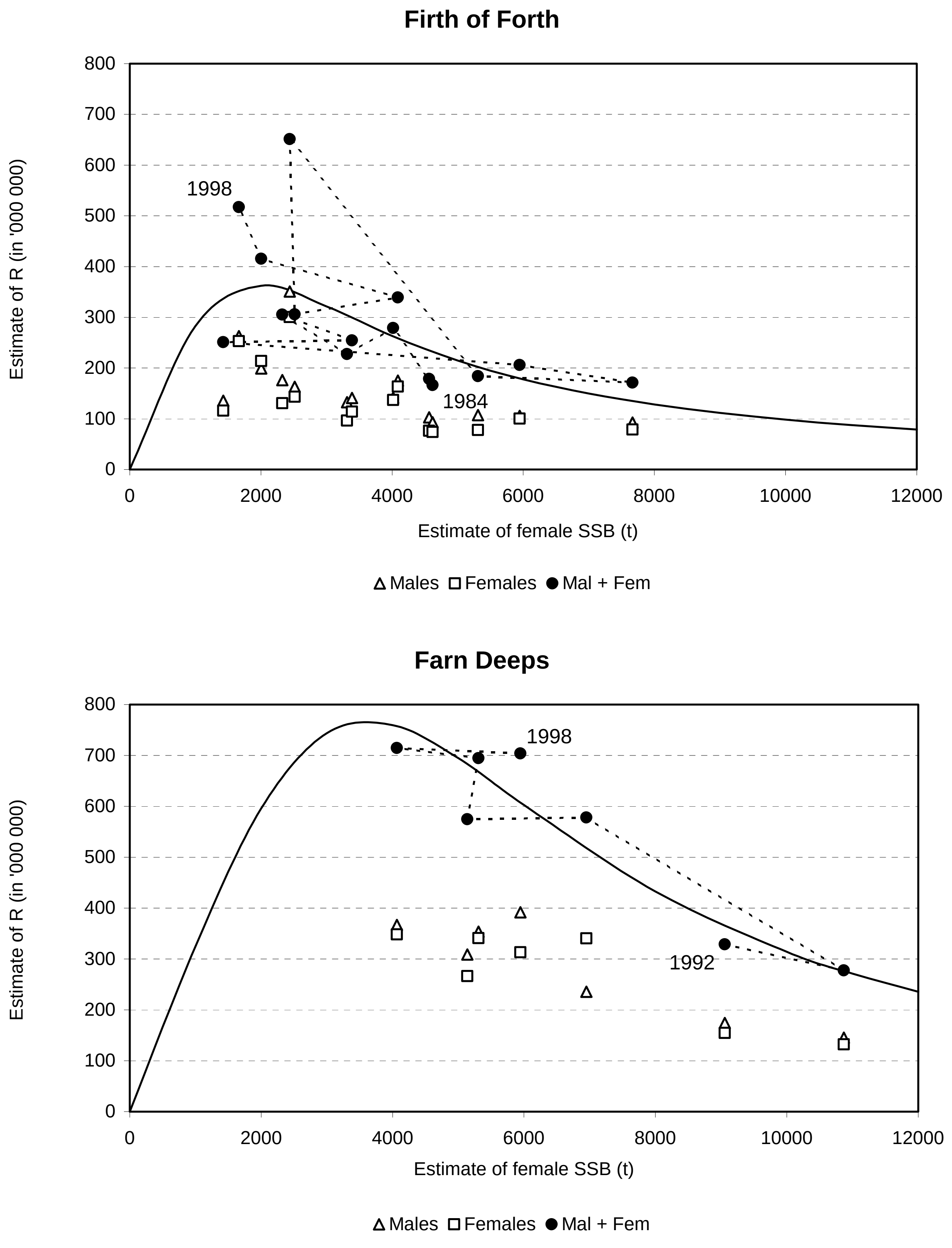
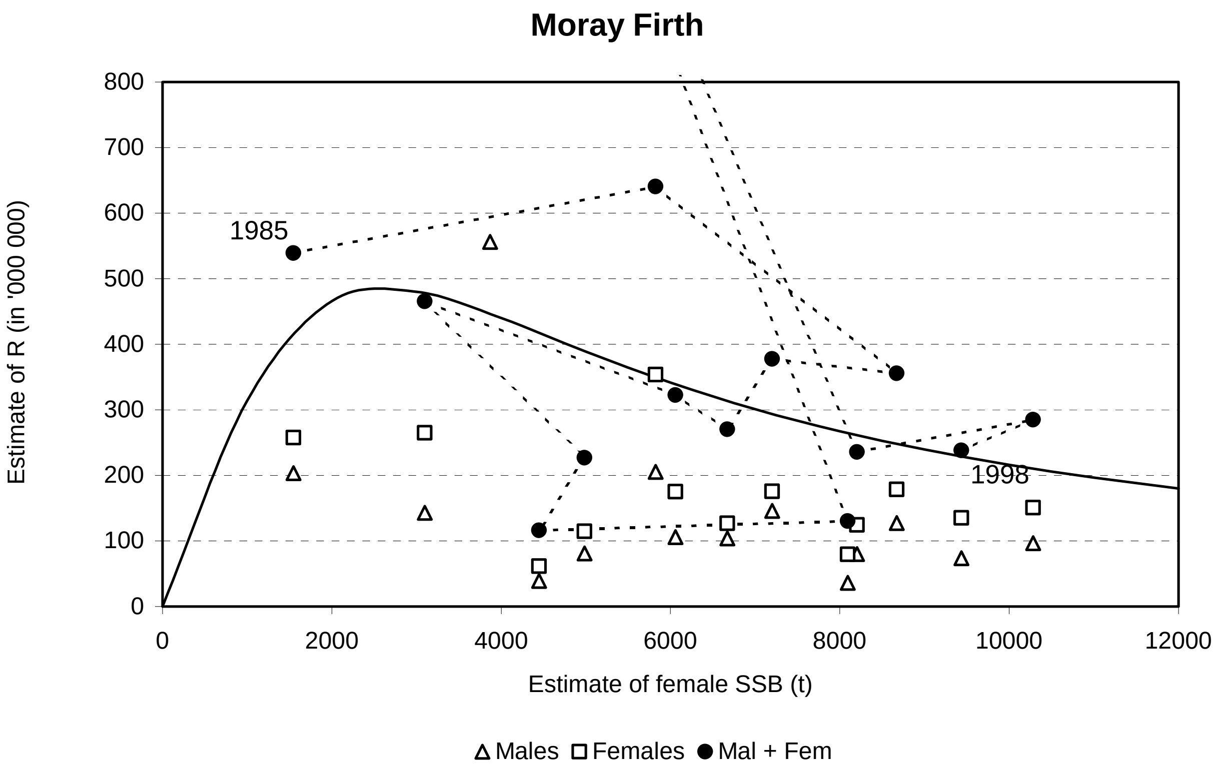


Figure 6.2.5.A. - Relationships between recruitment and female SSB (rescaled).



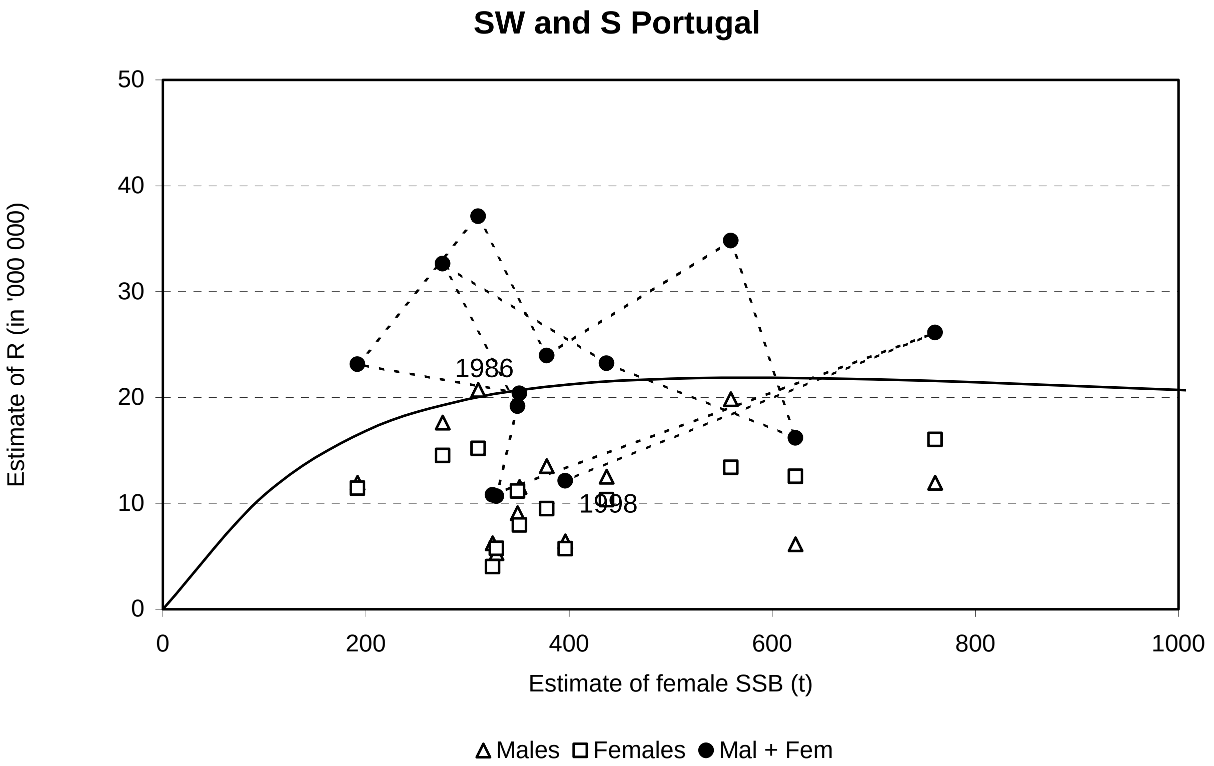


Figure 6.2.5.B. - Relationships between recruitment and female SSB (rescaled).

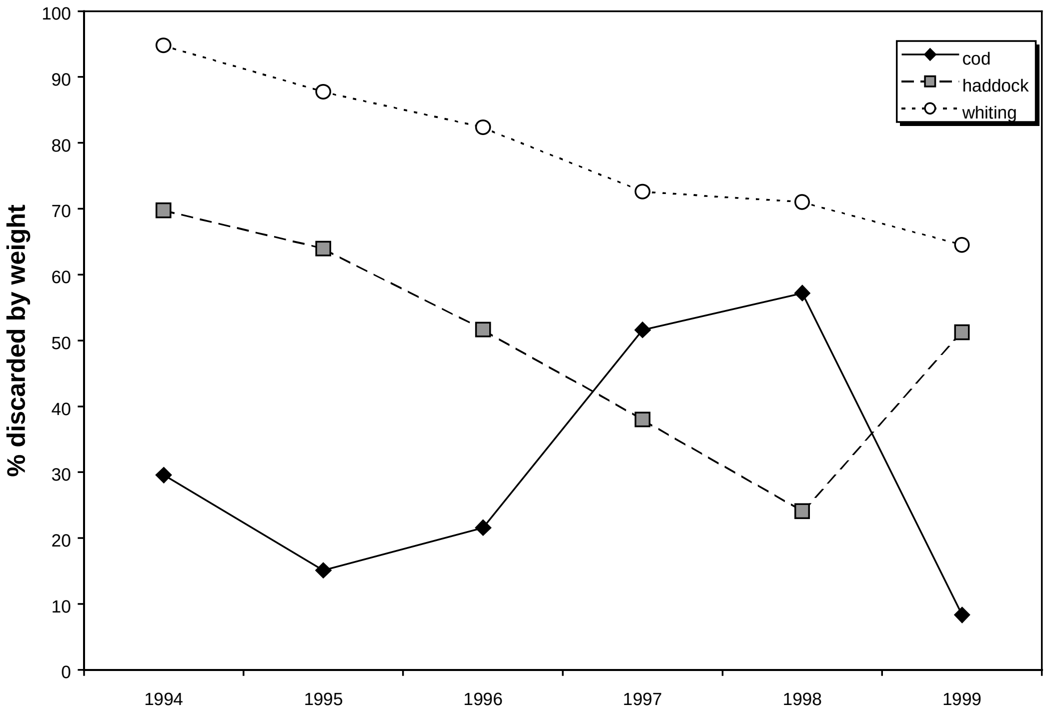


Figure 8.1.1 Fish discards (% by weight) on *Nephrops* fishing vessels in the Farn Deeps 1994-1999

APPENDIX 1

Dynamic Factor Analysis to detect common trends in *Nephrops* LPUE and CPUE time series

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Introduction

In this working paper time series of landing per unit effort (LPUE) and catch per unit effort (CPUE) of *Nephrops* are analysed. The LPUE series were measured for various stocks around Scotland, namely the Clyde, Forth, Fladen, Moray Firth, North Minch and South Minch. The series are available on an annual basis from 1965 up to 1998. The underlying question in the LPUE series is: 'what's going on?' The CPUE data are divided in *Nephrops* smaller than 35mm, and larger than 35mm. The CPUE (<35mm) data are available from Clyde, Forth, Moray Firth, North Minch and South Minch from 1990 up to 1998 on a quarterly basis. The CPUE data larger than 35mm are available from 1981. The underlying questions for the CPUE data are (i) what is going on and (ii) are there any relationships between CPUE data and mean sizes of individuals.

A common characteristic of many environmental time series studies is that the measured data consist of a relatively large number of short time series. The *Nephrops* data are not an exception to this. In order to answer questions like 'what's going on' and what are relationships between variables, only a limited number of statistical time series techniques exist for such data. One of them is dynamic factor analysis and is discussed in this paper. Dynamic factor analysis is a dimension reduction technique similar to factor analysis and principal component analysis, except that the factors/components are smoothing functions over time. A non-technical introduction is presented in Zuur et al (in prep.), and is summarised in Section 2. In Sections 3, 4 and 5 results for the LPUE, CPUE (<35mm) and CPUE (>35mm) are presented.

Methodology

The underlying model of dynamic factor analysis is a multivariate structural time series model. The general form of the structural time series model used in this paper is given by:

$$\text{data} = \text{trends} + \text{noise} \tag{1}$$

An interesting aspect of this structural time series model is that the trends can be stochastic. In this paper, we use random walk trends. This means that the trends in year t are equal to the trends in year t-1 plus a small noise component. As a result, the trends are not restricted to be neat straight lines or polynomial functions. Another aspect of the model is that it allows for a dimension reduction on the time series. Suppose that N time series are available. It is not uncommon in environmental studies that various series follow a similar pattern over time. Suppose that all time series follow the same pattern. In this case, a model containing one common trend would suffice. It might be that certain time series follow pattern A over time, whereas the other time series follow pattern B. In this case, a model with two common trends might be more appropriate. Dynamic factor analysis, based on model (1), identifies the number of common trends, the common trends themselves and which time series are related to which common trends. An additional benefit of the methodology is that missing values can easily be handled.

The mathematical formulation of the structural time series model in (1) is:

$$y_t = \Gamma\alpha_t + \mu + \varepsilon_t \tag{2}$$

$$\alpha_t = \alpha_{t-1} + \eta_t \tag{3}$$

The Nx1 vector $\mathbf{y}_t$ contains the observed data at time t. The Mx1 vector $\boldsymbol{\alpha}_t$ represent the M common trends at time t. The terms $\boldsymbol{\varepsilon}_t$ and $\boldsymbol{\eta}_t$ are noise factors and $\boldsymbol{\mu}$ is a constant level parameter of dimension Nx1. It is assumed that $\boldsymbol{\varepsilon}_t \sim N(\mathbf{0}, \mathbf{H})$, $\boldsymbol{\eta}_t$

~ N(**0**, **Q**), $\boldsymbol{\alpha}_0$ ~ N($\mathbf{a}_0$,$\mathbf{V}_0$) and that $\boldsymbol{\varepsilon}_t$, $\boldsymbol{\eta}_t$, and $\boldsymbol{\alpha}_0$ are independent distributed of each other. In this paper we use diagonal matrices for the three covariance matrices **H**, **Q** and $\mathbf{V}_0$. The unknown parameters in the model are the elements of $\boldsymbol{\Gamma}$, $\boldsymbol{\mu}$, **H**, **Q**, $\mathbf{V}_0$, $\mathbf{a}_0$, and the trends $\boldsymbol{\alpha}_t$. Details of the parameter estimation procedure and identification problems can be found in the appendix of Zuur et al (in prep).

The interpretation of the model is probably the easiest if M=2. In this case, we have:

$$\begin{pmatrix} y_{1t} \\ \vdots \\ y_{Nt} \end{pmatrix} = \begin{pmatrix} \varphi_{11} & \varphi_{12} \\ \vdots & \vdots \\ \varphi_{N1} & \varphi_{N2} \end{pmatrix} \begin{pmatrix} \alpha_{1t} \\ \alpha_{2t} \end{pmatrix} + \begin{pmatrix} \mu_1 \\ \vdots \\ \mu_N \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \vdots \\ \varepsilon_{Nt} \end{pmatrix}$$

$$\begin{pmatrix} \alpha_{1t} \\ \alpha_{2t} \end{pmatrix} = \begin{pmatrix} \alpha_{1,t-1} \\ \alpha_{2,t-1} \end{pmatrix} + \begin{pmatrix} \eta_{1t} \\ \eta_{2t} \end{pmatrix}$$

The value of the ith time series at time t, y_{it}, is modelled as the sum of four components, namely:

1. φ_{i1} times the value of the first common trend at time t,
2. φ_{21} times the value of the second common trend at time t,
3. a constant level parameter μ_i,
4. and an error term ε_{it}.

The terms φ_{i1} and φ_{i2} are called factor loadings and indicate which of the common trends are important for the ith response variable. The trends are constructed as follows. The first common trend at time t, α_{1t}, is equal to the value of the first common trend at time t-1 plus a noise component η_{1t}. If this noise component has a small variance, its contribution to the trend is likely to be small and the trend will be a smooth curve. If the variance of the noise is large, its contribution to the trend might be large and the trend is likely to be a more rapidly changing curve. Other common trends are modelled in the same way. Hence, the diagonal elements of **Q** determine the smoothness of the trends. The diagonal elements of the variance matrix **H** indicate how the observations deviate from the trends.

The more common trends are used, the better the fit will be, but the more parameters have to be estimated and the more information has to be interpreted. From an interpretation point of view, estimating two common trends is the easiest, since factor loadings can then be plotted versus each other. However, we need a more formal criterion to decide how many common trends to use in the model. Various statistical criteria can be used for this. In this paper we use Akaike's information criterion (AIC). This criterion is defined as the difference between a measure of fit (typically the log likelihood function) and a function of the total number of parameters in the model. The AIC can be calculated for models containing any number of common trends and the model containing the smallest AIC value can be selected as the most appropriate model.

Results for LPUE Data

Prior to the analysis, the LPUE time series were standardised (each series was mean deleted and divided by its standard deviation). Although it can be shown that standardisation does not influence the final results, interpretation of the factor loadings for standardised data is in general easier (Zuur et al, in preparation). The dynamic factor model containing one, two and three common trends were applied on the 6 LPUE time series. The AIC values for these three models were 519.33, 519.28 and 526.69 respectively. Differences between the models containing one and two common trends were only marginal. This means that both models were candidate models, as judged by the AIC. We decided to present results for the two common trend model.

The estimated common trends, 95% confidence intervals and the corresponding factor loadings are presented in Figure 1. The estimated factor loadings indicated that the first common trend was important for the stocks North Minch (5), Moray Firth (4), South Minch (6), Clyde (1) and in a lesser extend to the stocks Fladen (3) and Forth (2). The second common trend is important to the stocks Forth (2) and Clyde (1). Note that the factor loadings along the second common trend are negative. Another interesting point is that the factor loadings of the Moray Firth and North Minch are close to each other. This means that the time series of these two stocks are similar. The same holds for South Minch and Clyde. These conclusions are in line with the cross-correlations between the 6 series, which are presented in Table 1. Cross-correlations significantly different from 0 are in bold face. Cross-correlations between Moray Firth (4), North Minch (5) and South Minch (6) are relatively high. These stocks correspond to the first common trend. The correlation between Clyde (1), and Forth (2) is relatively high as well. These two stocks correspond to the second common trend. The time series from Fladen (3) is much shorter since observations were only made from 1980 onwards. As a result, the significance levels of cross-correlations involving Fladen are higher.

Table 1: Estimated cross-correlations between LPUE time series. Cross-correlations significantly different from 0 are in bold face. The numbers correspond to Clyde (1), Forth (2), Fladen (3), Moray Firth (4), North Minch (5) and South Minch (6).

	1	2	3	4	5	6
1	1.00	**0.37**	0.08	0.08	0.11	0.20
2		1.00	-0.08	-0.20	-0.06	0.07
3			1.00	0.35	0.32	0.32
4				1.00	**0.70**	**0.36**
5					1.00	**0.43**
6						1.00

In Figure 2, we have presented the original data and fitted values plus 95% confidence intervals for each site on the original scale. The fitted values were obtained by adding three components, namely the first common trend times a factor loading, the second common trend times a factor loading and a constant level parameter. Except for Fladen, all series were fitted reasonably well. The first common trend showed a steady increase between 1965 and 1985, except for a dip in and around 1980. After 1985, abundances declined and stay on an approximately constant level. This pattern is reflected in the fitted values of the stocks North Minch, Moray Firth, South Minch and Fladen series. In Figure 3, we have plotted the fitted curves again, but now in one figure and on the standardised scale. The thick lines correspond to the Clyde (1) and Forth (2) series. One can clearly see the influence of the second common trend on these two fitted curves. The main difference is the decrease in the Clyde and Forth series in the late 60's, and the increase in the late 90's.

Results for CPUE Data (<35mm)

The CPUE data were measured for five stocks and a distinction was made between male and female *Nephrops*. Furthermore, mean sizes for male and female species were measured as well. The data were measured on a quarterly basis. Since we were not interested in analysing interannual relationships in this study, we removed the seasonal effects. This was done by calculating the mean value of the CPUE per quarter (for each sex and site), and we looked at deviations from these mean values. The same procedure was carried out for the mean sizes.

There are various ways to apply dynamic factor analysis on these data. One option is to apply it on all 20 series (male and female CPUE values and mean sizes at 5 stocks). However, results indicated that at least 4 common trends were needed and interpretation of these common trends was non-trivial. Simple time plots indicated that male and female series had similar patterns over time for the same stock. Dynamic factor analysis applied on all 20 series confirmed this; estimated factor loadings of male and female *Nephrops* of the same stock were almost always close to each other. To avoid an ordination diagram showing trivial information like this, we separated the male and female *Nephrops* series (and the mean sizes), and applied dynamic factor analysis on each set. Results for male *Nephrops* and mean sizes are presented in Figure 4. A two common trend model was used. Results for female *Nephrops* are presented in Figure 5.

There are five stocks, namely Clyde, Forth, Moray Firth, North Minch and South Minch. The numbers 1 and 2 refer to male and female CPUE values of the Clyde. The numbers 11 and 12 refer to the mean sizes of male and female *Nephrops* of the Clyde. The numbers 3, 4, 13 and 14 refer to male CPUE, female CPUE male, mean male size and mean female size of the Forth. The same holds for the numbers 5, 6, 15, 16 and Moray Firth, 7, 8 17, 18 and North Minch, and 9, 10, 19, 20 and South Minch. Figure 4 indicates that the factor loadings for male CPUE and mean male sizes of most stocks are on opposite sides of the origin. For example, the points 1 and 11 (referring to male CPUE and mean male sizes at the Clyde) are at opposite ends along the first common trend. This means that the male CPUE values at the Clyde follow the pattern of the first common trend whereas the mean male sizes at this site follow the opposite pattern of this trend. The same holds for Forth and Moray Firth. The series corresponding to 5 and 9 are not fitted well. The female series show a similar pattern. The common trends of the male and female series are similar as well.

Results for CPUE Data (>35mm)

The same analysis was carried out on the CPUE data of *Nephrops* larger than 35mm. Results for the male species are presented in Figure 6. The factor loadings indicate a rather different behaviour compared to the *Nephrops* smaller than 35mm. The factor loadings 1 and 11, 3 and 13, 5 and 15 7 and 17, and 9 and 19 are all close to each other. This means that CPUE and mean sizes at the same site behaved similar over time. Most factor loadings have relative large values along the first common trend and small values along the second common trend, except for Moray Firth (3 and 13). This means that all time series follow approximately the pattern of the first common trend. Only the CPUE and mean sizes at Moray Firth followed a different pattern.

The female data show a different pattern, see Figure 7.

Discussion and Conclusion

In this working paper, dynamic factor analysis was applied on the LPUE and CPUE time series of various stocks around Scotland. Results for the LPUE series showed that a model containing one and two common trends gave similar AIC values. Conclusions for the two common trend model were as follows:

- The first common trend is related to North Minch, Moray Firth, South Minch, Clyde and in a ***lesser extend*** to Fladen and Forth.

- The second common trend is important to Forth & Clyde.
- The main pattern is the first common trend.
- The stocks Moray Firth and North Minch behave similar.
- The stocks South Minch and Clyde behave similar.
- The findings in line with the cross-correlations between the stocks.
- Except for Fladen, all series are fitted reasonably well.
- The pattern of common trends can be recognised in the fitted values of all series.
- The pattern of the first common trend is as follows: there is a steady increase between 1965 and 1985 and a dip in and around 1980. After 1985 the trend declined and stayed on constant level.
- The second common trend is responsible for decrease in Clyde & Forth series in the late 60’s, and increase in the late 90’s.

The results for the CPUE (<35mm) data were as follows. For the male species, factor loadings for CPUE and mean sizes were on opposite sides. This indicates that CPUE and mean sized followed an opposite pattern. A few series are not fitted well. For female species, factor loadings for CPUE and mean sizes were on opposite sides as well. Hence, mean sizes and CPUE for females followed an opposite pattern as well. However, this behaviour was more obvious for females than for males. The common trends for males and females were similar

Results for the male CPUE (>35mm) data indicated that CPUE and mean sizes behaved similar at most stocks. The first common trend was the most important one. The CPUE and mean sizes at Moray Firth followed a different pattern. For female species, the CPUE and mean sizes behaved similar at most sites. The first common trend was the most important one. Mean sizes at Moray Firth followed a different pattern. The common trends of males and females were different. Factor loadings of males and females were not the same.

The common trends, factor loadings and measures of fit were different for the CPUE (and mean sizes) data smaller than 35mm and larger than 35mm.

The structural time series model discussed in this paper is a very simple model. It can be extended in various ways. Harvey (1989) used structural time series models of the form:

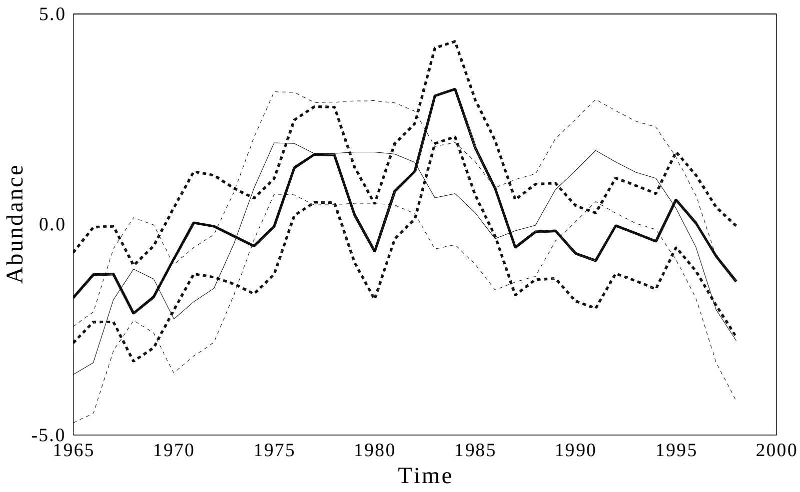
$$\text{data} = \text{trends} + \text{seasonal effects} + \text{cycle} + \text{explanatory variables} + \text{noise} \qquad (4)$$

Common seasonal (or quarterly) effects can be defined as well. Another possible extension is the way the trends are modelled. In this paper, we used random walk trends. Harvey (1989) discussed local linear trends and cyclical trends. Although these trends require more parameters, they might result in better models. The way explanatory variables are dealt with in (4) also requires further work. For example sea surface temperature could be used as an explanatory variable for the LPUE series. However, if explanatory variables are available at each site, the number of parameters increase. This might be a motivation to apply a dimension reduction similar to the ‘common trend approach’ on the explanatory variables as well.

A disadvantage of the structural time series model in (2)-(3) is that it takes only limited account of possible time lags in the series. Molenaar (1994) discussed dynamic factor models in which some of the common trends were directly related to time lags. The need for such models becomes clear from Table 2, in which the largest cross-correlations for the LPUE series are presented again, but now time lags are considered as well. For example, the cross-correlation between Clyde and Forth had a maximum for k=-2, where k is the delay in the Forth series. This means that if the abundances are high in the Clyde series in year t, abundances in the Forth series tend to be low in year t-2, and vice versa. Similar remarks can be made for other series. Although significant cross-correlations with time lags larger than 3 years can not be considered as biological relevant, there are a significant cross-correlations with time lags of 1 and 2 years. The dynamic factor analysis models discussed in this paper do not reveal this information. We are currently extending dynamic factor analysis to take account of time lags.

Table 2: Largest estimated cross-correlations (upper diagonal) between LPUE time series with time lag k (lower diagonal). Cross-correlations significantly different from 0 are in bold face. The numbers correspond to Clyde (1), Forth (2), Fladen (3), Moray Firth (4), North Minch (5) and South Minch (6).

	1	2	3	4	5	6
1	1.00	**0.40**	**-0.50**	0.31	-0.37	0.23
2	**-2**	1.00	-0.42	**-0.44**	-0.35	**-0.59**
3	**-3**	-4	1.00	**-0.60**	**-0.76**	**-0.47**
4	2	**-3**	**4**	1.00	**0.70**	**0.37**
5	-3	-2	**4**	**0**	1.00	**0.43**
6	1	**-3**	**-1**	**1**	**0**	1.00



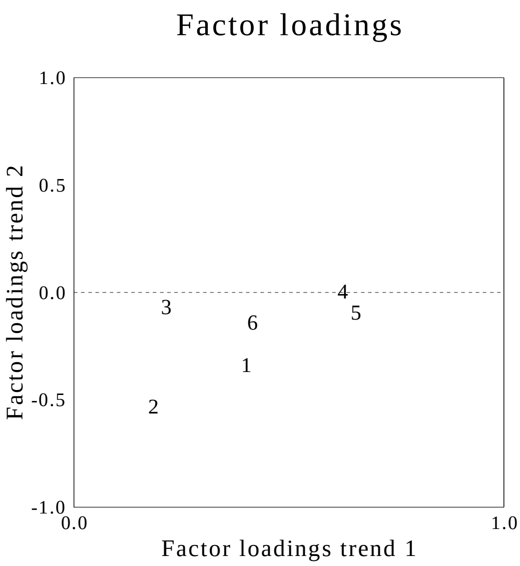


Figure 1. Estimated common trends and factor loadings for LPUE data obtained by a two common trend dynamic factor model. The bold lines correspond to the first common trend. The numbers correspond to Clyde (1), Forth (2), Fladen (3), Moray (4), North Minch (5) and South Minch (6).

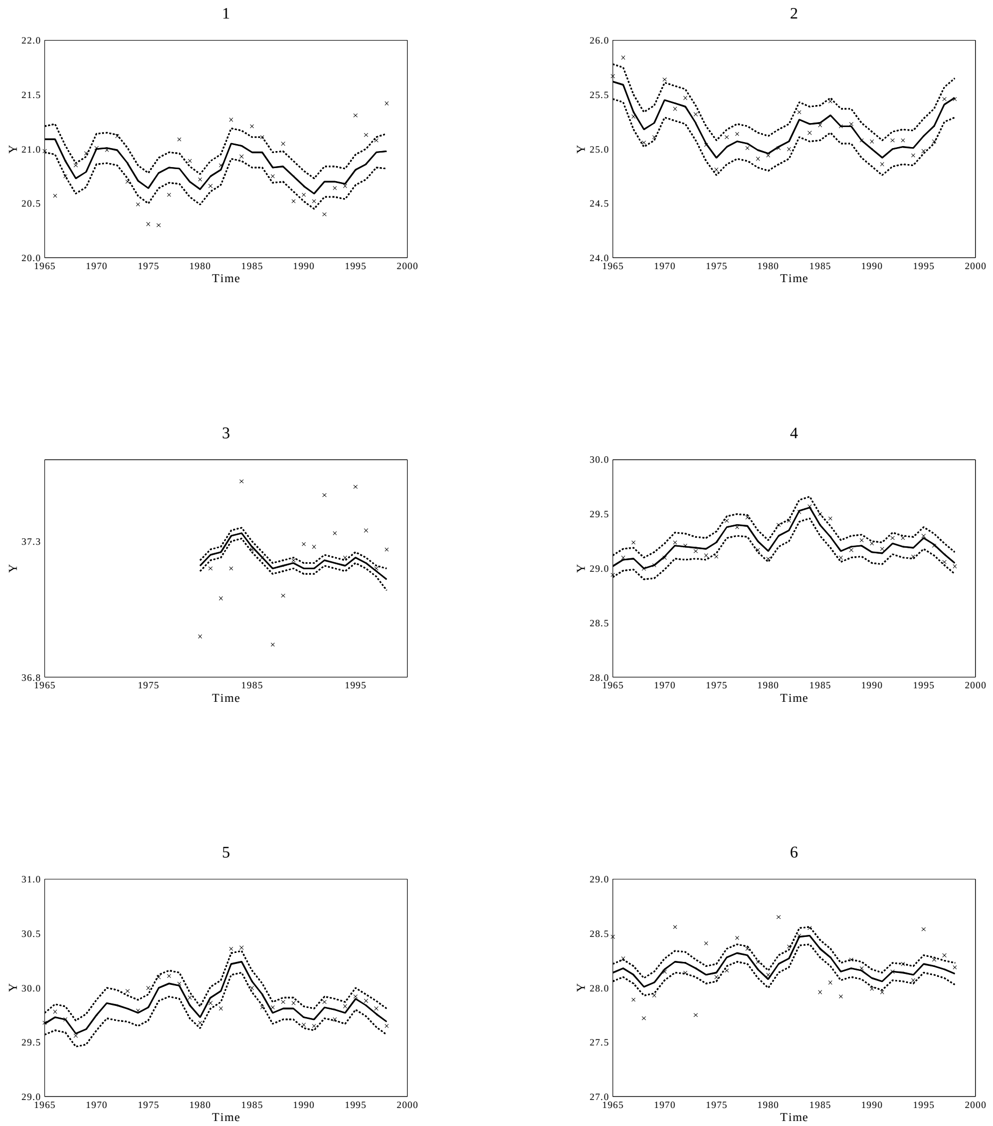


Figure 2: Fitted values for the 6 LPUE time series obtained by the two common trend dynamic factor model on original scale. The numbers correspond to Clyde (1), Forth (2), Fladen (3), Moray Firth (4), North Minch (5) and South Minch (6).

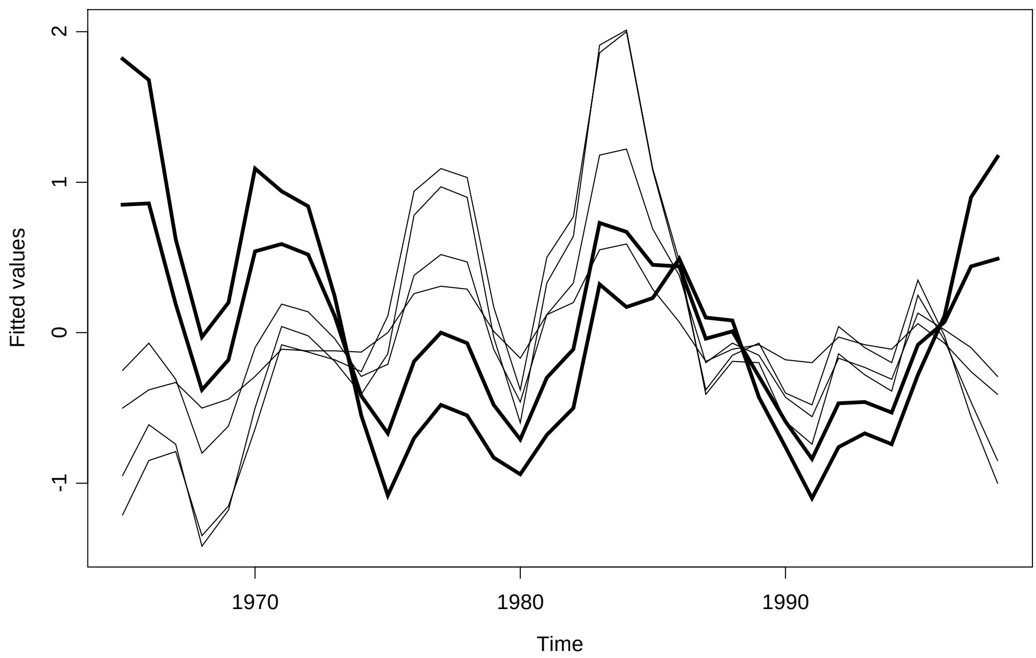


Figure 3: Fitted values for the 6 LPUE time series obtained by the two common trend dynamic factor model on standardised scale. The two thick lines correspond to the Clyde and Forth series.

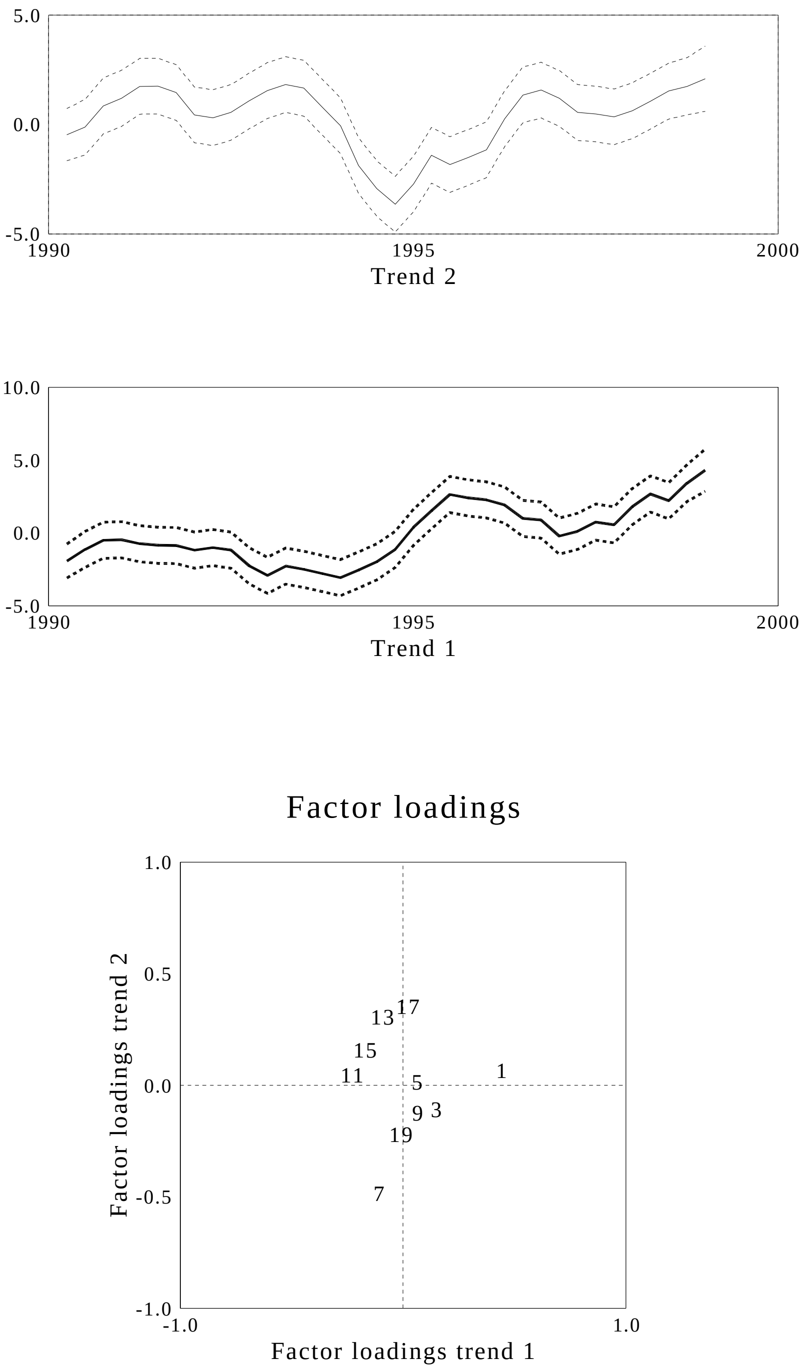
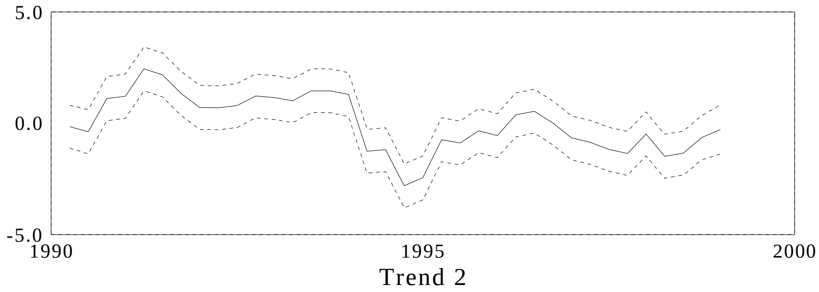
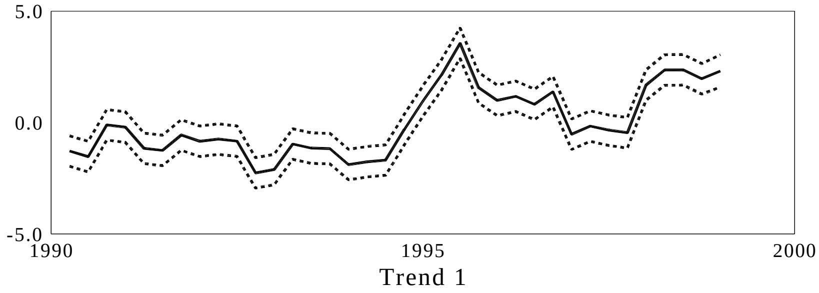


Figure 4: Estimated common trends and factor loadings for male CPUE (<35mm) data and mean sizes.





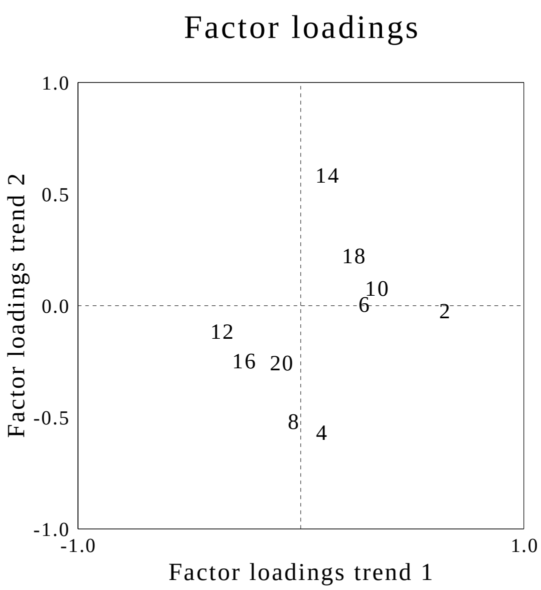


Figure 5: Estimated common trends and factor loadings for female CPUE (<35mm) data and mean sizes.

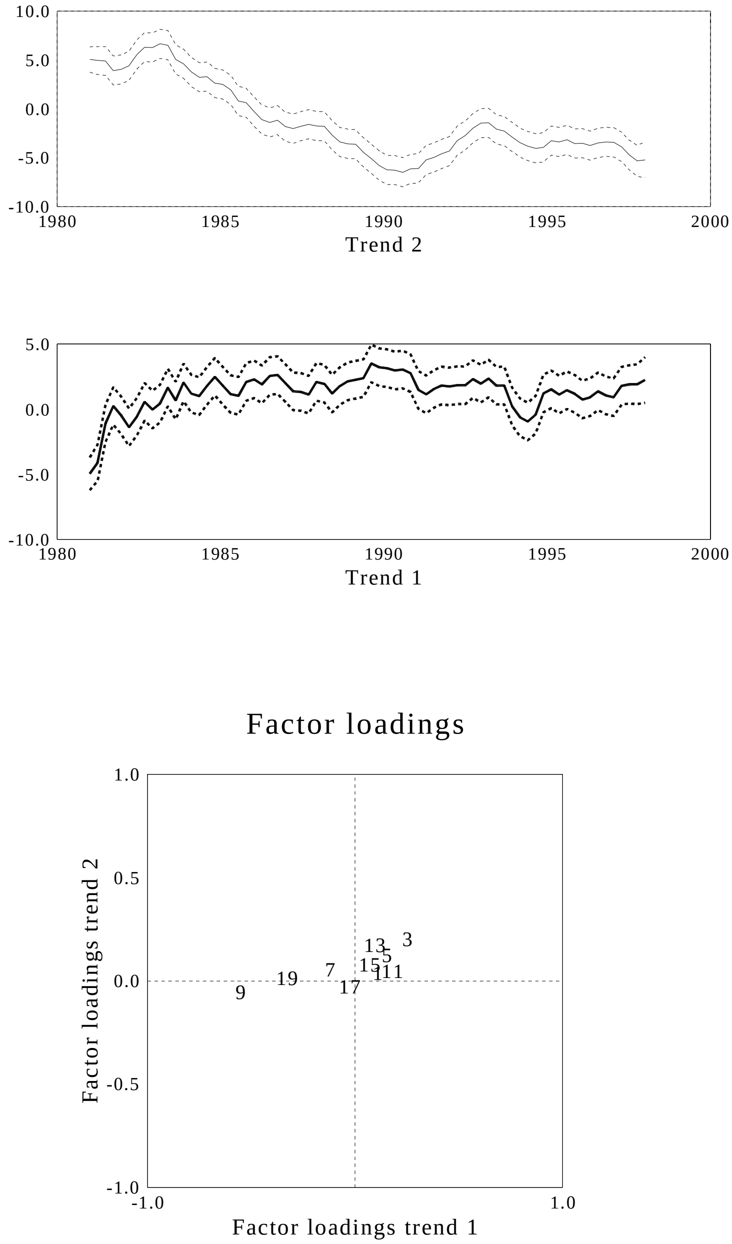


Figure 6: Estimated common trends and factor loadings for male CPUE (>35mm) data and mean sizes.

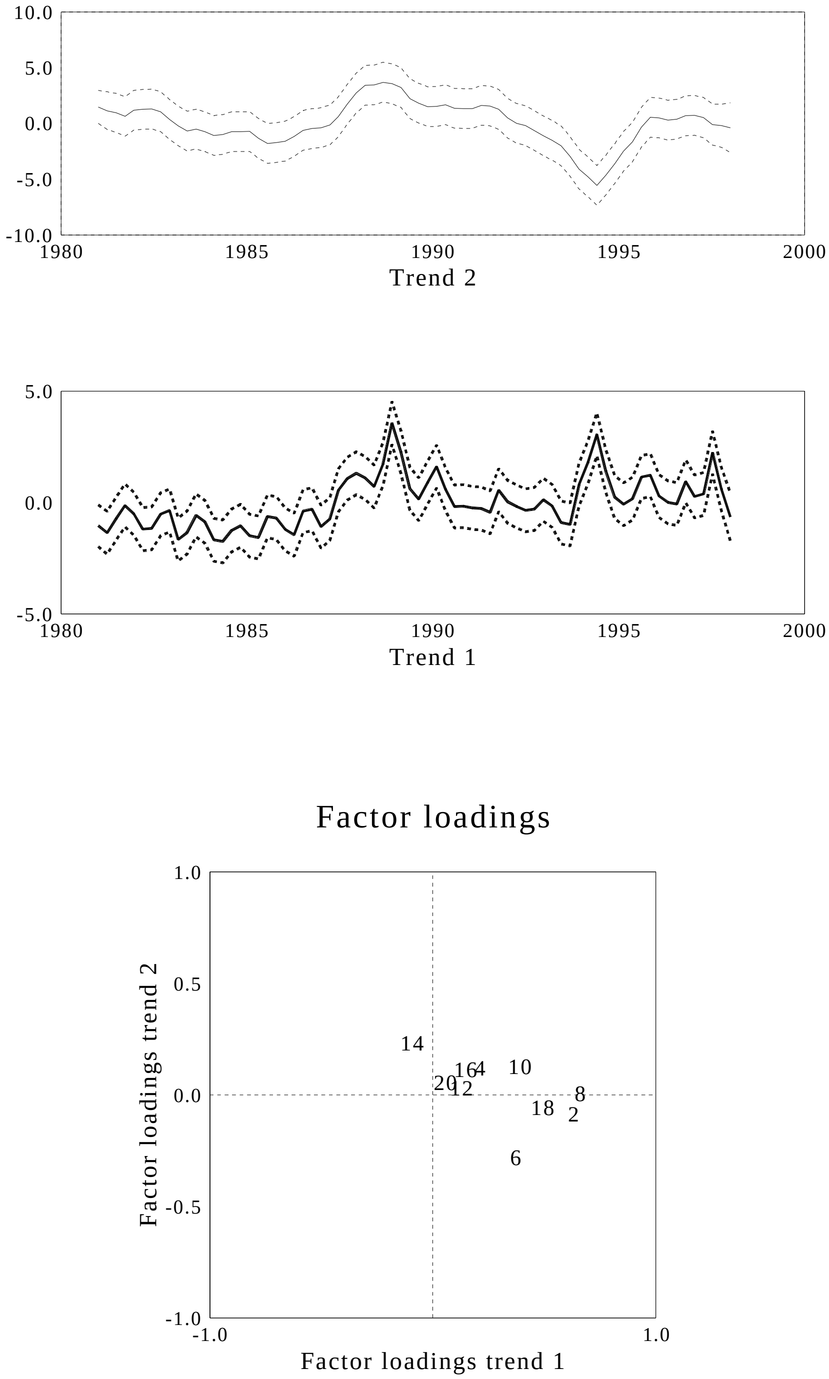


Figure 7: Estimated common trends and factor loadings for female CPUE (>35 mm) data and mean sizes.

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APPENDIX 2

Projecto de Investigação Pesqueira
Universidade do Algarve

GeoCrust (DG XIV 99/059) Project

"USE OF SATELLITE GPS DATA TO MAP EFFORT AND LANDINGS OF THE PORTUGUESE CRUSTACEAN FLEET "

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Introduction

This document aims to introduce GeoCrust, a two years research project, started in April, to be conducted in Portugal by the University of Algarve. This study, in support of the Common Fishery Policy, is supported by the European Commission (Study Contract DG XIV 99/059). Preliminary results will be disseminated in the GeoCrust Webpage, that will be available from mid May onwards.

Background

The Portuguese crustacean trawl fleet operates mainly off the Southwest and South coasts of Portugal, from 200 to 500m deep. This fishery started in 1983 with 35 vessels but since 1996 only 25 trawlers are still operating. These vessels range from 20 to 35 meters in size and 350 to 700 HP. Four of these vessels are freezer trawlers. A 55 mm mesh size has been used in this fishery. The crustacean species are also captured as by-catch of the bottom trawl fishery targeting fish, such as hake, horse mackerel, anglerfish and others (Anon., 1999).

The Portuguese crustacean fishery has two main target species, the Norway lobster (*Nephrops norvegicus*) and the pink shrimp (*Parapenaeus longirostris*), hereafter designated only by *Nephrops* and *Parapenaeus*, respectively. These two species have an overlapping distribution. However, *Nephrops* is more abundant in deeper waters than *Parapenaeus*, as shown by Figueiredo (1989). Therefore, each fishing haul must be directed to one of these two species. The Red shrimp (*Aristeus antennatus*) is the third most important species caught by this fishery. *Nephrops* is the most valuable of the three species.

Only *Nephrops* is under TAC regulation and has a minimum landing size of 20 mm carapace length. *Nephrops* stock assessment is conducted by the ICES *Nephrops* Working Group, NWG (Anon., 1997; 1999). In Portugal the two most important *Nephrops* stocks are distributed off the Southwest (Alentejo stock, ICES Functional Unit 28) and South coasts (Algarve stock, ICES Functional Unit 29) (Figure 1).

In Portugal, the crustacean fleet operates on the two stocks and the fishery statistics on landings and effort are given for the whole area (Alentejo and Algarve). Furthermore, fishing effort directed to *Nephrops* has been difficult to estimate. At the present, each vessel of the crustacean trawl fleet, landing *Nephrops* is considered as been fishing for *Nephrops*. As a consequence, the NWG has been assessing the two Portuguese Southern stocks (Functional Units, FU 28 and 29) as a whole stock (see *e.g.*, Anon., 1997). A recent assessment of this stock showed that stock biomass and recruitment continue at a very low level, the fishing pressure is very high, affecting more intensively the male component of the stock (Anon., 1999). Independent surveys carried out by IPIMAR shows a continuous decline in *Nephrops* abundance since 1992 (Anon, 1999).

As a consequence of *Nephrops* decline and due to the high abundance of *Parapenaeus*, in the past ten years there has been a shift of target species to *Parapenaeus*. During this period, and despite the state of overexploitation of the Algarve stock of *Parapenaeus* (Mattos-Silva, 1995), the landings did not decrease due to good recruitment. These changes are illustrated by the specific composition of the crustacean fleet landings (source of data: DGPA). Between 1983 and 1989, 47% (around 720 tonnes/year) of the total landings of the three main crustacean species were *Nephrops*. The *Parapenaeus* landings (620 tonnes/year) accounted for 40% of the total crustacean landings, whereas *Aristeus* landings (200 tonnes/year) only contributed with 13%. In 1993, 60 % of the crustacean landings were *Nephrops* (185 tonnes) and 30% were *Parapenaeus* (94 tonnes). In 1999, *Parapenaeus* landings represented 83% (1695 tonnes) of the total of the three main crustacean species landed, while *Nephrops* landings only contributed with 7 % (150 tonnes). A remarkable increase in *Parapenaeus* landings has occurred in the past five years, in particular in the last year where landings increasing almost tripled

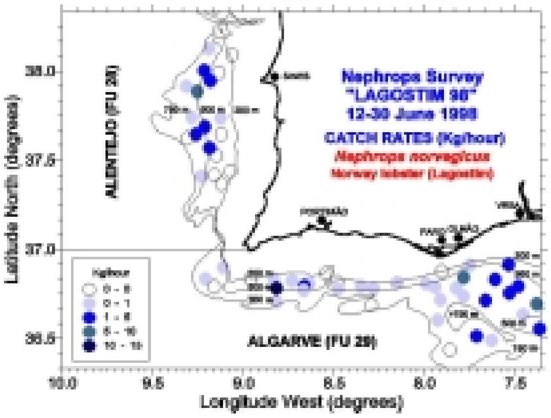

Figure 1. Distribution and Abundance of *Nephrops* in Functional Units 28 and 29 (South-Southwest Portugal), in June 1998 (Afonso-Dias, 1998).

Objectives

This research project has the following objectives:

The main goal of this research project is to make use of data collected within the Portuguese satellite-based Vessel Monitoring System (VMS), restricted until now to Fisheries Inspection purposes only, to improve the stock assessment of the main commercial crustacean species, *Nephrops* in particular. This will be done by:

- Analysing the spatial and temporal distribution of specific fishing effort on the Southern Portuguese Crustacean fishery (Alentejo and Algarve), for the period between 1998 and 2000, using Geographical Positioning System (GPS) data transmitted *via* satellite from each crustacean trawler. Fishing effort in this fishery is split between deep-water species, the *Nephrops* and *Aristeus* and the shallow water species, the *Parapenaeus*. The annual fishing effort directed to *Nephrops* will be estimated by stock (ICES Functional Units 28 and 29). The Geographical Information System (GIS) data will also be used to analyse the dynamics of the fleet, *i.e.*, its exploitation regime (number of days per fishing trip, number of hauls per day; number of hours per haul and distance trawled by haul).

- Analysing the characteristics of the crustacean trawl landings and their spatial and temporal distribution in the study period (1998-2000), using daily landing data for each individual vessel. Spatial analysis data is, however, limited to daily landings resulting from fishing in restricted geographical areas. In these cases, spatial information on catch per unit effort (CPUE) of the target and associated species can be computed. Multivariate techniques will be used to identify *Nephrops*, *Aristeus*, *Parapenaeus* and other possible types of fishing trips according to the specific composition of the daily landings

- Developing a sampling plan to obtain spatial allocated information on the characteristics of the catches and CPUE, on board the crustacean fishing vessels.

Relevance of the study

This study aims to analyse the spatial distribution of fishing effort (and landings) of the crustacean fishery in the South-Southwest coasts of Portugal using GPS data collected by the national Vessel Monitoring System (VMS) in the period 1998-2000. Portugal was the first European country to implement a VMS. At the present the monitoring of the fishing activity of vessels larger than 20 metres is performed by routine in the Portuguese coast, by the General Fisheries Inspection Board (IGP). In this study it is aimed to use these data for fisheries research purposes, specifically, to improve the assessment of *Nephrops* and other species caught in the Southern Portuguese crustacean fishery.

The spatial analysis of such data will allow, for the first time, to separate the amount of effort directed to *Nephrops* from that directed to *Parapenaeus*, the other target species in the fishery. Specific effort will be mapped by geographic area and quantified for different periods of time. Daily data on landings will be also analysed and related to the spatial data on fishing effort. For *Nephrops*, in particular, it will be possible to allocate specific fishing effort and landings to each of the *Nephrops* stocks (FU 28 and 29).

The present research project will provide the basis to implement in Portugal a system that will allow the better understanding and management of the main crustacean stocks, particularly, *Nephrops*. Data on the geographical distribution of fishing effort, landings and landings per unit effort, collected along the years and stored in an appropriate GIS database will allow spatial-temporal analysis of the data, improving largely the quality of the assessments and then contributing to the common fisheries policy. The future implementation of sampling onboard of the crustacean vessels will complement this system.

The final report of this study will provide information on the spatial pattern of fishing effort and catches in the Southern Portuguese crustacean fishery. This data will improve the assessment of the Southern Portuguese *Nephrops* functional units (FU 28 and 29), providing some tools for the improvement of the management of this fishery. These results will also provide the basis for the future collection of information on the catches (biological characteristics) and catch per unit effort directly from the crustacean fishing vessels. The experience gained and the methodology developed during this project may also be applied to other fishing fleets (e.g., the demersal fishing fleet), included in the Portuguese VMS.

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APPENDIX 3

Report of a Workshop held at CEFAS, Lowestoft to consider the use of estimates of *Nephrops* abundance derived from burrow counts.

Compiled by

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A workshop was convened at CEFAS, Lowestoft from 25-27 October 1999 to consider the use of abundance estimates derived from counts of *Nephrops* burrows using underwater television. The following nine scientists from England and Scotland attended the workshop and contributed to the report:

J. Addison	CEFAS, Lowestoft (Chair)
J. Atkinson	UMBS, Millport
M. Bell	CEFAS, Lowestoft (Rapporteur)
C. Brown	CEFAS, Lowestoft
J. Elson	CEFAS, Lowestoft
S. Marrs	UMBS, Millport
G. Stentiford	Univ. of Glasgow
I. Tuck	FRS, Aberdeen
A. Weetman	FRS, Aberdeen

Introduction

Pioneering work by Scottish laboratories showed that measurement of *Nephrops* burrow densities is possible in photographic and television surveys of commercial grounds (e.g. Chapman, 1979, 1985). The approach has been developed into a full method of stock assessment (Bailey et al., 1993), and surveys are now undertaken annually for a number of stocks in the North Sea and around the coast of Scotland. Tuck et al. (1997) found that TV burrow counts, larval surveys and analytical assessment of fishery data gave comparable estimates of *Nephrops* stock biomass in the Firth of Clyde. The importance of such fishery-independent assessment methods is increasingly recognised in the face of uncertainties about the interpretation of fishery statistics. Stock estimates from burrow counts have recently been the basis for advice given on a TAC for *Nephrops* on the Fladen Ground (ICES, 1999).

The technique has recently been trialled by CEFAS for stocks in the Farn Deeps and the eastern Irish Sea. This workshop was convened by CEFAS to bring together different research teams in the field to discuss the technique. The overall aims were to achieve some conformity of approach across teams and to identify areas for development. The workshop considered all aspects of the burrow counting technique, the calculation of abundance estimates using that technique, and the comparison with estimates produced using analytical techniques by the *Nephrops* Working Group. We hope that this report, which summarises the main conclusions drawn from the workshop, will prove helpful in ensuring that all teams currently using the technique will use the same methodology, and that it will provide guidelines for those teams who are considering carrying out burrow count surveys in the future.

As a general starting point it was agreed that counting burrows provides an index of abundance of *Nephrops* only. We recognised that there were various sources of error in the technique which at present may preclude calculating an absolute abundance estimate using this technique, and we discussed ways in which these sources of error might be controlled. The workshop therefore focussed on possible errors which could systematically influence trends in any index of abundance derived from the burrow count method.

Counting techniques

Gear set-up

The positioning of the camera on the sledge may influence the counting technique. The height of the camera and its position on the sledge determine the camera angle. An oblique camera angle provides a wider field of vision and gives the counter longer to determine whether a feature is a *Nephrops* burrow, and thus will ease the counting procedure. An oblique camera angle also provides a clearer view of the profile of the burrow which can be important in discriminating between *Nephrops* burrows and those of other species. However experience with a particular camera angle is important. The workshop found that experienced counters were more confident with the camera angle to which they were accustomed. However the key determinant is to ensure that the width of field is appropriate to the size of the burrow complexes; the more oblique the camera angle, the wider the field of view.

The weight of sledge is important; light sledges may lift off the sea-bed ('fly') which will increase the field of view and hence increase the area searched. When the sledge flies therefore, it could cause abundance to be overestimated. If individuals get better at keeping the sledge on the bottom, then it is possible that a declining abundance estimate might be observed over time. Heavy sledges may sink in soft sediment but this would have a negligible impact on the field of view and so would not be a problem for abundance estimation. The Marine Laboratory, Aberdeen use a Rangefinder which alerts you as to whether the sledge is on the ground.

Achieving an accurate measure of distance run is essential to estimating *Nephrops* abundance, and thus extreme care must be taken to ensure that the wheel is recording correctly. For example the wheel can judder or may lose contact with the ground if the sledge starts to fly. It is essential therefore to have an independent estimate of the distance run, e.g. DGPS recording of the start and end of tow. For example, CEFAS uses three sources of distance run: distance travelled by wheel, positional information recorded by the 'Sextant' software package and GPS records from the ship's log. It is recommended that 'distance run' should be displayed at all times on the video screen. Focussing a camera on the wheel to check whether it is turning freely provides independent information on the accuracy of the recording of distance run.

Doing the counts

There are two common methods of actually counting burrow numbers on the video over, say, a 10 minute recording period: either counting 10 x 1 minute sections or simply counting 1 x 10 minute stretch. The former allows sections of the 10 minute run to be easily omitted when, for example, visibility was poor or the sledge left the sea-bed, but if the distance run is recorded permanently on the video screen, then the latter approach also permits the omission of "difficult" sections. The former method allows for an analysis of patchiness of burrows on the substrate directly from the counts, whereas the later would require re-analysis of the tapes to obtain information on patchiness.

There is no clear preference as to the point at which a burrow or burrow complex should be counted as it passes across the screen. Some groups count as the burrow passes the bottom of the screen, whereas others count each burrow as it passes some pre-determined line further up the screen. The key issue is to count at the position which gives an ideal width of view, e.g. 1 metre. The only obvious advantage of counting at the bottom of the screen is that there is a longer time in which to determine whether or not the feature is a *Nephrops* burrow.

'Edge effects' are a possible source of error as the width of view on the video screen can be quite small in comparison to the size of burrow complexes. Previous studies suggest that edge effects may account for an overestimate of abundance up to 30%. However, to date most groups have not corrected their abundance estimates for edge effects, primarily because the technique is being used only to calculate an index of abundance and thus this error is assumed to be constant across surveys. Nevertheless this is an area for concern in analysis of burrow counts because it is likely that edge effects will be greater in areas with larger burrows. It is also important to note that the magnitude of edge effects will vary with the width of view. Two surveys of the same grounds with different widths of view will not be directly comparable. Thus quantification of edge effects may be important for between-survey comparison. There could be a similar problem when variation in density on the same ground over time is observed, which has occurred recently on the Clyde grounds. There is scope therefore to address this issue further through simulation exercises, and to consider whether such edge effects need to be added to confidence intervals generated from the burrow counts.

Comparison of burrow counts from TV images and from diving along the transect line suggest that burrows may be missed on the video screen, but that this is probably only a small percentage error. The only possible problem is that a higher proportion of burrows could be missed at higher densities.

<u>Burrow occupancy issues</u>

In general unoccupied burrows soon collapse, whether the ground is heavily trawled or not, and therefore the conventional assumption that all burrows contain a *Nephrops* is reasonable. This is not considered to be a major problem, as studies suggest that occupancy rates are at least 75% in most areas. Only if the area had been heavily trawled very recently and burrows had not had time to collapse would an overestimate of abundance be likely. Similarly if burrows are temporarily broken up by trawling over them, then the animals quickly rebuild them. The probability of multiple occupancy by adults of a single burrow is considered to be extremely unlikely. Although there may be numerous small *Nephrops* in one single adult-juvenile complex, there is always only one adult. Thus when estimating abundance of adults, the rule should be one burrow complex represents one adult *Nephrops*. An important conclusion from the workshop was that all counters were agreed upon what constituted a single burrow complex.

Another possible source of error is the misidentification of the burrows of other species. The ability to discriminate between *Nephrops* and other burrows is dependent on the nature of the ground. For example, Irish Sea *Nephrops* grounds are characterised by large numbers of other species burrows. Some of these burrows are not easily distinguishable from those of *Nephrops*, e.g. the angular crab, *Goneplax rhomboides*, and even those species whose burrows are easily distinguishable, e.g. the mud shrimp *Caloceros macandreae*, may occur in such high densities that counting *Nephrops* burrows becomes difficult. In contrast, North Sea *Nephrops* grounds are relatively easy to count because there are relatively few burrows of other species on the same grounds, and the only species which causes problems of discrimination of burrows, *Goneplax*, is relatively rare. The workshop agreed that the take-home message from grounds which have a high density of burrows is to count only those which you are certain are *Nephrops* burrows, as this will minimise errors due to the counting of burrows of other species.

Comparison between counters

Statistical analysis of TV data for the Farn Deeps showed that there was no significant difference in *Nephrops* burrow counts between two CEFAS Lowestoft counters analysing the same video tapes. Estimates of trends, distribution and absolute abundance were virtually identical between the counters. Pairwise comparison of counts shows that although counts from any one station were not identical, there is very little variance about a line of absolute equivalence (Figure 1).

A small number of Farn Deeps stations were also analysed by two counters from FRS Aberdeen. Burrow counts were consistent between the two Aberdeen counters, but at higher burrow densities Aberdeen counters were counting smaller numbers of burrows than Lowestoft counters (Figure 2).

Clearly, there is satisfactory consistency within survey teams, but we need to account for the discrepancy between teams. During joint viewing of video tapes from both Scottish and English surveys there was a high level of agreement on identification of *Nephrops* burrows and on interpretation of multiple burrow openings as single burrow systems. Thus, it seems unlikely that the discrepancy is due to a fundamental difference of interpretation. The most likely explanation is that the steeper camera angle employed in the English surveys made it difficult for the Aberdeen counters to interpret the tapes, since they were more familiar with the more oblique camera angle of the Scottish surveys. This will need to be confirmed by Lowestoft counters analysing Scottish tapes. It would be predicted that Lowestoft counters, being similarly unfamiliar with the Scottish shallow camera angle, would record lower burrow counts than Aberdeen counters.

Emergence rates

Emergence rates of *Nephrops* can be strongly influenced by season, time of day or night, *Hematodinium* infection, and may be higher at higher densities. All of these factors have important implications for the analysis and interpretation of catch rates from trawl surveys. Similarly *Hematodinium* is known to have a differential effect by size and sex on emergence of *Nephrops*. All of this means that estimating abundance of *Nephrops* through burrow count surveys is particularly appropriate because the estimates do not rely on their emergence pattern. Most TV surveys record the number of emerged *Nephrops* but these counts need careful interpretation and there is clearly scope here for additional studies. It would be very helpful to gain an estimate of emergence rate at size, particularly if an idea of the size structure of the population is required. Secondly information on current rates, light levels (can we find a sensitive enough light meter? Do *Nephrops* respond to the camera lights?) would all be useful information to record alongside emergence rates. It would be useful to record also whether the animal is in the burrow opening or out of the burrow.

Visibility

Changes in clarity could influence the estimate of burrow numbers and experience from a number of groups suggests that poor visibility has influenced specific surveys and the subsequent abundance estimates. However we know little of how visibility does actually influence our ability to count burrows. We could test for this by simulating poor visibility by using, for example, filters on screens and then we could compare burrow counts with those done previously in ‘good visibility’. Secondly it might be possible to carry out replica tows on the same ground at various time intervals after a trawler has towed across the grounds. This would provide useful information on burrow counts as a function of visibility in the area.

Sampling strategy

Stratification is an important component of survey design, and any stratification which reduces variance within individual strata will improve the survey. The question of how to define strata depends upon the grounds, but anything that relates to burrow density, e.g. sediment type, would be a good starting point. Stratification may also increase the statistical precision of confidence intervals for abundance estimates derived from the burrow counts.

The choice of station positions on each survey differs between groups. One method is to stratify the sampling area, and then choose a fixed number of random samples within each grid within each stratum. The second method is to stratify as before but then to sample at a pre-determined set of stations within each stratum on each successive survey. There are benefits to both methods; the former introduces more randomisation in the sampling grid, but the latter allows the burrow count at a single station to be followed through time (see appendix).

The workshop recommended that an adaptive sampling strategy should be adopted whereby high density areas can be re-sampled after the normal grid of stations has been completed. This strategy increases the precision of estimates from high density areas, with the consequent effect on confidence intervals.

Size distributions

Estimating the size distribution of *Nephrops* populations on grounds surveyed by underwater television is a key problem area at present. If we can resolve this issue, it may help to explain discrepancies between abundance estimates from the burrow count and analytical methods. Furthermore the ability to estimate size distributions directly from video images of the grounds provides great promise of gaining a clearer understanding of *Nephrops* recruitment patterns.

Currently the size distribution of trawl catches is used to convert abundance to biomass of *Nephrops* from the video counts of burrows. The consensus view however is that emergence patterns of *Nephrops* and mesh selectivity factors are such that size distributions from trawl surveys give a biased estimate of mean size. Thus converting abundance to biomass using this method is unreliable. It would be much better to use the size of burrows as an estimate of size distribution of *Nephrops*. This would aid comparison of abundance estimates from the different methodologies by allowing comparison of the same portion of the total stock. Furthermore identifying size distribution of *Nephrops* from burrow counts could provide an index of recruitment. Variation in recruitment over time could be the cause of any discrepancy between burrow count and analytical estimates.

Two methods of estimating burrow size were recognised. Visual measurements from the screen are possible, and the recent development of image analysis techniques to automate estimation of burrow size appear promising. Indeed it may be possible in the near future to automate imaging techniques such that burrow size is automatically measured in real time of the sledge passing over the burrows. Two recent studies have shown that estimation of size distribution of *Nephrops* from size of burrows may be sufficiently accurate. Marrs et al. (1996) measured burrow size from resin casts of burrows and measured entrapped animals. They incorporated similar unpublished data collected by C. J. Chapman with their own and found a good correlation between size of burrow and size of animal. Secondly the Marine Laboratory, Aberdeen measured burrow sizes off the video screen and these showed good correlations with an estimate of the size of emerged animals and with the market sampling size distribution (S. McWilliam, unpublished M.Sc. thesis). If nothing else, separating out burrow sizes by crude categories of pre- and post-recruits would still give an index of recruitment. Such techniques would of course require calibration for each survey and each ground using emerged animals close to burrow openings, and with the size distribution of landings by the local fleet.

The ability to estimate *Nephrops* size distribution from burrow size would be a major step forward in understanding the recruitment dynamics of *Nephrops*. The techniques are developing and hold great promise. Visual counts could of course miss small burrows, but would still give an index of recruits. However more are likely to be missed at higher densities, which could cause bias in any trends in recruitment calculated from this method. To provide some independent check on the validity of the method, it would be interesting to compare the size distribution of burrows with the spatial pattern of discarding of small *Nephrops*. Similarly it would be insightful to investigate the relationship between predator (e.g. cod) abundance and an index of recruitment of *Nephrops* derived from the burrow counts.

The ability to gain an index of recruitment from estimating the size of burrows would be a major tool for fisheries managers, but it would require annual surveys of the fishing grounds. Surveys done on a periodic basis only would not of course pick up year on year trends in recruitment.

Discrepancies between burrow count and analytical assessments

Mismatches between burrow count and analytical (VPA) estimates of *Nephrops* abundance are due in great part to two factors: (1) burrow count estimates include individuals that are too small to appear in fishery catches, hence are invisible to VPA; and (2) the model underlying VPA is inappropriate for the fishery due to the biological and spatial characteristics of *Nephrops* stocks.

The first factor accounts for differences in both trends and absolute abundance. Recent Scottish assessments suggest that recruitment to *Nephrops* stocks is more variable than has previously been recognised. Correspondence with stock recruitment indices (e.g. CPUE of animals <35 mm CL) indicated that TV abundance estimates are strongly influenced by recruitment, whereas VPA estimates apply to only part of the total stock. Separation of burrow counts into pre- and post-recruit categories, according to a lower size limit determined from catch data (see above) might improve the validity of comparisons between assessment methods.

The second source of discrepancy is more serious in that it implies that analytical assessments of catch data might be dangerously misleading. The VPA assessment model is inappropriate in two major respects. Firstly, seasonal changes in size- and sex-specific catchability can easily cause departures from the Extended Survivors Analysis (XSA) assumption of constant annual catchability at age. This applies particularly when there are shifts in the seasonal distribution of effort (e.g. in response to bad weather conditions, or because of targeting other species). Emergence behaviour is a major source of variation in catchability. Gross seasonal changes in emergence are well-known, such as the non-emergence of ovigerous females during the winter brooding period, resulting in low fishing mortality on females. However, many and various factors influence emergence patterns at a variety of time scales, and the effects of, for example, parasitisation, density and light levels are not well described or understood. The application of seasonal assessment models, such as SXSA, may offer some progress in this area.

A more fundamental problem with the VPA approach is that it takes no account of the spatial distribution of the stock and of fishing effort. *Nephrops* are essentially sedentary after settlement of the second post-larval stage, which violates the dynamic pool assumption of VPA – i.e. the assumption that the stock will re-distribute itself in response to removals. This violation becomes serious if fishing effort is distributed non-randomly in relation to the stock. TV burrow counts show that *Nephrops* stocks are not distributed homogeneously across their grounds. Density varies at a scale which is larger than the length of commercial trawl tows, so that it is reasonable to suppose that fishing effort would be targeted at the higher densities. Mapping of fishing activity in the Clyde Sea area shows that effort is not distributed homogeneously across the ground. The implication is that, within limits, fishers should be able to maintain a high, stable CPUE, irrespective of the underlying stock trend, thus conferring artificial stability on estimates of recruitment and stock size from analytical assessments of catch data. A simulation study is needed to quantify the effect of searching behaviour by fishers on analytical assessments of catch data from a spatially structured, sedentary stock. Clearly, it will be advisable for future analytical assessments to take account of the spatial distribution of landings and effort. This will require the development of new assessment models. Further, it will require data on the distribution of fishing effort at a finer spatial scale than is currently available. Log-books coupled with automated logging of vessel positions, as currently applied in the Clyde Sea area, show the way forward in this respect. Some qualitative effort mapping may be possible by recording trawl marks on TV recordings.

Clearly, there is much scope for development of analytical assessment models tailored to biological and fisheries patterns of *Nephrops* stocks. Spatially and seasonally structured models are needed, with an efficient method of combining male and female catch data. However, even if such models were available, they would still depend on the quality of fishery data. Landings can be both under-reported (to avoid quota restrictions) and over-reported (to establish track records), so that there is much uncertainty about the reliability of reported landings data in some areas. There is particular concern about the quality of discard data and the consequences for recruitment estimates from VPA. Another source of uncertainty about the data is the use of growth curves to 'slice' length distributions into nominal age-classes. Even if average growth rates are constant between years and known precisely, the slicing approach would lead to errors because of differences of individuals from the average, variations in recruitment strength and the spread of sampling effort through the year. It is generally recognised that growth rates are unlikely to be constant, and may well be lower at high stock densities. In a preliminary analysis Tuck (unpublished) looked at growth rate in relation to mean catch rate for an individual station in the Clyde for four years of data, and found a significant negative relationship between density and L_∞ suggesting density-dependent growth. Tuck found little contrast in either growth or density and so further more detailed studies, such as that by Tuck and by Parslow-Williams (1998), are needed to quantify density-dependence of growth and to explore the consequences of uncertainty in age-determination for analytical assessments.

In the light of the foregoing discussion about the shortcomings of analytical assessments, the value of using TV surveys to estimate *Nephrops* abundance becomes increasingly apparent. For the purposes of stock projection and application of biological reference points it will always be desirable to estimate fishing mortality from fishery data. However, it may be possible to use recruitment and fishable stock indices from TV surveys to drive the analytical assessments. Using TV abundance estimates to tune analytical assessments has already been attempted for Scottish *Nephrops* stocks using the Integrated Catch Analysis (ICA) method. The resulting stock estimates tended to be dominated by the TV data, but this need not be a problem if the TV abundance estimates were separated into pre- and post-recruit categories, and if the assessment can be tuned with the correct weighting of both TV and commercial CPUE data.

Other methods of abundance estimation

There are two other main methods of fishery-independent estimates of *Nephrops* abundance. Larvae production methods have been used to estimate abundance, but the consensus was that such approaches require too much information which may be unknown (i.e. fecundity-at-size, egg loss during incubation, larvae survival) and are logistically difficult to carry out on a regular basis. Secondly independent trawl surveys can provide an estimate of abundance, but this approach suffers greatly from the variation in emergence rate of *Nephrops* discussed previously. Consequently this workshop did not recommend such trawl surveys.

Acoustic techniques for mapping the seabed are developing rapidly and may be an important tool in the future for mapping *Nephrops* distribution and abundance. Clearly the acoustic technique would need firstly to be sensitive enough to identify burrows on the seabed, but secondly to be able to discriminate between burrows of *Nephrops* and other species. However one path which might be worth following is to try an acoustic imager attached to the sledge itself. Thus a high resolution system could be used as it would be deployed only 2 m above the seabed. M. Ulmstrand of the Institute of Marine Research in Lysekil, Sweden (personal communication) has had only very limited success at identifying burrows on the seabed using 500kHz sonar, and concluded that the use of 1MHz sonar would be required to get any realistic estimate of burrow numbers. However the technology does not yet appear to be available that is capable of distinguishing between burrows of *Nephrops* and those of other species.

Ground-penetrating radar is another developing technology which shows promise for identifying burrow structure and inhabitants. It is already used in terrestrial systems to locate burrowing animals.

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Appendix: Statistical considerations

Burrow count data from the Farn Deeps were analysed to assess two statistical issues:

(1) how does choice of statistical model influence the estimation of abundance? and (2) do differences between stations bias the estimation of an overall abundance trend?

Statistical models were fitted to the count data assuming Normal, lognormal or Poisson error distributions. Burrow densities or absolute burrow counts were considered as alternative data representations. In the latter case, counted area was used as a model covariate. The results showed that choice of statistical model had very little influence on the estimation of the trend of abundance over the surveys, although densities gave slightly more consistent results than absolute counts. On theoretical grounds, a log-linear model (i.e. Poisson error) for the data is likely to give the least biased estimates. However, probable non-random spatial distribution of burrow systems ('contagion') and modelling of densities rather than counts will mean that variance estimates are incorrect. Lognormal models will yield better variance estimates and hence confidence intervals. The standard burrow count assessment method is effectively equivalent to assuming a Normal distribution of errors for density data. This appears to be a reliable method of estimating trends, but the validity of confidence intervals needs to be investigated.

Statistical analysis (using burrow densities and lognormal errors) showed that there were statistical differences between stations in the trend over surveys. However, despite the statistical significance of a Station $\times$ Survey effect, it had virtually no influence on the estimation of the overall trend over surveys. Cluster analysis showed that there was some spatial pattern of trends, although this could not be interpreted in terms of densities or sediment types. However, differences in trend between cluster groups were relatively minor. It cannot be assumed that these findings would apply to all survey areas, particularly if there is greater heterogeneity of ground types or population structure.

Figure 1 Comparison between Lowestoft counters

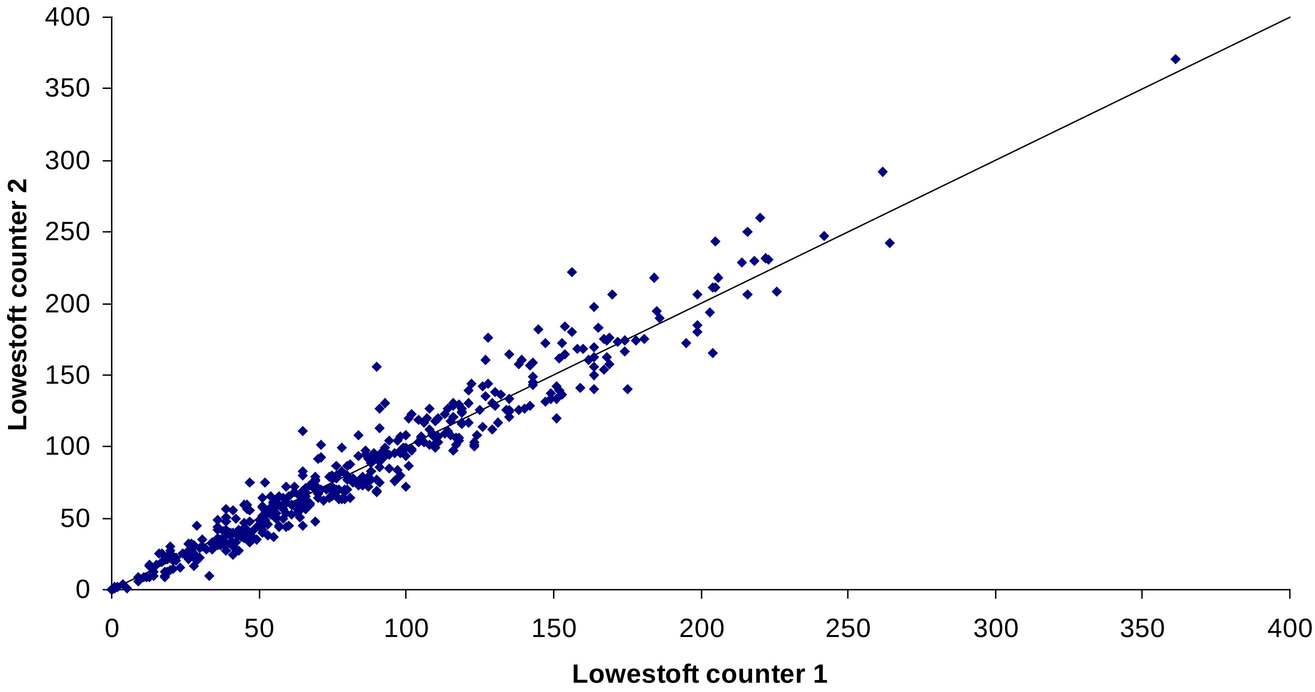
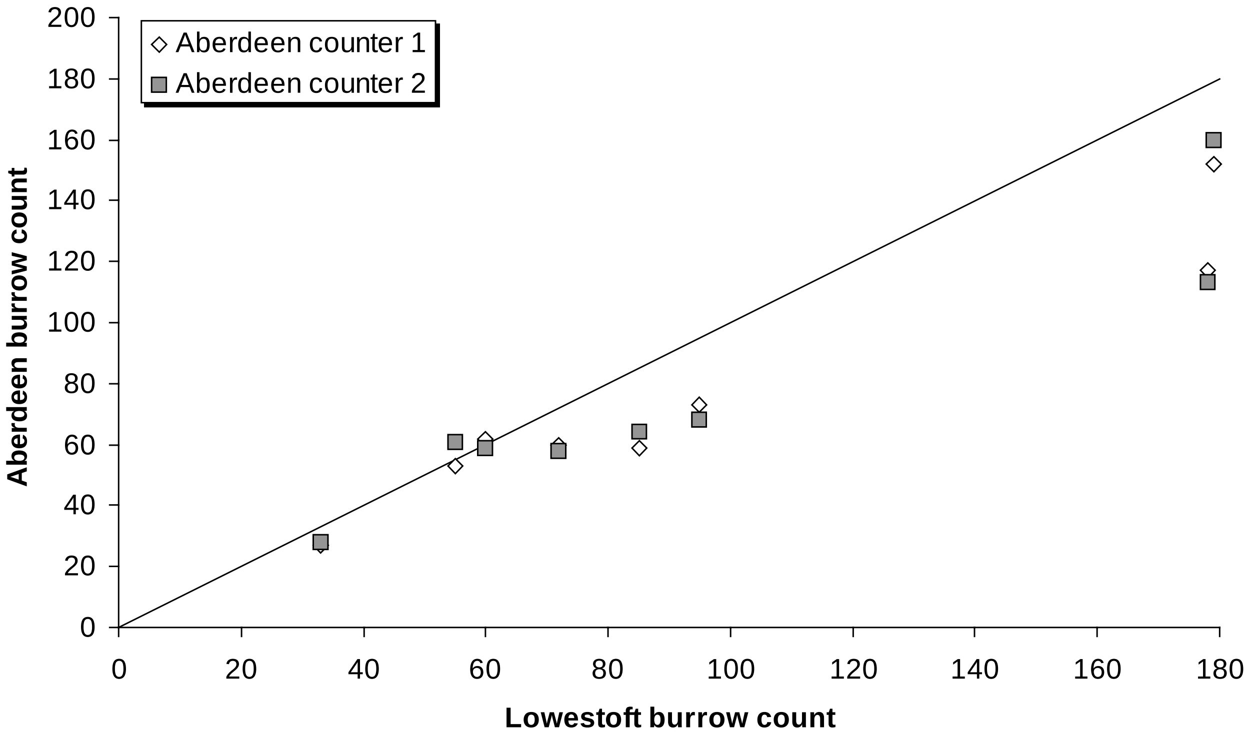


Figure 2 Comparisons between counts of Lowestoft and Aberdeen teams



APPENDIX 4

A preliminary analysis of *Nephrops* survey data from the western Irish Sea

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Introduction

Total international *Nephrops* landings from the Irish Sea have been maintained at over 8,000 tonnes per year for the past 10 years. These landings are mainly by Northern Ireland and the Republic of Ireland and have a first sale value of around 14.3 million Euros, making *Nephrops* the most valuable fishery in these waters. Catches are primarily (over 90%) from the thermally stratified western Irish Sea (Figure 1) where important cod, whiting, haddock and herring fisheries are also located. Management advice for the *Nephrops* in this area arises mainly from biennially performed ICES assessments. These assessments use data collected from both the Northern Ireland and Republic of Ireland commercial fisheries. In addition to commercial fishery data DARD(NI) perform at least 2 fishery independent trawl surveys of the western Irish Sea *Nephrops* grounds per year. These surveys are in spring (April) and early autumn (August/September) and are generating an extensive time series database on *Nephrops* and bycatch species. In view of the higher fishing mortality and natural mortality on male *Nephrops* it is this part of the stock that is likely to show early changes attributable to exploitation. This preliminary analysis is therefore primarily on male *Nephrops* data.

Methods

Trawl stations covering a range of depths throughout the commercially fished part of the western Irish Sea were established during the early nineties. Trawls of 60 minutes duration and covering a distance of 2-3 nautical miles are performed at each station using a custom made 20-fathom *Nephrops* trawl of nominal mesh size 50mm throughout. Catch bulk is quantified by counting baskets filled from the catch and sample baskets of catch are sorted to provide an assessment of species composition. The *Nephrops* in a sub-sample are divided into male and female components and the ovary maturity stage of the females are noted according to an arbitrary scale (Bailey, 1984 and Briggs, 1988). Carapace length frequency distributions for both male and female *Nephrops* are measured and the number of recently moulted (soft shelled) animals noted. The contribution of all bycatch species are quantified and their size compositions measured. Stratified sampling procedures for sampling bycatch are similar to those used during DARD groundfish surveys.

Results

Table 1 is a summary of DARD(NI) *Nephrops* surveys completed over the period 1994-2000 and Table 2 gives *Nephrops* catch rates per nautical mile during these cruises. Figure 2 shows the mean catch rate by station and the maximum and minimum catches during surveys since 1994. Figure 3 is the mean catch rate per cruise and Figure 4 shows the stations characterised by large and small *Nephrops.* Figure 5 is the mean carapace length by station and the temporal mean size data since 1994 are plotted in Figure 6. Figure 7 is the temporal data for two selected stations (8 & 104) and Figure 8 is a plot of mean sex ratios for all stations from April cruises.

Discussion

Preliminary analysis of spatial and temporal data for western Irish Sea *Nephrops* indicates a variation in catch rates between cruises which may be attributed to environmental factors, eg tidal state, rather than changes in the stock. Mean *Nephrops* size shows more variation between stations than between years. These data agree with those presented for an analysis of commercial data (Briggs, 1995). Preliminary examination suggests that stations sampled over the period 1994-2000 have a relatively stable *Nephrops* size. This stability is more marked when the affects of discarding and variable recruitment are removed by examining the mean size of *Nephrops* larger than 30mm carapace length. As male *Nephrops* are generally more vulnerable to fishing than females it is likely that an increase in the proportion of females would occur if exploitation was affecting the stock. Although sex ratio differs significantly between spring and autumn due to the different emergence patterns of male and female animals there is no apparent temporal trend in the April cruise data. Since the minimum number of males required to sustain spawning stock is not known it is not yet possible to prescribe a sex ratio-based biological limit to exploitation level. Preliminary analysis of DARD(NI) survey data seem to suggest a stable sex ratio and mean size. Although further analysis is essential these observations support the results of analytical assessments which indicate that western Irish Sea *Nephrops* are withstanding current exploitation levels.

References

Bailey, N., 1984. Some aspects of reproduction in *Nephrops*. *ICES, Shellfish Committee, CM1984/K:4 (mimeo).*

Briggs, R P 1988. A preliminary analysis of maturity data for Northwest Irish Sea *Nephrops ICES CM988/K:21 pp16***.**

Table 1

DARD(NI) *Nephrops* cruises in western Irish Sea by *R.V Lough Foyle*

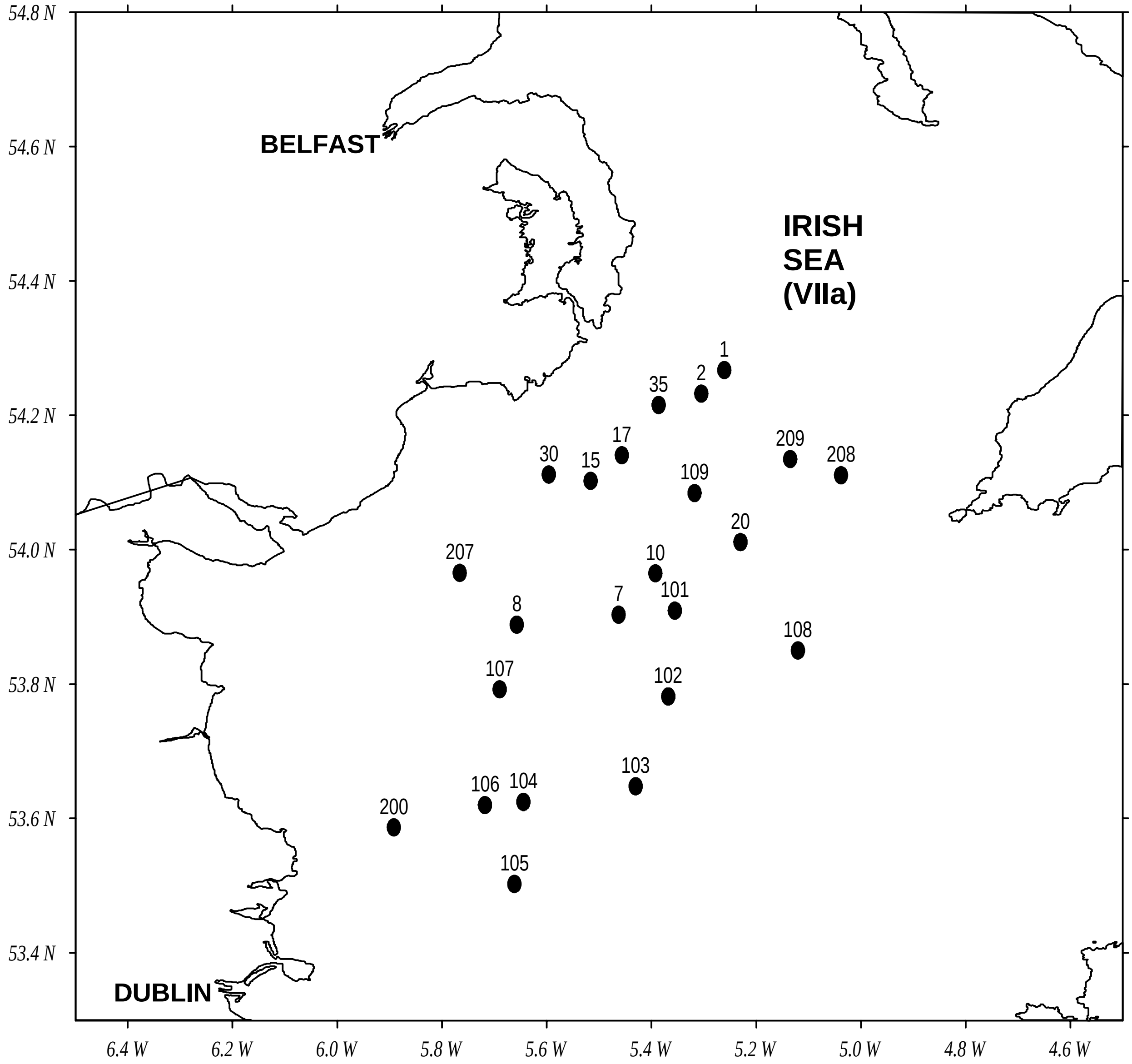
Date	Code
18-22 Apr 1994	LF10/94
23-28 Oct 1994	LF26/94
10-14 Apr 1995	LF06/95
15-20 Oct 1995	LF21/95
22-26 Apr 1996	LF17/ 96
17-21 June 1996	LF25/96
23-27 Sep 1996	LF38/96
14-18 Apr 1997	LF16/97
17-27 Aug 1997	LF34/97
6-10 Apr 1998	LF15/98
17-27 Aug 1998	LF34/98
26-30 Apr 1999	LF17/99
16-25 Aug 1999	LF33/99
10-14 Apr 2000	LF15/00

Table 2
Nephrops Catches during DARD(NI) surveys of western Irish Sea (kg per nautical mile)

code	10/94	26/94	06/95	21/95	17/96	25/96	38/96	16/97	34/97	15/98	34/98	17/99	33/99	15/00
stn	Apr94	Oct94	Apr95	Oct95	Ap-96	Jun96	Sep96	Apr97	Aug97	Apr98	Aug98	Apr99	Aug99	Apr00
1	72.9	47.2	76.7	30.2	19.6		22.7	69.7		7.4	96.4	69.96	37.1	8.0
2	41.5	25.6	33.0	62.3	15.6	0.4	1.3	25.8	77.3	9.5	125.0	59.9	55.9	
7	44.5	36.7	12.0	92.9	14.9		10.1	7.3	6.7	25.6	1.2	72.2	24.2	41.1
8	14.1	49.3	46.5	40.9	4.3	4.7	28.8	55.5	35.3	25.6	78.6	8	98.2	34.9
10	26.4	38.5	19.0	54.4	0.3			29.9	55.5	28.2	10.7	78.5	35.6	12.6
15											59.5	44	86.3	
17	7.0	75.6	0.4	54.6	45	2.6	10.1		12.4	0.6	48.0	58.1	81.7	
20	32.3	51.3	31.9	33.2	4.2		28.6	49.1	51.7	7.0	24.2	49.1	53.3	39.9
30	0.1	94.1	<0.1	62.5	6.9				1.7		74.6	38.8	41.5	
35	0.4	27.0	0.2	66.4	31			0.2	24.1	0.4	30.7	61.3	103.6	
101	6.9	8.0	17.5	51.8	6	6.0	10.4	5.5	29.1			43.9	19.0	7.4
102		22.8	4.6	105.0	17.7	14.3		34.6	65.2	7.7	4.0	78.3	91.2	58.2
103		18.2	1.0	101.4	0.4	2.4		100.9	28.0	4.4	27.2	2.4	3.8	2.4
104	16.3	14.7	5.4	68.2	3.4	19.1	4.4	62.8	3.3	70.7	24.0	23	5.3	2.6
105	41.6	12.4	56.9	19.4	3.4	6.2	10.1	64.9	34.9	14.2	1.3	13.5	35.7	9.2
106	9.1	50.7	13.5	23.0	2	8.9	45.3	47.2	51.3	33.4	33.7	4	80.0	17.5
107	13.5	30.6	50.7	50.6	8.6		81.7	99.8	117.3	19.1	25.3	41.2	155.6	41.2
108	0.7										135.6	17.4	93.3	
109	4.3	27.1	35.3	25.3	2.4	8.3		66.9	75.1	45.3	37.9	27.6	36.7	25.3
200			2.0						28.6	1.8	19.8	0	20.6	
207					14	11.3			28.7	0.4	4.2	54.4	115.3	
208							14	35.9	162.6	62.9	123.5	24.2	235.5	
209							21.9	17.5	32.9	2.0	4.1	1.5	9.5	5.5

Figure 1

Western Irish Sea Nephrops Stations



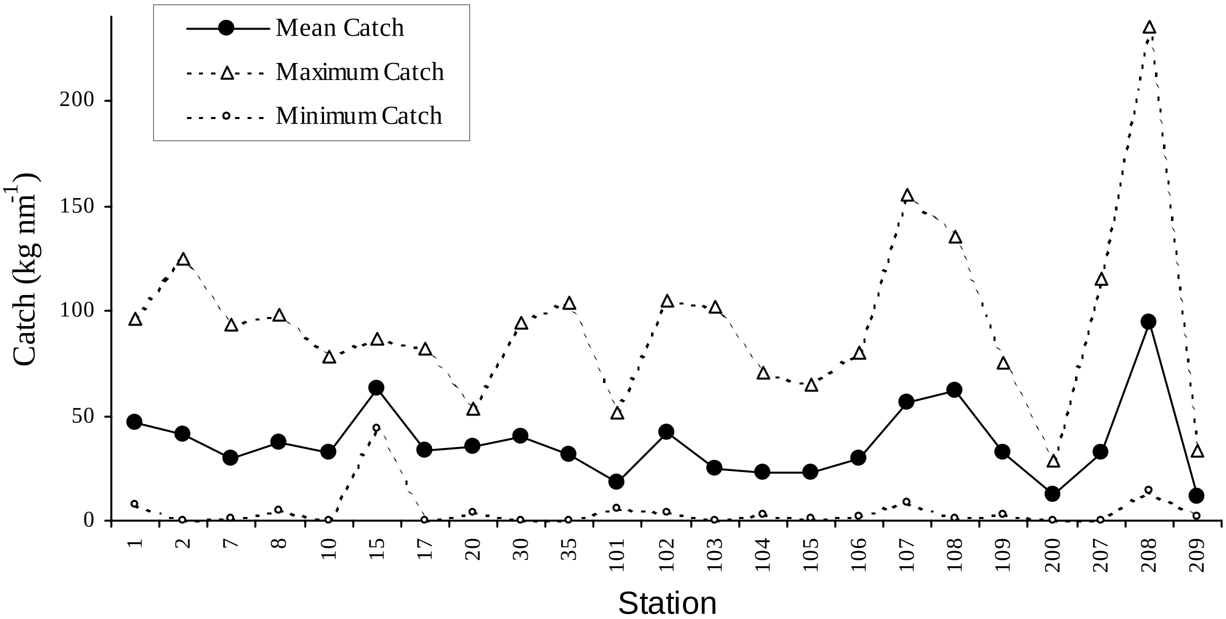


Figure 2 Mean, Maximum and Minimum Catch (kg) per nautical mile at each station (pooled data for 1994 – 2000

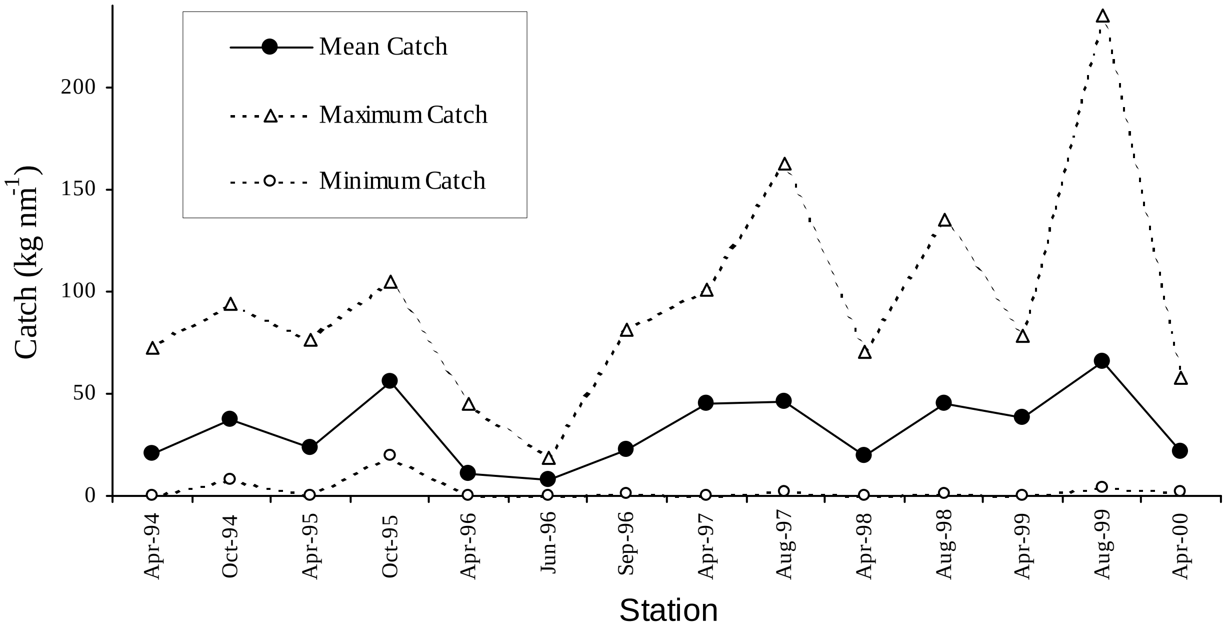
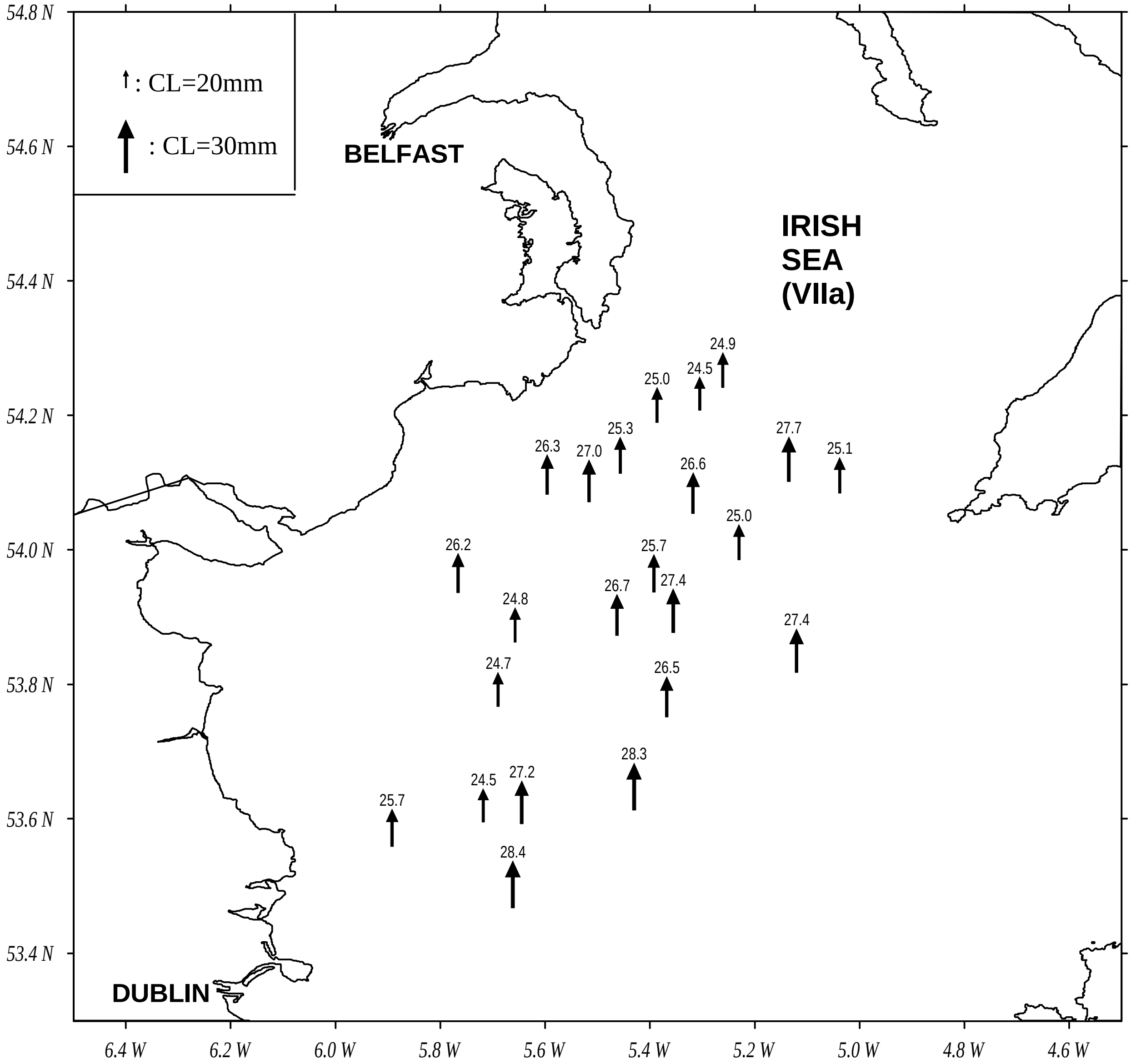


Figure 3 Mean, Maximum and Minimum Catch (kg) per nautical mile for each survey 1994-2000 (pooled data for all stations)

Figure 4

Mean size of male Nephrops during April cruises 1994-2000



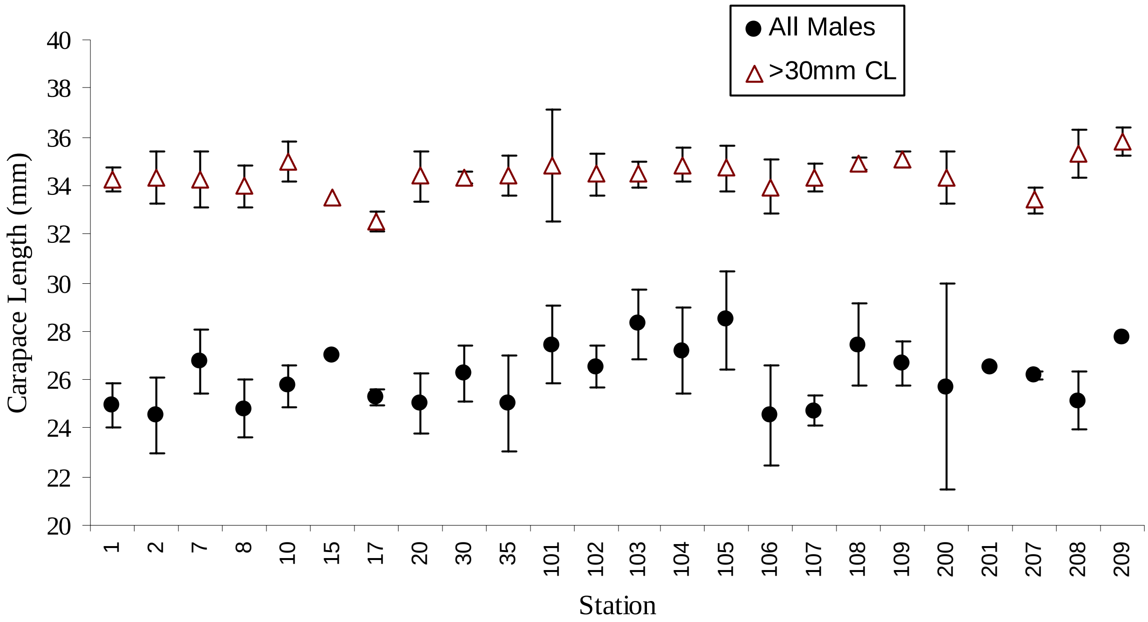


Figure 5 Mean carapace length of male *Nephrops* from April cruises by station (pooled data for 1994-2000 surveys: vertical bars =sd

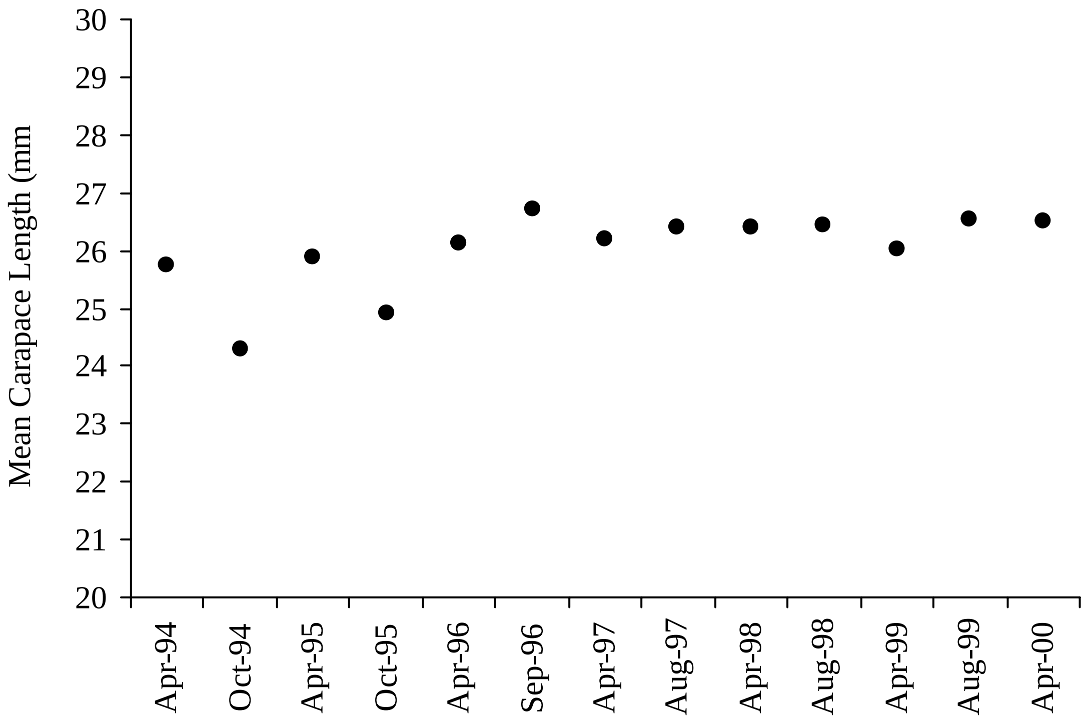


Figure 6 Mean carapace length of male *Nephrops* 1994-2000 (pooled data from all stations)

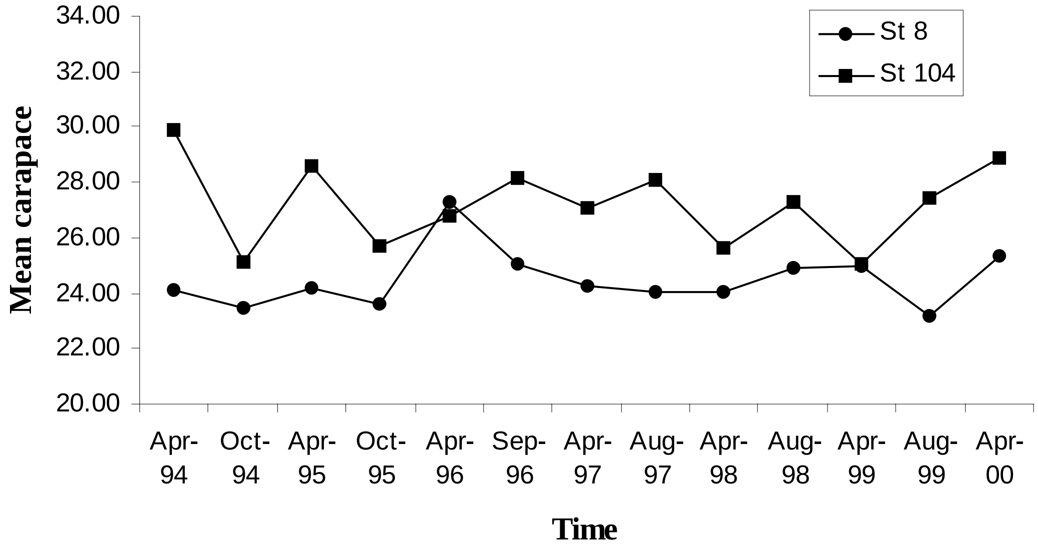


Figure 7 Carapace length from selected stations 1994-2000

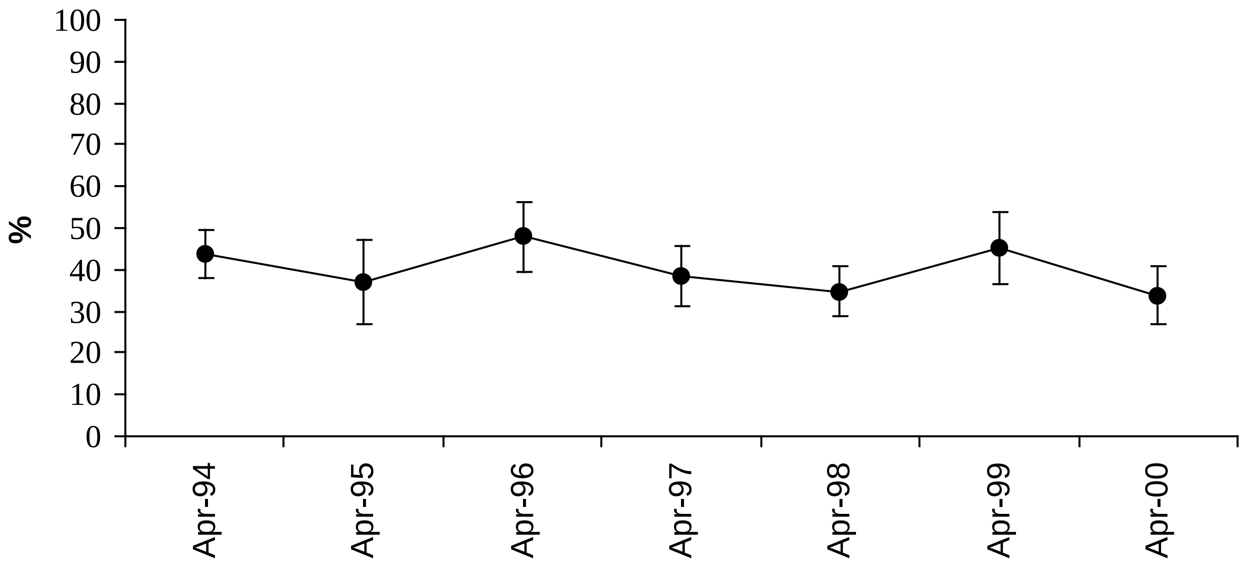


Figure 8 Percentage female *Nephrops* in catches during April surveys 1994-2000

APPENDIX 5

Data on *Nephrops* Discards in Spanish Trawl Fisheries

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Introduction

Nephrops, along with hake, megrim and anglerfish are the most profitable species of the Spanish mixed bottom fisheries in the North and Northwest of Spain (ICES VIIIc and IXa) and South and West of Ireland (ICES VIIc,j,k,h). *Nephrops* is caught exclusively by the trawl fleets. Only small catches using traps are reported in the Cantabrian Sea. *Nephrops* catches are seasonal, with peaks during the 2nd and 3rd quarters of the year. More details on these *Nephrops* fisheries are given in the ICES (1999).

The lack of information on discards of bottom species has been commented on by the ACFM, nevertheless the amount of *Nephrops* discards by Spanish fleets in the fisheries of ICES Sub-area VII and Divisions VIIIc and IXa was considered negligible. The Spanish sampling programme on discards of bottom species, financed by the EU, was carried out in 1994, 1997 and 1999. This paper present the results on *Nephrops* discards from the trawl fleet in these areas. This information is the only field data available to corroborate the low level of *Nephrops* discarding practises in the Spanish fisheries.

Material and Methods

Table 1 shows details of the Spanish sampling programme on discards in the mixed bottom trawl fisheries of Galicia, Cantabrian and ICES Sub-area VII. On each sampling trip, the observer recorded the *Nephrops* number at the length discarded and retained (landed). These data were transformed to biomass using the length/weight relationship.

Because of the small number of *Nephrops* discarded, data correspond to males and females combined (Pérez et al, 1999; Trujillo et al, 1997).

Various methods of raising trip results to estimate discarding by the fleet are currently in use (ICES, 2000). Some of these might cause the estimations to be biased or inaccurate (Pérez et al, 1999). In our case, raising by means of the landing method was applied to raise *Nephrops* discard sampling to the total discard fleet. In this method, discard is raised in relation to landings by the observed vessels and landings by the whole fleet. The method assumes that all vessels have an equal chance of being sampled.

To determine the percentage of retained catch per length class, the proportion of retained catch per length of the total fleet in relation to total catch was used. The data were adjusted by linear regression of a logistic distribution.

Results and Discussion

Total discard by area (in weight and numbers) and the percentage of discard estimated in relation to total catch (retained catch plus discard) are shown in Table 2. *Nephrops* discard ranged 4.9-7.3 % by weight in Sub-area VII in 1994 and 1999 respectively, while they are low in the N and NW Spain (min 0.0% – max 3.8%) during the three years sampled.

Length compositions of *Nephrops* discards (Figure 1) show that individuals of the whole range of sizes are discarded. There is not a clear pattern of discarding related to sizes. They are more associated with soft, broken specimens or market procedures than with technical management measures such as minimum landing size. Minimum landing size is 20 mm CL in Region 3 (North and West Galicia, and the Cantabrian are included in Region 3) and 25 mm in Sub-area VII.

Figures of the estimated curves of retention (Figure 2) provide the theoretical behaviour of the discarding practises although they do not explain their causes. In North Galicia and Sub-area VII the discards vary considerably from year to year.

There are only three years of discard estimates available for this species. In the past, the discard rates have been unknown, and the use of the values obtained in the years sampled to correct the time series of catches would cause substantial bias. In particular, the effects of the variability of recruitment, and changes in fisheries policy and market may alter the discard rates (Pérez et al, 1996). These aspects could be the factors that result in the different estimates of discard proportion obtained in the years sampled. Differences are observed in North Galicia, probably due to the small quantity of discard produced in this area, particularly in 1999. In this year, discards are almost non-existent in West Galicia. In Sub-area VII major differences were observed in the length composition of the two years sampled. From preliminary length composition of landings in 1999, catches of juveniles *Nephrops* (<25 mm CL) were low and the discarding practises would have been directed at more abundant or lower length classes in these catches.

References

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Pérez, N., P. Pereda, A. Uriarte, V. Trujillo, I. Olaso and S. Lens. 1996. Descartes de la flota española en el área del ICES. *Datos Resúm. Inst. Esp. Oceanogr*. Nº 2. 142 pp.

Pérez, N., V. Trujillo and P. Pereda. 1999. Landings and discards of the trawl fleets of Spanish ICES Divisions VIIIc and IXa in 1997. Final Report EU. Study contract 95/094.

Trujillo, V., N. Pérez and P. Pereda. 1997. Factors affecting catches discarded by the coastal Spanish North Atlantic trawlers. *ICES CM* 1997/DD:03.

Table 1. Discard sampling level of Spanish trawlers per ICES areas and years.

	VIIc,j,k, h		VIIIc (N Galicia+Cantabrian)			IXa (West Galicia)		
*Year	1994	1999	1994	1997	1999	1994	1997	1999
f. h.	3894	999	1608	1465	542	802	797	408
Hauls	730	230	301	298	118	220	188	90
Ships	15	7	14	25	31	18	22	16
Fishing Days	301	83	109	105	75	67	59	34
Trips	18	7	33	64	46	37	36	21
Harbour	3	3	6	6	6	3	3	3

*Year 1994 From Pérez et al 1996
*Year 1997 From Pérez et al 1999

Table 2. Estimates of *Nephrops* discards by Spanish trawlers in the bottom fisheries of the Subarea VII and N and NW of Spain

		Tonnes		Number (x1000)		(%) Discard/Tot Catch	
	Year	Retained	Discarded	Retained	Discarded	Weight	Number
Sub-area VII	1994	959	49.3	19305	1902	4.9	9.0
	1999	502	39.4	9338	1538	7.3	14.1
Cantabrian Sea	1994	142	2.6	1922	95	1.8	4.7
	1997	97	0.5	1167	14	0.5	1.2
	1999	124	0.0	3022	0	0.0	0.0
North Galicia	1994	246	1.5	6622	62	0.6	0.9
	1997	219	5.5	5967	281	2.4	4.5
	1999	40	0.2	487	15	0.4	2.9
West Galicia	1994	426	14.0	11471	711	3.2	5.8
	1997	427	16.8	10819	737	3.8	6.4
	1999	240	0.2	5242	32	0.1	0.6

Figure 1. Length composition (% of annual discard in number -N- by length class) of *Nephrops* discards per area.

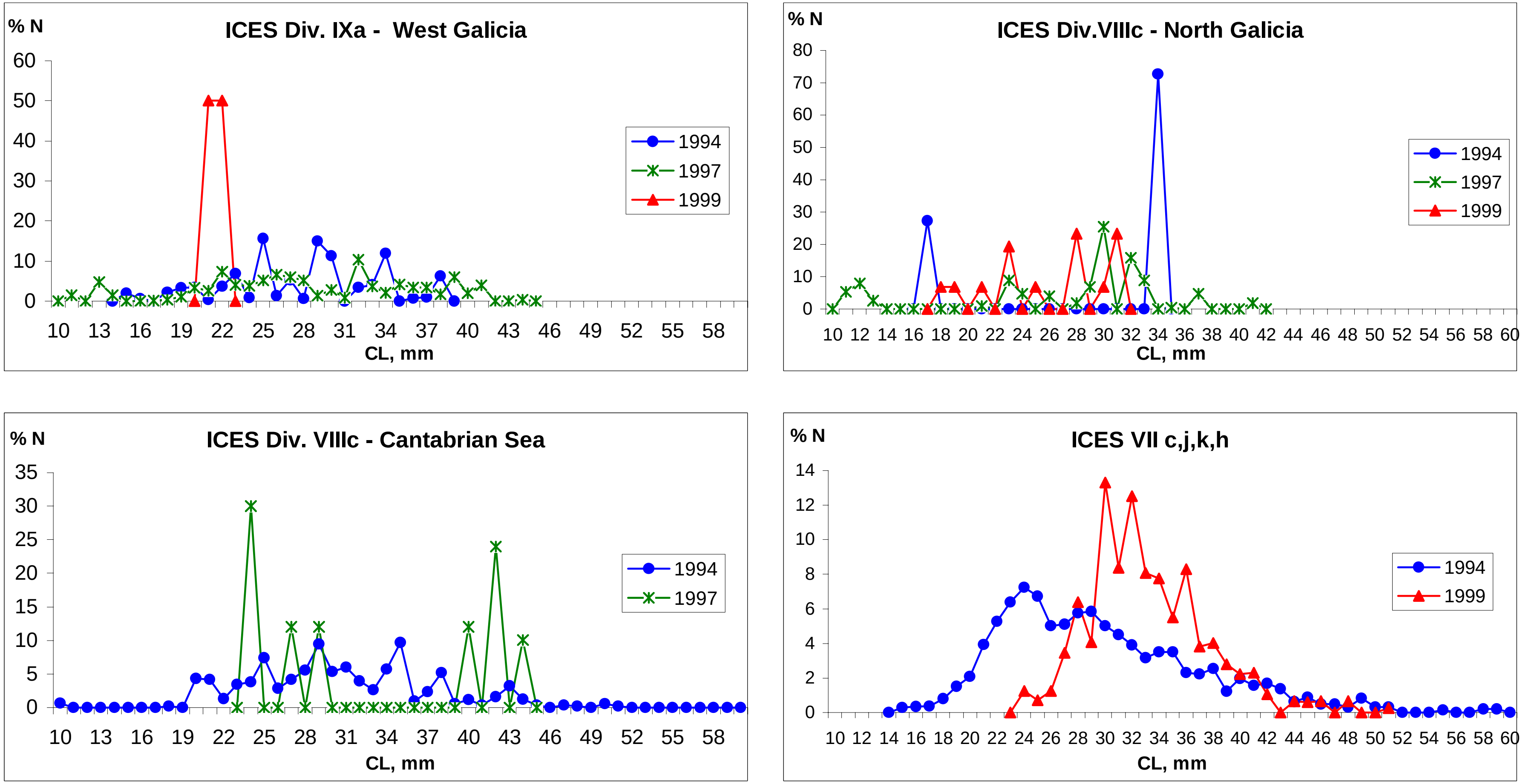
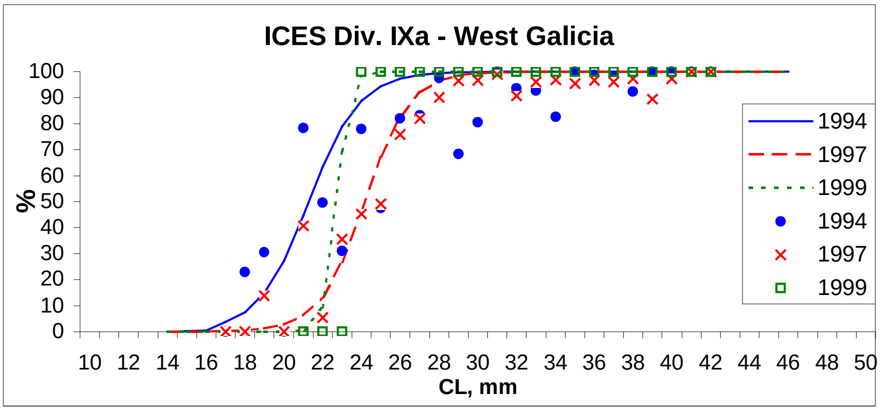
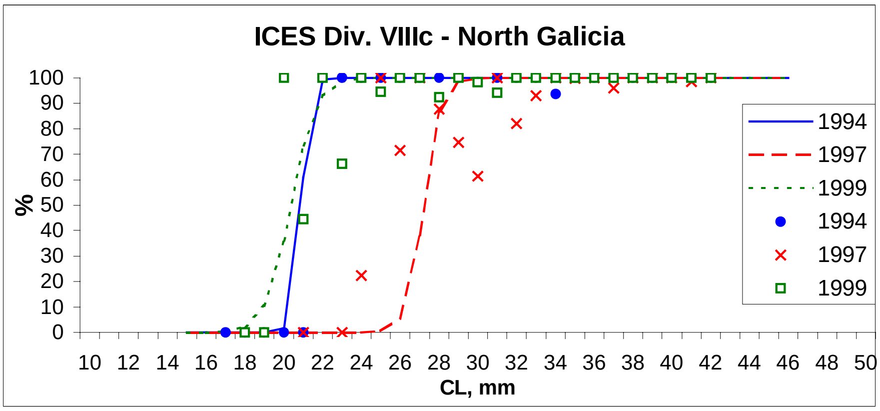
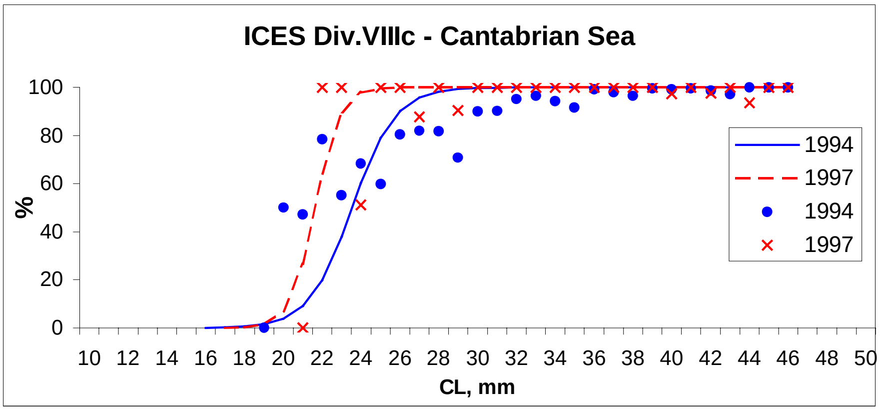
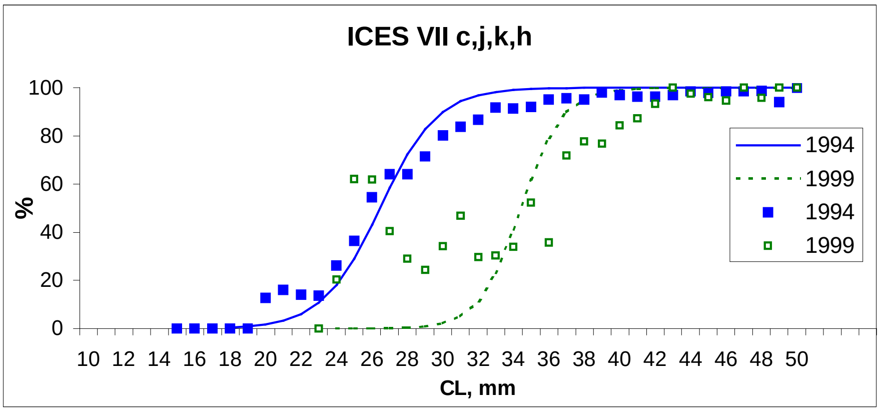


Figure 2. Observed and estimated values (points and lines, respectively) of the percentage of *Nephrops* retained by length class (CL, mm) in 1994, 1997 and 1999.









APPENDIX 6

The composition and fate of discards from *Nephrops* trawling in Scottish (Clyde) waters

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Background

Large quantities of non-landable or undesired components of trawl catches in the *Nephrops norvegicus* (hereafter referred to by genus alone) fishery are usually discarded after sorting. Sorting can take several hours, and duration in the trawl and on deck has a marked effect on discard survival (M.Bergmann, pers. comm.; Wileman *et al*., 1999). The composition and fate of discards associated with the *Nephrops* fishery has recently been investigated in two regions, the Clyde Sea area, Scotland and the Central Adriatic region, Italy. This paper summarizes some of the results of this work, concentrating on Scottish data. The component of discard that reached the sea bed received most attention. Results are given in full in a Study Project Report to the EC (Wieczorek et al*.*, 1999).

In the Clyde Sea area the bulk of *Nephrops* landings is made by around 90 inshore trawlers (10 - 21m length) using single-rig (70mm mesh) or twin-rig trawls (80mm mesh). Nets are required to contain a square mesh panel to aid the escape of roundfish. Trawling for *Nephrops* is permitted throughout the year, but vessels are restricted to a maximum length of 21m, and are not allowed to fish at weekends. The permitted landing of fish bycatch of protected species (i.e. those with a minimum landing size) is restricted to not more than 60% by weight of the total catch and at least 30% of the catch must be *Nephrops*. The minimum landing size for *Nephrops* is 25mm CL. A quota system operates. These measures notwithstanding, the proportion of the material discarded may be substantial and, in the Clyde Sea area, is usually a combination of undesired small round- and flatfish, invertebrates and undersized *Nephrops* and *Nephrops* 'heads' (cephalothoraces).

The characteristics of the *Nephrops* populations (density, growth rate, mean animal size) in the northern and southern parts of the Clyde Sea area have been shown to differ (Tuck et al., 1997a,b) so these areas have been treated separately in the work reported here. The division used is an imaginary line drawn between Troon Point (55°33.00'N, 004°40.20'W) on the Ayrshire mainland and the northern tip of Holy Island (55°32.02'N, 005°04.05'W).

Monthly routine survey trips on local commercial prawn trawlers and/or UMBSM research vessel *Aora* were conducted in the North Clyde Sea between October 1997 and October 1998, in order to assess discard compositions and proportions for this area, and for comparison with discard composition and proportion data for the South Clyde Sea area, obtained quarterly either from local commercial *Nephrops* trawlers or RV *Aora*. Underwater television (UWTV) was deployed in each region to assess the fate of representative discards attached to the camera frame. Also, baited traps and creels were used to determine the benthic processors of *Nephrops* and associated bycatch discards. SCUBA studies at two Scottish sites (one in the Clyde) aided interpretation of discard utilization.

Summary of Results

Discard composition

The total catch composition and composition of the discard component of the catches were markedly different for North and South Clyde Sea areas. The South Clyde Sea catches had a higher proportion of smaller sized *Nephrops*, thus undersized *Nephrops* and *Nephrops* 'heads' account for a larger proportion of the discarded material compared with the North Clyde Sea area (approximately 12% and 18% of the discard biomass, respectively, in the South, and approximately 2% and 2%, respectively, in the North Clyde Sea area). The proportion of unlandable commercial fish in the discards was higher for the South (around 55% of the total discard biomass) than for the North Clyde Sea area (around 32% of the total discard biomass).

The proportion of roundfish among total discards was higher (around 25% - 35% of the total discard biomass) for South compared with North Clyde Sea *Nephrops* trawls (around 1% - 5% of the total discard biomass), which had comparatively higher proportions of flatfish (around 4% - 5% of the total discard biomass in the North, and around 1% - 2% in of the total discard biomass in the South Clyde Sea area).

North Clyde Sea discard compositions were higher in invertebrates other than *Nephrops* in terms of both total discard biomass (around 60%) and abundance (around 80%), and crustaceans in particular, compared with the South Clyde Sea (around 14% and 25%, respectively). Crustaceans (mainly *Liocarcinus depurator* and *Munida rugosa*) and echinoderms (mainly *Asterias rubens* and *Ophiura ophiura*) accounting on average for 50.2 and 22.8% of the total discard abundances in the North. Species diversity was also higher in the North. Ninety three invertebrate taxa were identified in the North compared with 51 taxa in the South Clyde Sea discard samples.

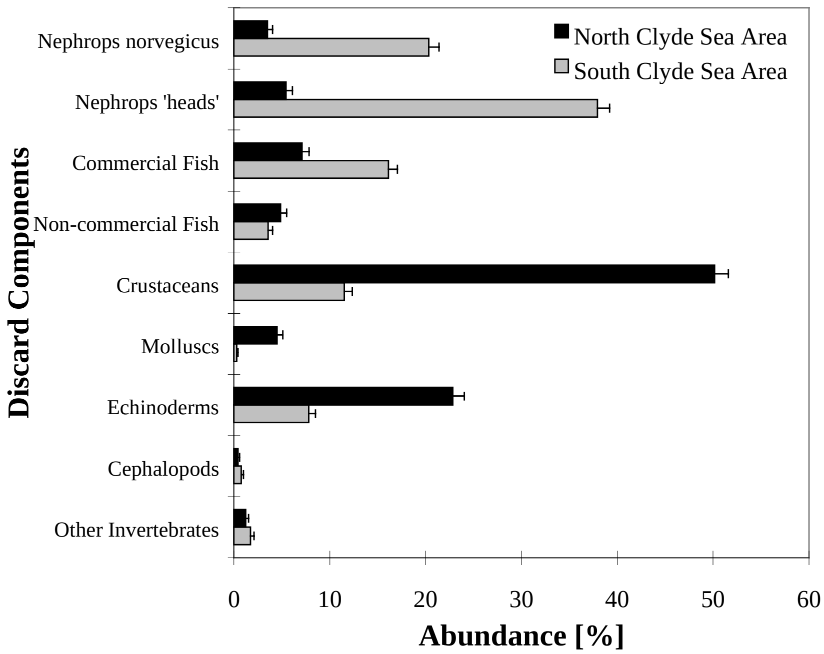

Figure 1. Discard abundances: composition of the Clyde Sea area samples. Error bars = standard errors of the proportions.

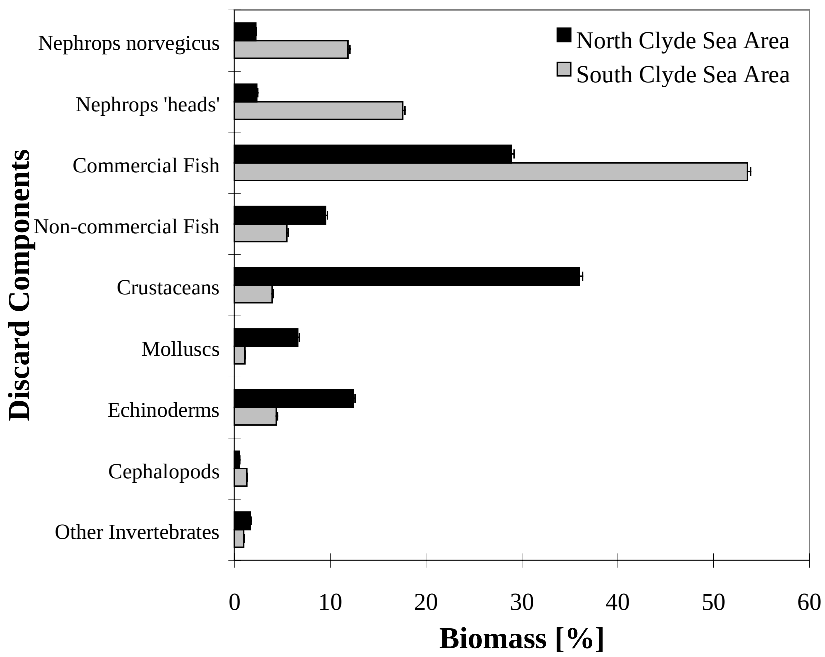

Figure 2. Discard biomass: composition of the Clyde Sea area samples. Error bars = standard errors of the proportions.

Table 1. Mean weight of discards produced per kg of *Nephrops norvegicus* and total catch landed. SE = standard error, given in brackets.

	mean weight of discards produced per kg *Nephrops* landed [kg]	mean weight of discards produced per kg of total catch landed [kg]
North Clyde Sea area (n = 39)	10.4 (± 1.3)	6.7 (± 0.8)
South Clyde Sea area (n = 15)	6.2 (± 1.2)	2.7 (± 0.4)
Clyde Sea area total (n = 54)	9.2 (± 1.0)	5.6 (± 0.6)

Further significant differences (ANOVA, P = 0.001) were detected for the amounts of discards produced per kg total catch landed between the two Clyde Sea areas sampled (including landed *Nephrops* and other commercial species which, for the Clyde Sea area trawls consisted almost entirely of fish species such as *Melanogrammus aeglefinus*, *Merlangius merlangus*, *Merluccius merluccius*, *Gadus morhua*, *Clupea harengus*, *Scomber scombrus*, *Pleuronectes platessa* and *Glyptocephalus cynoglossus*). In the trawls of the North Clyde Sea area a mean of 6.7kg discards per kg total catch landed were produced, whereas in the South Clyde Sea area an average of only 2.7kg per kg total catch landed were discarded.

Total catch composition

The average total catch compositions of North and South Clyde Sea trawls were found to be significantly different. Whilst the overall weight of *Nephrops* landed did not vary markedly between the two sample areas (ANOVA, P = 0.106), the proportion of landed fish was more than twice as high in the South than in the North Clyde trawls (ANOVA, P = 0.001). The mean proportion of total discards was, on average, 65.8% in the South and 80.3% in the North Clyde Sea trawls, and thus significantly different between sample areas (ANOVA, P = 0.001).

Size-frequency data

The mean size of *Nephrops* caught in the North Clyde Sea area was larger than of *Nephrops* caught in the South and a larger proportion of *Nephrops* 'tails' were landed in the South compared with the North. On average, more male than female *Nephrops* were caught in both sample areas (particularly for the larger size categories).

North Clyde Sea discards were characterized by a comparatively larger proportion of undersized flatfish (such as *Hippoglossoides platessoides*, *Limanda limanda* and *Pleuronectes platessa*). Undersized roundfish (e.g. *Merlangius merlangus* and *Melanogrammus aeglefinus*) were particularly abundant in the catches from the South Clyde Sea area. The survival of undersized fish discards was low and fish mortality related to *Nephrops* trawling is likely to have an effect on the population ecology of some commercially important fish species in some areas.

Baited creel and funnel trap deployments

The mean total numbers of macrofaunal scavengers caught in creels baited with *Nephrops* discards were higher and scavenger composition more diverse in the North than in the South Clyde Sea area. The predominant macrofaunal scavenger species caught in creels baited with *Nephrops* discards in the North Clyde Sea area included *Asterias rubens*, *Liocarcinus depurator*, *Pagurus bernhardus*, *Carcinus maenas*, *Cancer pagurus*, *Neptunea antiqua* and *Buccinum undatum*; in the South Clyde Sea area the predominant scavenger caught in similar deployments was *Nephrops norvegicus*.

The number of amphipods caught in funnel traps baited with *Nephrops* discards was variable and ranged between 15 and 1100 animals per trap (the predominant species caught were *Scopelocheirus hopei* and *Orchomene nanus*). *O. nanus* is thought to specialize on crustacean carrion. Creels baited with *Nephrops* discards exposed for 4h and 24h caught significantly fewer macrofaunal scavengers than creels exposed for 48h. No significant differences were detected between numbers of macrofaunal scavengers caught in creels baited with *Nephrops* which had been dead for 24h or 48h.

Underwater baited camera observations

Time Lapse Camera (TCL) deployments indicated utilization times for batches of mixed discards of between 24h and 48h. The predominant scavengers observed exploiting discards in the TLC deployments were *Asterias rubens* and *Carcinus maenas* (this species reflecting the nearshore location of this observation site – camera powered from shore).

UWTV deployments (using underwater TV camera and infra red lights, deployed from research vessel) indicated that mean densities of total macrofaunal scavengers were higher for the North compared with the South Clyde Sea area. Macrofaunal scavenging species including *Liocarcinus depurator*, *Asterias rubens*, *Pagurus bernhardus*, *Cancer pagurus*, shrimps and *Buccinum undatum* were commonly seen during UWTV deployments in the North Clyde Sea area, whereas the main macrofaunal scavenger observed in the South was *Nephrops norvegicus*. Therefore, these findings correspond with the results of the creel deployments.

Higher numbers of amphipods and isopods were encountered during night-time, compared with day-time deployments. For most scavengers, fish discards were utilized in preference to invertebrate discard items. Aggressive inter- and intra-specific interactions occurred around the discard bait, especially between crabs. Among the first scavenger species to arrive at discard bait were hermit crabs (*Pagurus bernhardus*) and brachyuran crabs (mostly *Liocarcinus depurator*). Slower-moving species, such as *Asterias rubens* and *Buccinum undatum*, arrived at the discard bait subsequently.

SCUBA diving observations

SCUBA diving observations on a nearshore *Nephrops* ground in Loch Sween in Argyll (12-15m depth) indicated mixed discard utilization times of < 24h. The predominant scavengers of *Nephrops* and other discards were the crabs *Carcinus maenas*, *Liocarcinus depurator* and *Cancer pagurus*. *Carcinus maenas* arrived at the discard bait within minutes after deployment. The gastropod *Philine aperta* left the area of bait deployment as scavengers, such as *Carcinus maenas* and *Cancer pagurus*, arrived at the discards. Slower-moving scavengers, such as *Asterias rubens* and *Buccinum undatum*, were among the last species to arrive at the discard bait. Inter- and intra-specific interactions among scavengers were common, particularly among the brachyuran crabs. Similar, but less extensive, observations were made at Loch Riddon in the North Clyde, this site being less suitable for diving work.

Sinking rate experiments

Mean sinking rates for typical discard components from Clyde Sea area catches measured by SCUBA divers *in situ* matched those from laboratory trials. Mean sinking rates for whole undersized *Nephrops* and *Nephrops* 'heads' were approximately 11.6 and 10.3cm.s^{-1}, respectively. Heavier shelled species, such as *Buccinum undatum* and *Neptunea antiqua*, showed fastest mean sinking rates (between 25.8cm.s^{-1} and 36.2cm.s^{-1}), compared with species such as *Allotheuthis subulata*, *Rossia macrosoma*, *Ophiura ophiura* and *Asterias rubens* (with mean sinking rates between 4.9cm.s^{-1} and 9.0cm.s^{-1}). About three times higher 'sinking' rates were obtained for live (34.1cm.s^{-1}) compared with dead *Munida rugosa* (11.2cm.s^{-1}), due to living animals swimming actively downwards. Thus at the depths most commonly fished in the Clyde sea area (50-100m) discards will arrive at the sea bed rapidly (*ca* 8-16min for *Nephrops* 'heads'). On no occasion did camera deployment viewing discard attached to the camera frame provide evidence for utilization of discard in the water column, but investigation of this was not extensive.

Seabird surface scavenging behaviour and dietary preferences for discards

The vast majority of the seabirds following discarding *Nephrops* trawlers in the Clyde Sea area were herring gulls (*Larus argentatus*). *Nephrops* discards were taken by seabirds, when offered on their own, but were clearly a less preferred discard food item when offered together with other more preferred items, such as roundfish. There was no obvious difference in the frequency with which male *vs.* female *Nephrops,* or whole *Nephrops vs. Nephrops* 'heads' were taken by seabirds. Smaller *Nephrops* (≤ 25mm CL) seemed to be slightly preferred over larger individuals (> 25mm CL). Fish discards, and roundfish in particular (which tended to float on the water surface), were preferred over invertebrate discards. The least preferred (or accessible) invertebrate discard species were the fast-sinking *Echinus esculentus* and *Buccinum undatum*.

The most preferred discard items, roundfish, were more likely to be taken by larger seabird species, such as gannets and greater and lesser black-backed gulls, as well as adult herring gulls. Less preferred items, such as most invertebrate species, when offered individually, were more likely to be taken by seabirds than when offered together with other more preferred discard items. Less preferred discard items were more likely to be taken by juvenile rather than adult seabirds. Seabird numbers following the vessel during discard assessments varied from 35-140 birds.

Discussion

The commercial trawlers used in the Clyde study, although typical of the smaller vessels participating in the *Nephrops* fishery locally, are not wholly representative of the fleet. A minority of the local fleet (*ca* 18%) are larger, more powerful vessels including trawlers using twin-rigged gear whose catching and discarding characteristics may differ from the smaller vessels. Our study only included three hauls from one twin-rigged vessel so we have not investigated these vessels with the same degree of intensity accorded the smaller vessels. Thus any extrapolation beyond the data presented runs the risk of compounding erroneous assumptions.

Based on our findings for *Nephrops* trawlers, we calculate that the average weight of discarded material per vessel per working day in the Clyde Sea area is 1.5t (representing between 56% - 89% of the total catch volume). Raised to the fleet on an annual basis that represents a minimum of $25{,}000 t.y^{-1}$ for the Clyde Sea area (note: these calculations are minimum estimates only and are based on rather crude data, but they probably reflect reality within a factor of 1.5 to 2).

In many cases, discards which are returned to the sea do not survive (Pascoe, 1997). Ulmestrand et al. (1998) noted *ca* 29 % survival (after $\geq$ 11 days) of discarded *Nephrops* in Scottish waters. Polet & Redant (1992) tentatively estimated the short-term survival of discarded *Nephrops* in Belgium as being 40%, with survival being size-dependent (smallest size-classes having the lowest survival). A significant proportion of discards were still alive (see Wieczorek et al. 1999), but survival experiments suggest that many will not survive for long (M.Bergmann, see Section 8.7.).

The area of ground fished for *Nephrops* in the Clyde Sea is approximately $3{,}000 km^2$. Thus the discard biomass (wet weight) input to these ecosystems is calculated roughly to be $8.3 t.km^2.y^{-1}$. The majority of the material discarded sinks to the sea bed and is available to benthic scavengers. The rate of consumption of carrion varies in relation to the abundance of different scavenging species at the bait, but is typically rapid. In the Clyde Sea area, crabs were consistently among the most important benthic scavengers, consuming discards from experimental arrays within hours of their arrival at the sea bed.

The energy subsidy to seabirds represented by discarding from trawlers is considerable, reflecting the mobility of seabirds and their ability to follow trawlers. Monaghan & Zonfrillo (1986) pointed out that the numbers of gannets, gulls and fulmars have all increased in the Clyde Sea area since the 1950s associated with consumption of fisheries offal and discards. Calculations suggest that > 25% of discards are consumed by sea birds in the South Clyde Sea *cf.* < 25% in the North Clyde Sea area, together accounting for around $6000 t.y^{-1}$.

Most of the energy represented by *Nephrops* discards in the fisheries studied ends up on the sea bed. There was no evidence of mid-water utilization, though investigation of this was limited. Information on the ecological energetics of *Nephrops* is only just now beginning to emerge (Parslow-Williams, 1998). As yet, too little is known to decide to what extent discarding practices subsidise the food supplies (energy availability) of local benthic populations of this or other species. *Nephrops* will consume discards of conspecifics. In fact the main macrofaunal scavenger trapped in creels baited with *Nephrops* discards in the South Clyde Sea area was *Nephrops*, which might be an indication of food limitation experienced by this population of small, slow-growing, but densely packed individuals.

Any amplification of benthic scavenger populations caused by discarding practices may, however, feed-back to the target *Nephrops* indirectly via routes involving disease transmission, if scavengers act as disease vectors, since *Nephrops* will consume significant discard scavengers like *Natatolana borealis* and *Liocarcinus depurator*.

Our studies on discard practices in two important *Nephrops* fisheries have highlighted several important issues: *viz*.

- the mortality of juveniles of commercial fish species that are already overexploited;
- potential waste of the target species (*Nephrops*), which in some areas could profitably grow further before being caught;
- damage to sensitive benthic species
- potential disturbance caused to ecosystem balance; and

- the risk to seabird populations posed by ceasing discarding altogether.

Acknowledgements

Special tanks go to Melanie Bergmann whose Ph.D studies interacted with those reported here; to the skippers and crews of the commercial prawn trawlers *Red Baron, Andrias, Andrew* and *Tricia Anne*, and the research vessels *Aora* and *Aplysia*; to the Millport divers, technicians and scientific colleagues who assisted in various aspects of the work and to Dr Bernard Zonfrillo kindly offered his expertise in seabird identification and feeding behaviour.

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APPENDIX 7

Reproduction, development and growth in Irish Sea *Nephrops*

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Introduction

Nephrops is the most valuable single species exploited in the Irish Sea with a first sale value of around £10 million. Although the characteristic burrowing behaviour of *Nephrops* offers natural protection it does hamper life cycle studies in that the sampling of ovigerous females needs to be geared to their emergence rhythms. Recent studies (Anon., 1999) have highlighted three areas of *Nephrops* biology that merit further investigation:

- Fecundity
- Larval Culture and Development
- Growth.

This paper is a summary of research being performed in Northern Ireland under the tenure of a postgraduate studentship.

Methods

Adult and juvenile *Nephrops* were collected from trawls performed by the DARD(NI) research vessel, *RV Lough Foyle*, in August 1998, April 1999 and August 1999. Animals were transferred to a holding facility at the Centre for Marine Resources and Mariculture (C-Mar) in Portaferry, Northern Ireland, where they were successfully maintained in individual containers for over a year.

Fecundity:

Both potential and realised fecundity were studied. Potential fecundity is defined as the total number of eggs extruded by a female prior to the incubation period. Traditionally potential fecundity has been estimated using three techniques: Firstly, by estimating the number of available oocytes in the ovaries (Thomas, 1964; Figueiredo and Nunes, 1965). This method tends to over-estimates fecundity (Farmer, 1974) as not all oocytes in the ovaries are actually extruded. Secondly, by counting the number of eggs on trawl caught females immediately after egg extrusion (Farmer, 1974). This technique also under-estimates fecundity as eggs lost through trawl abrasion and handling are not accounted for. Thirdly, by counting eggs extruded by females while in captivity. The second and third techniques have been addressed in this study and the results are compared in Figure 1. A comparison of these results and those from an earlier EU funded project on *Nephrops* biomass estimation (Anon., 1999) are presented in Figure 2.

Realised fecundity was estimated by counting the number of eggs attached to the pleopods on females trawled immediately prior to hatching (April). This estimate makes the assumption that all eggs attached at that time will hatch into healthy larvae. A second method was used to estimate realised fecundity by counting the number of larvae produced by females trawled immediately prior to egg hatching. Individual ovigerous females were maintained in the laboratory until the larvae hatched. The larvae were then collected and counted from each female *Nephrops*. This method tends to under-estimate realised fecundity because eggs are lost due to the stress on females during handling and transport to the laboratory. Figure 3 compares the results of the two techniques used to estimate realised fecundity. As both sets of data are taken from females trawled in April (end of incubation period in Irish Sea) the data is directly comparable. The observed discrepancy in realised fecundity estimates may be attributed to egg loss from handling and transport.

Overall, specific potential and realised fecundity estimates (107.7 eggs g^{-1} and 46.5 eggs g^{-1} respectively) from the current study were similar to those from the earlier (Anon., 1999) EU funded project (104.3 eggs g^{-1} and 55.1 eggs g^{-1} respectively) which used similar techniques (Figure 4).

Larval Culture:

Several aspects of larval rearing have been investigated and a range of culture techniques have been tried. These include mass culture, individual culture (Static system) and individual culture (recirculation system). All the above culture systems were maintained at two temperature regimes: 12°C, similar to the maximum ambient Irish Sea temperature, and 15°C found to be the optimum temperature for growth and survival (Smith, 1987).

Mass Culture

A detailed study of larval development and behaviour was described by Smith (1987) who emphasised the problems associated with rearing *Nephrops* larvae under mass culture conditions. He found that even with a low stocking densities of 3-10 larvae L^{-1} survival to the post larval stage (stage IV) was lower than 3%. The current study carried out mass culture trials with a larval density of 5 L^{-1} using a system which has been successfully used for rearing larvae of other decapod species e.g. *Homarus gammarus* (Mercer and Browne, 1996). There was however no survival of *Nephrops* larvae beyond stage I. Smith (1987) collected larvae from females which had been captured immediately before spawning, whereas the larvae used in this study were collected from females which had been over-wintered in the holding system. This suggests that larvae from over-wintered females are not as viable as those collected from females in the wild. Other possible causes for the high mortality include the aggressive and cannibalistic behaviour of the *Nephrops* larvae and the mechanical damage sustained from the vigorous aeration applied.

Individual Culture

Previous authors have noted that individual culture trials showed enhanced survival for all 3 larval stages with individual rearing (Smith, 1987, Thompson and Ayers, 1989). In the current study larvae collected from over-wintered females were maintained individually in 500ml beakers. Mechanical damage was reduced by excluding aeration instead the water was changed every other day and temperature, salinity and dissolved oxygen monitored. While survival to stage II increased to 15% and 22.5% at 12°C and 15°C respectively, there was no survival to stage III. It was noted that dissolved oxygen levels dropped as low as 60% in some beakers, which may account for the low survival. Increased handling of the larvae in this intensive system may also have indirectly resulted in increased mortality.

A recirculation system was developed in which individual larvae were maintained separate compartments placed within a flow tray. A reservoir tank supplied UV filtered sea-water to the flow tray through an upwelling system. The water was changed in the reservoir tank twice weekly and the flow tray cleaned by siphon every other day. This cleaning regime reduced handling of the larvae significantly. The larvae used in this trial were collected from females over-wintered in the laboratory and from animals collected from trawls performed in the Irish Sea at the end of the brooding period (April). Although survival of larvae to stage II from eggs of over-wintered females was low, at 4% and 9% in 15°C and 12°C respectively, two individuals reached stage III and one reached stage IV. Survival of larvae from females collected at the end of the brooding period was notably higher at both temperatures. The highest survival recorded to stage II was 78% at 15°C and 54% at 12°C. The survival rate to stage III was 43% at 15°C and 35% at 12°C and was comparable with similar studies carried out by Thompson and Ayers (1989) who achieved a survival rate of 40% to stage III. The highest overall survival to the first post-larval stage (stage IV) was 8%. Stage duration was observed and is listed for the nine trials carried out in table 1. These data will be compared with recently published data for stage duration in the wild (Dickey-Collas, *et al.*, 2000). Future larval Culture trials will further compare the two individual culture systems, the re-circulation system and a new flow through system. The larvae will be collected from females over-wintered in the Irish Sea as these appear to be more viable than those from females over-wintered in the laboratory (Figures 5&6). Reasons for the better survival of eggs incubated in the wild will also be explored.

Growth Trials:

A number of males and females of a similar size, ranging from juvenile to mature adults were collected and transferred to the holding system in the laboratory. Moult increment, time of moult and number of moults in a year are being recorded. *Nephrops* in the size range, 14.1-20mm, have been placed in two temperature regimes 10°C and 14°C to determine the effect of temperature on growth parameters. Moult increment was converted to percentage increase in size are presented in Tables 2 and 3 and Figures 7 and 8. It is planned to collate these data to provide revised growth parameters for Irish Sea *Nephrops.*

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Table 1: Details of trials carried out using the recirculation system. OW: larvae from females overwintered in the laboratory holding system. LF: larvae from females trawled immediately prior to hatch (April).

Exp.	Start Date	Source of larvae	No. of days run	Initial no. of larvae	No. to stage II	Stage duration days	No. to stage III	Stage duration days	No. to stage IV	Stage duration days	No. to stage V	Stage duration days	Mean Temp.
1	14.maí	LF	56	54	42	10	18	10	4	15	0	0	15
2	1.jún	LF	49	48	13	9	5	12	2	13	1	15	15
3	16.jún	LF	42	51	24	8	12	10	8	12	0	0	15
4	14.maí	LF	71	54	29	10	10	14	1	15	0	0	13
5	1.jún	LF	52	48	11	13	4	14	1	13	0	0	13
6	14.maí	OW	48	54	2	10	2	10	1	11	0	0	15
7	1.jún	OW	13	42	0	0	0	0	0	0	0	0	15
8	1.jún	OW	6	42	0	0	0	0	0	0	0	0	13
9	14.maí	OW	39	54	5	13	1	11	0	0	0	0	13

Table 2: outlines the percentage increase in growth of *Nephrops* up to October 1999.

PERCENTAGE INCREASE IN CARAPACE LENGTH								
Size Categories	Mixture	n	Males	n	Non-Ovigerous Females	n	Ovigerous Females	n
6.1-9	13,7	12						
9.1-11	12,5	2						
11.1-14			7,5	1	7,2	1		
14.1-17			7	18	6,5	25		
17.1-20			6,3	12	7,2	8		
20.1-23			5,3	11	7,2	2	9	9
23.1-26			5,5	3	6,4	12	8,2	31
26.1-29			4,8	6	6,2	7	8	34
29.1-32			4,7	1			7,4	22
32.1-35							8,2	7

Table 3: outlines the percentage increase in growth of *Nephrops* up to March 2000.
n: refers to the number of observations.

Size Categories	Mixture	n	Males	n	Non-Ovigerous Females	n
6.1-9	11,8	8				
9.1-11	9,6	2				
11.1-14	6,5	1				
14.1-17			6,1	8	6,6	16
17.1-20			6,1	15	6,1	23
20.1-23			6,2	9	6,4	8
23.1-26			6,7	12	5,7	18
26.1-29			7,1	10	5,7	12
29.1-32			7,0	6		
32.1-35			6,4	1		

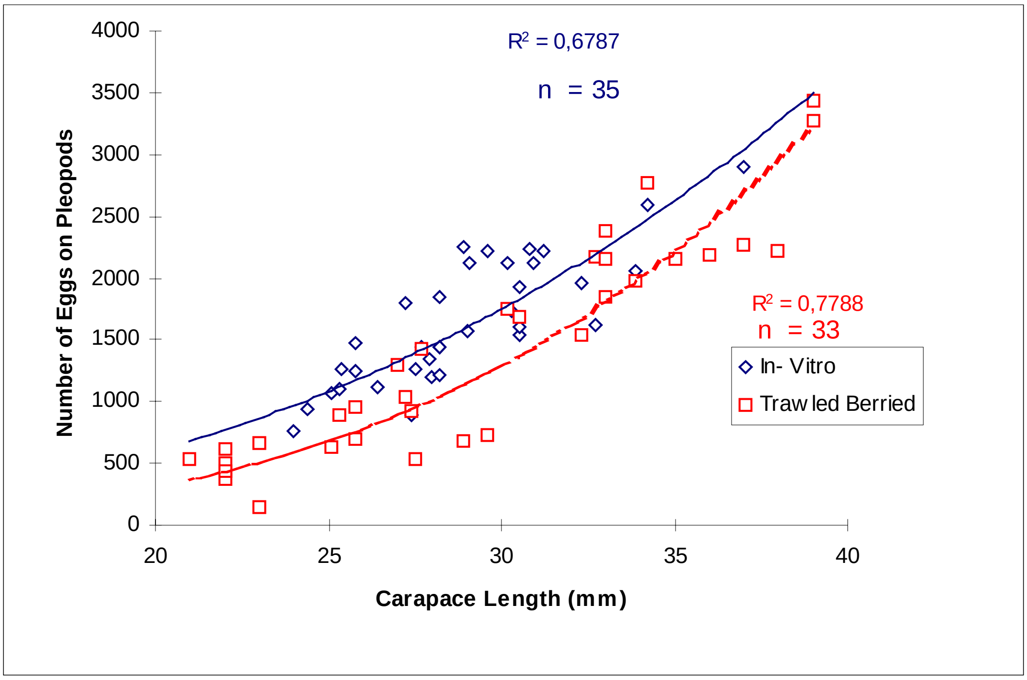


Figure 1: Comparison of total potential fecundity using two techniques firstly, by counting the eggs on pleopods of females which extruded eggs in captivity (In-Vitro) and secondly by counting the eggs on pleopods of females trawled at the start of the incubation period.

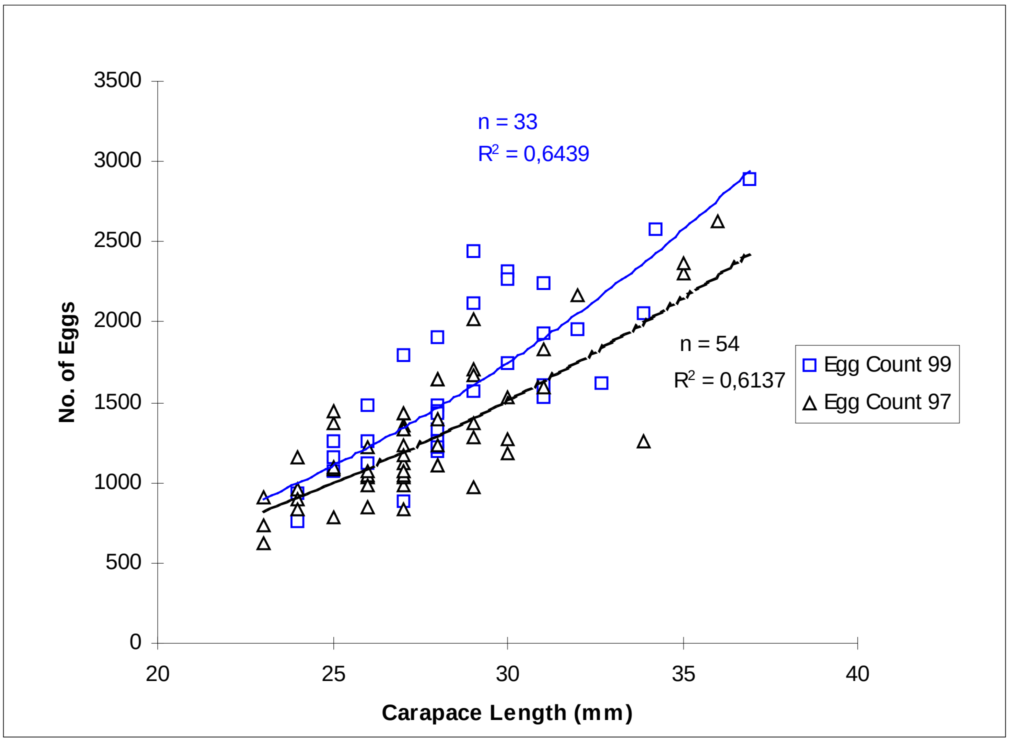


Figure 2: Comparison of total potential fecundity estimates using the same technique, counting eggs extruded by females in captivity from current study - Egg count 99 and EU Biomass Study (1998) - Egg Count 97.

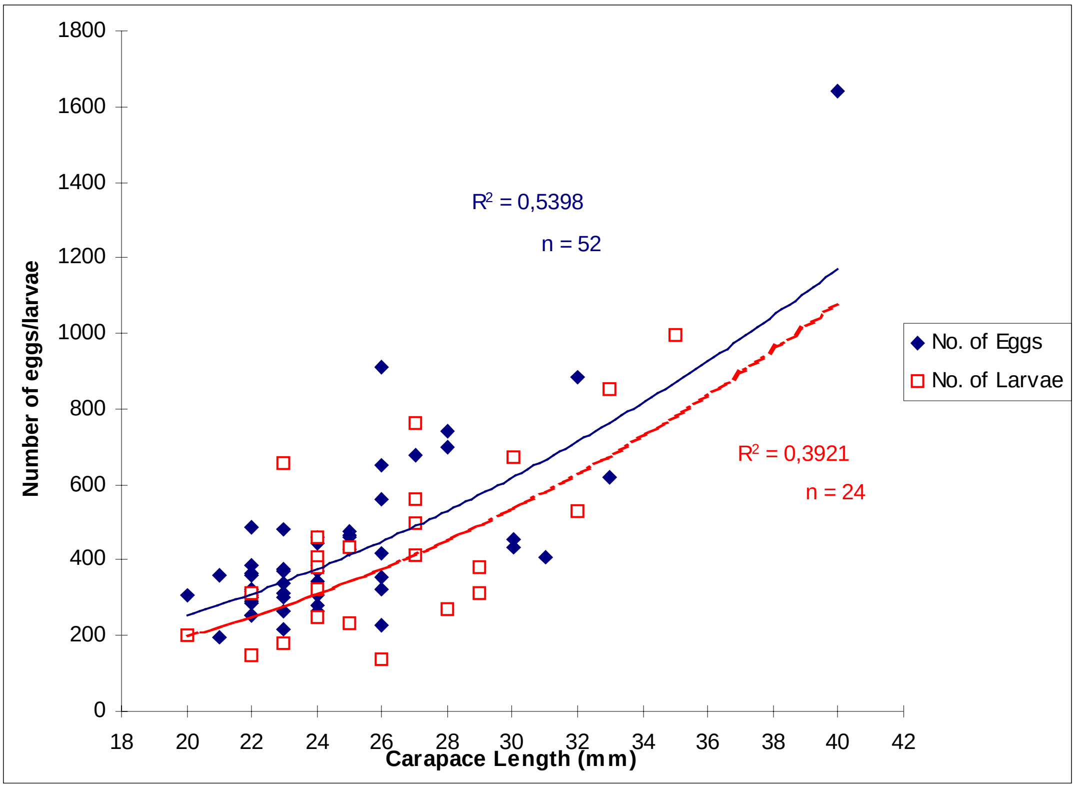


Figure 3: Comparison of two methods to estimate total realised fecundity. A number of females collected in April immediately prior to hatch were sacrificed and their eggs counted, the remaining berried females captured were returned to the laboratory until they released larvae which were subsequently counted.

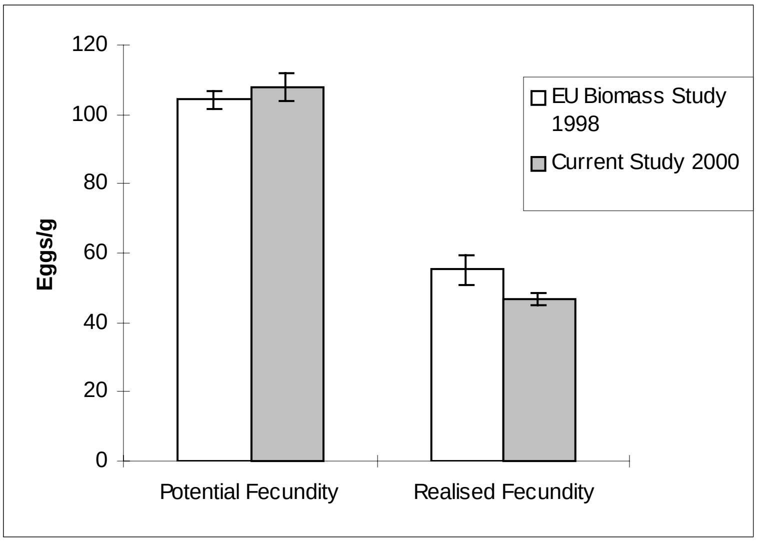
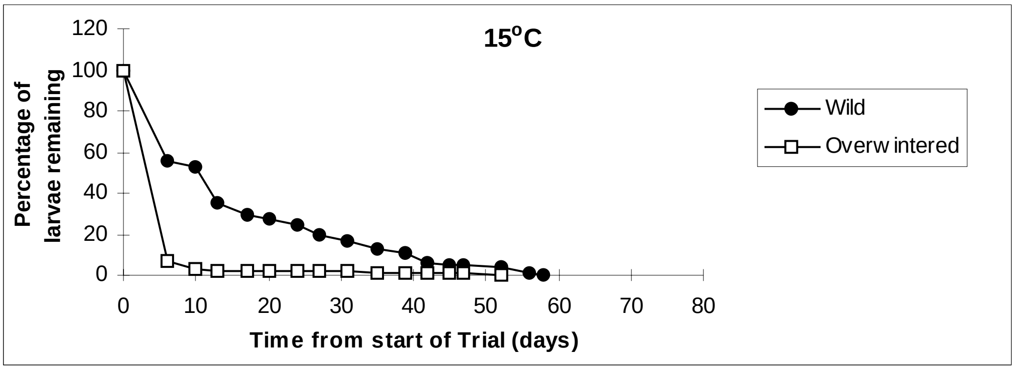
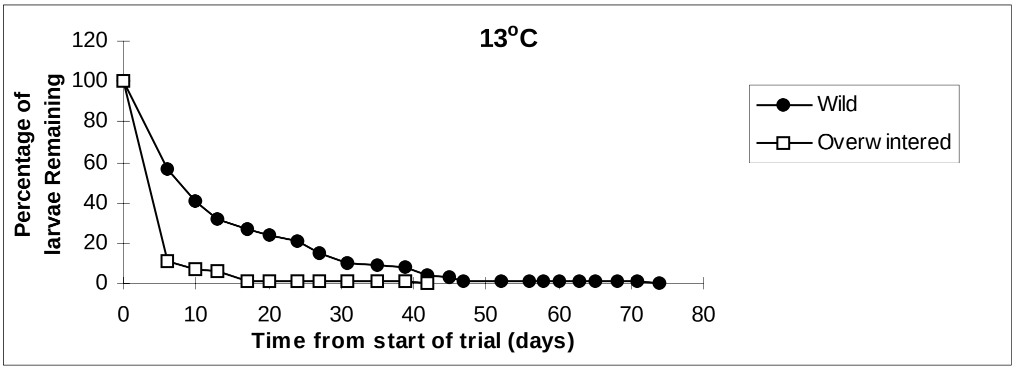


Figure 4: Comparison of specific fecundity estimates from current study and EU Biomass Study, 1998.





Figures 5 and 6: Illustrate the percentage mortality of larvae from two sources at two temperatures. Wild: Larvae from females collected in April (which have overwintered in the wild). Overwintered: Larvae from females which overwintered in the laboratory holding system.

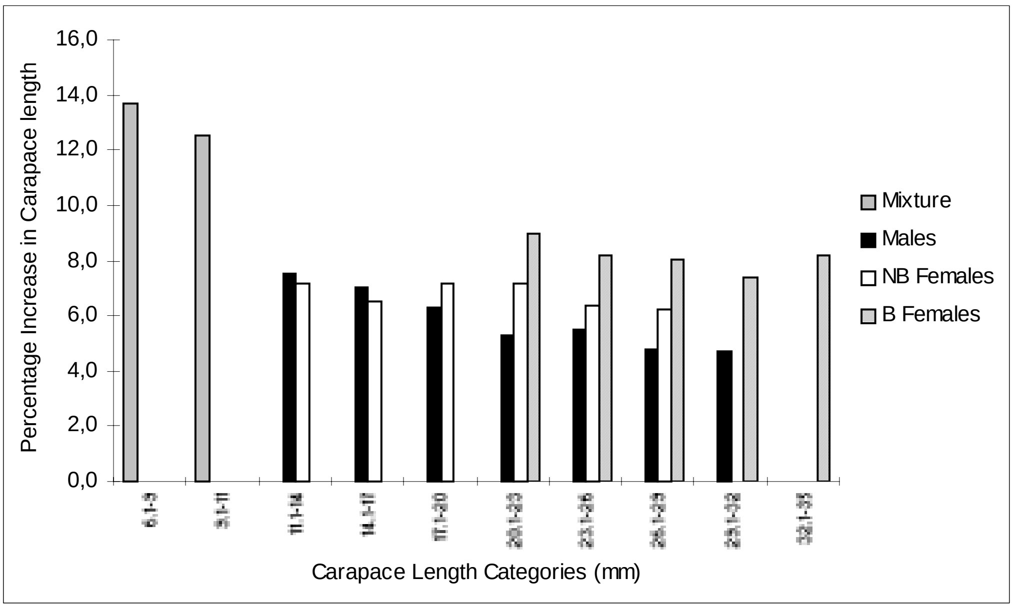


Figure 7: Percentage increase in growth of females both ovigerous (B) and non-ovigerous (NB), males and some individuals too small to sex (Mixture) up to October 1999.

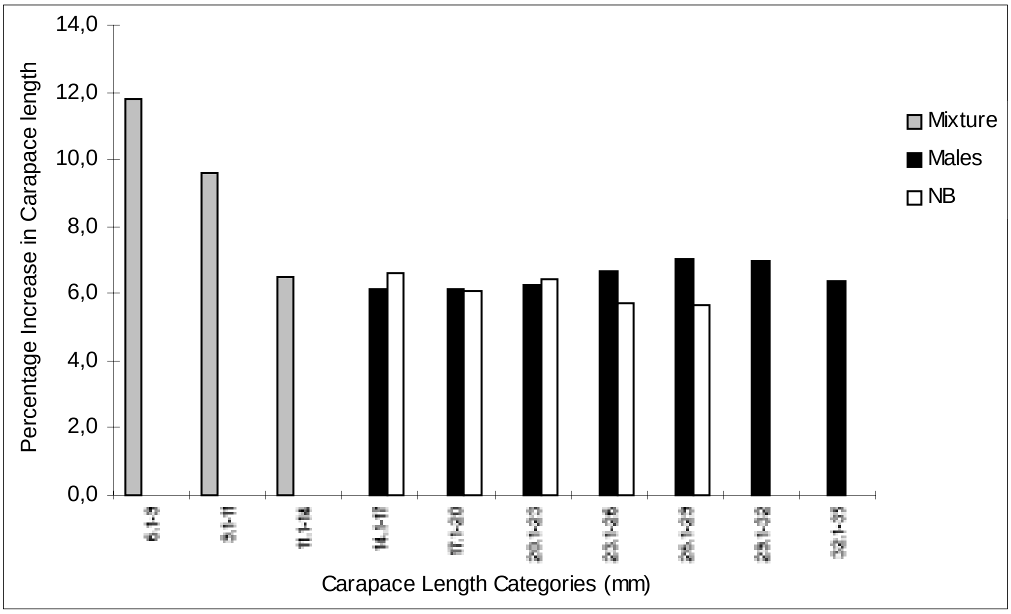


Figure 8: Percentage increase in non-ovigerous females (NB), males (M) and some individuals too small to sex (Mixture) from October 1999 to March 2000.

APPENDIX 8

Geographical patterns in the life history of the Norway lobster (*Nephrops norvegicus*): environmental and density-dependent effects

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Introduction

The Norway lobster *Nephrops norvegicus* has a broad geographical range of distribution in the NE Atlantic and Mediterranean that exhibits high environmental variability. *Nephrops* constitutes an adequate species to analyse the geographical variability in the life history tactics given that it has a broad distribution range, there is a large volume of information due to its fishery importance, and its postlarval phases are sedentary (there are no movements among different habitats).

In the present study, parameters describing the life histories of males and females of different stocks along their distribution range are summarized and assembled to analyse the existence of geographical trade-offs among the different parameters that vary as an adaptative response to the environment (defined by habitat characteristics and population density), showing compensatory mechanisms to maximize the reproductive output under the local environmental conditions (fig. 1). This analysis will allow to define the potential factors responsible for the population regulation and their geographical variability, a topic of high relevance for fishery management.

Methods

Information from 29 Atlantic and 5 Mediterranean populations was assembled. The data used were obtained from different bibliographical sources and from the ICES *Nephrops* Working Group reports (ICES, 1995; 1997). The following parameters were used as descriptors of the life history: growth (Von Bertalanffy growth function), size and age at sexual maturity, reproductive cycle (number of annual broods), relationship between fecundity per brood and body size, and natural mortality rate (M, years^{-1}). Fecundity was estimated using the available equation corresponding to the nearest geographical area. The natural mortality rate from the ICES WG was used (adults: M=0.2, juveniles: M=0.3 for all the stocks from Bay of Biscay to the north; and M=0.2 in the southern stocks). The number of annual broods range between 0.5 for all the stocks from Firth of Clyde to the north (except Moray Firth) and 1 for the other stocks.

Due to the high exploitation rate of *Nephrops* in all the Atlantic, the average landings per unit of effort (LPUE; kg/h of trawling) were used as correlates of population density in that geographical area (from ICES, 1995)

Reproductive success (defined as number of descendants that attain sexual maturity) can not be estimated in general in marine organisms with larval planktonic phases. Reproductive output, defined as number of embryos or larvae produced, can be used as a correlate of the reproductive success. The lifetime reproductive output (LRO) is the production of embryos per female cumulated along the reproductive lifespan. Average LRO has been estimated constructing a life table for each population using data of growth, reproductive cycle, mortality and fecundity, and modelling the dynamics of a cohort composed of 1000 females. For the estimation of LRO the following aspects were taken into account: the potential LRO corresponding to a virgin (non exploited) population was estimated; the size at maturity from the literature was used when it was available; if different estimates of growth from the literature and the ICES WG were available for the same population, two estimates of LRO were obtained using both data sets.

Results

Density is an order of magnitude higher in the northern Atlantic (where the primary productivity and the proportion of fine grain sediment, adequate for burrowing, are highest) than in the southern distribution area. Size at onset of maturity and growth rate (parameter k of the von Bertalanffy growth function) in females increase in the southern Atlantic area (23 mm carapace length and k 0.2 in Scotland, 30 mm and k 0.3 in Portugal). Due to this trade-off between growth and size at maturity, age at onset of maturity remains relatively constant (age classes 2+ and 3+) in the Atlantic stocks. Southern stocks show a lower fecundity (number of eggs per brood), but the reproductive cycle (seasonal cycle of gonad maturation, incubation and hatching) is annual in most of females, whereas it is biennial in northern areas, in relation to their lower sea temperatures (figs 2, 3 and 4).

A geographical gradient is proposed in the importance of density-dependent and environmental factors in the regulation of Atlantic *Nephrops* stocks. In high-density northern populations, lifetime reproductive output (accumulated production of embryos per female throughout her reproductive lifespan, used as a correlate of reproductive success) is lower (<4000 eggs per female) than in southern areas (>7000 eggs per female), where low-density populations could be more probably regulated by environmental factors (as recruitment to scarce habitats with adequate sediment) (figs. 5 to 8). The Mediterranean Sea show different life-history patterns, because density, growth rate and reproductive output are low, and probably populations are limited by food related to the low primary productivity of the area.

References

ICES, 1995. Report of the Working Group on *Nephrops* stocks. ICES CM 1995/ Assess: 12.

ICES, 1997.Report of the Working Group on *Nephrops* stocks. ICES CM 1997/ Assess: 9.

Figure 1

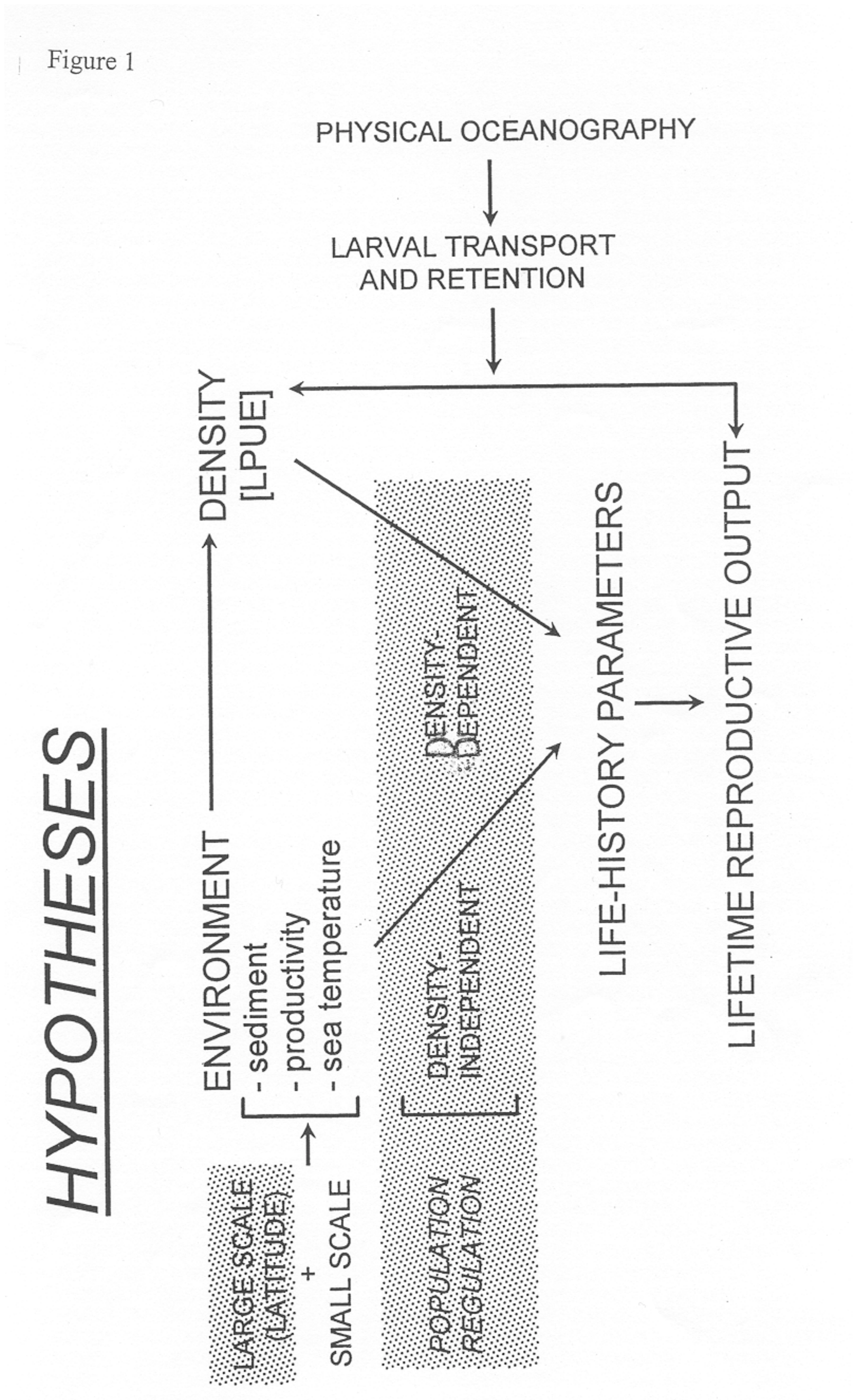

HYPOTHESES
PHYSICAL OCEANOGRAPHY
LARVAL TRANSPORT
AND RETENTION
DENSITY
[LPUE]
LARGE SCALE
(LATITUDE)
+
SMALL SCALE
ENVIRONMENT
- sediment
- productivity
- sea temperature
POPULATION
REGULATION
DENSITY-
INDEPENDENT
DENSITY-
DEPENDENT
LIFE-HISTORY PARAMETERS
LIFETIME REPRODUCTIVE OUTPUT

Figure 2

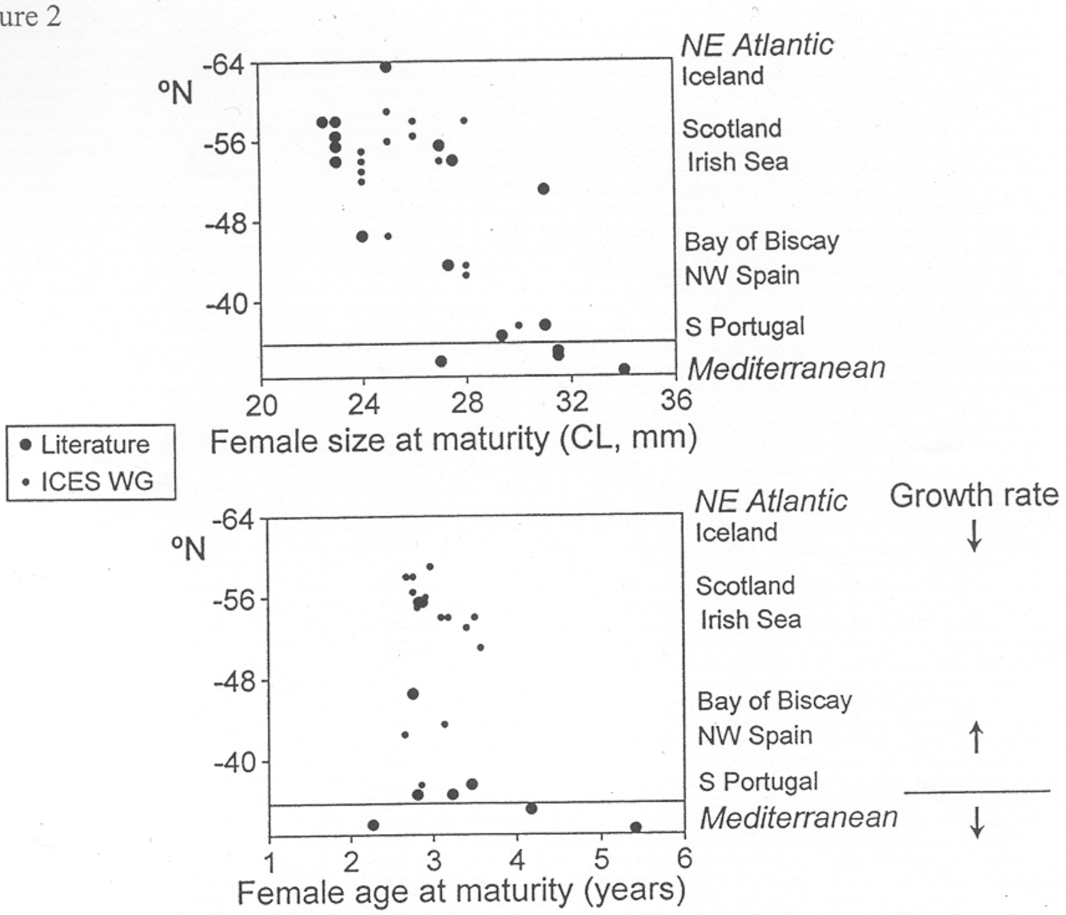
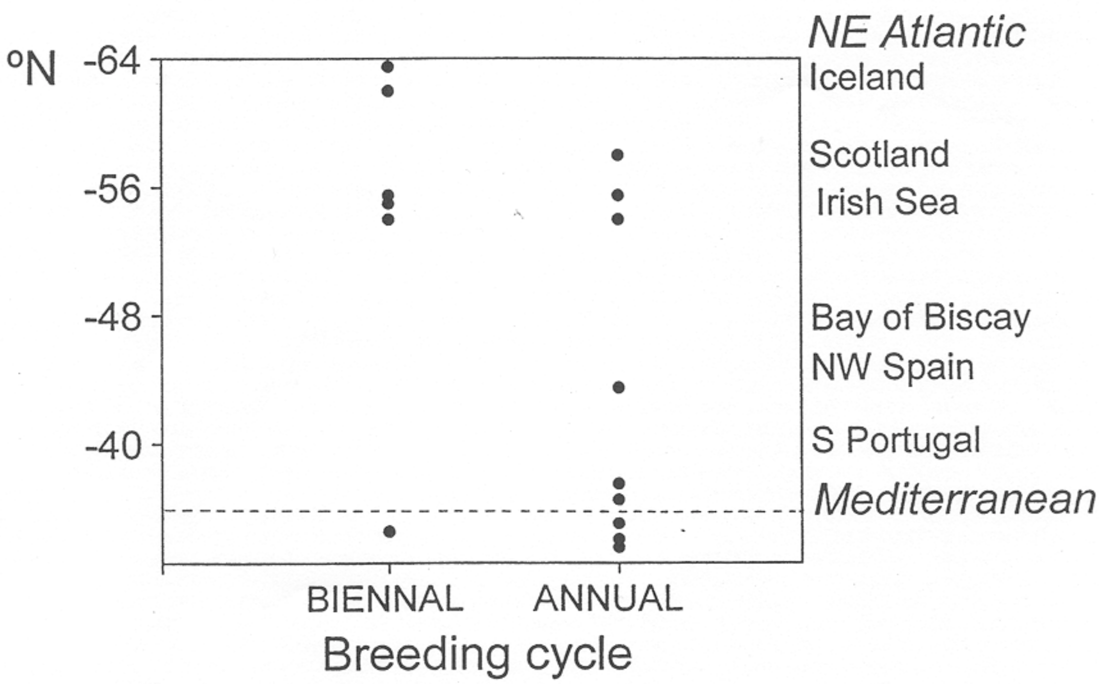


Figure 3



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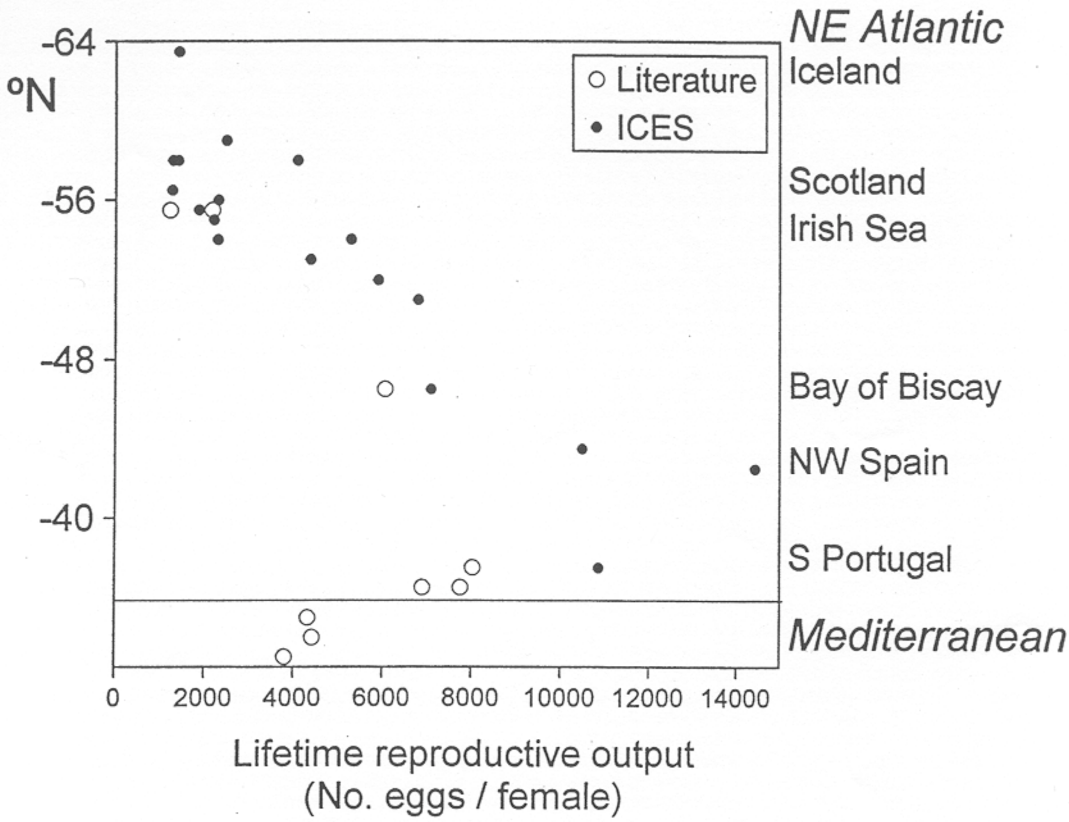

NE Atlantic
Iceland
Scotland
Irish Sea
Bay of Biscay
NW Spain
S Portugal
Mediterranean
-64
-56
-48
-40
°N
Literature
ICES
0
2000
4000
6000
8000
10000
12000
14000
Lifetime reproductive output
(No. eggs / female)

Figure 5

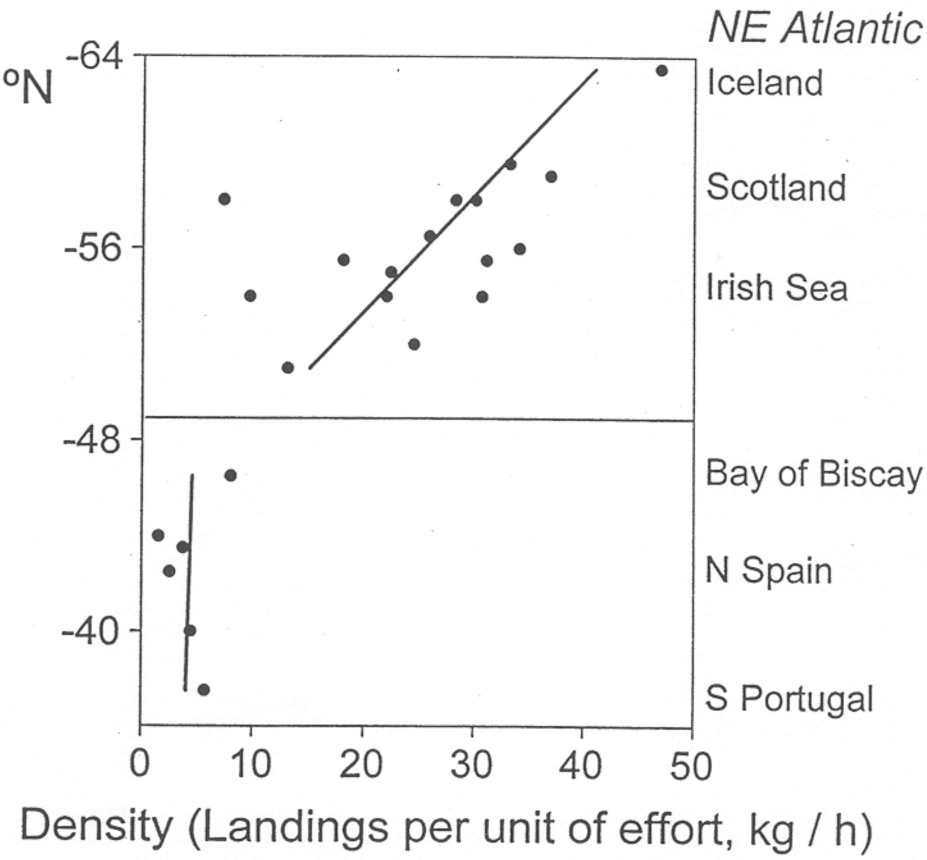
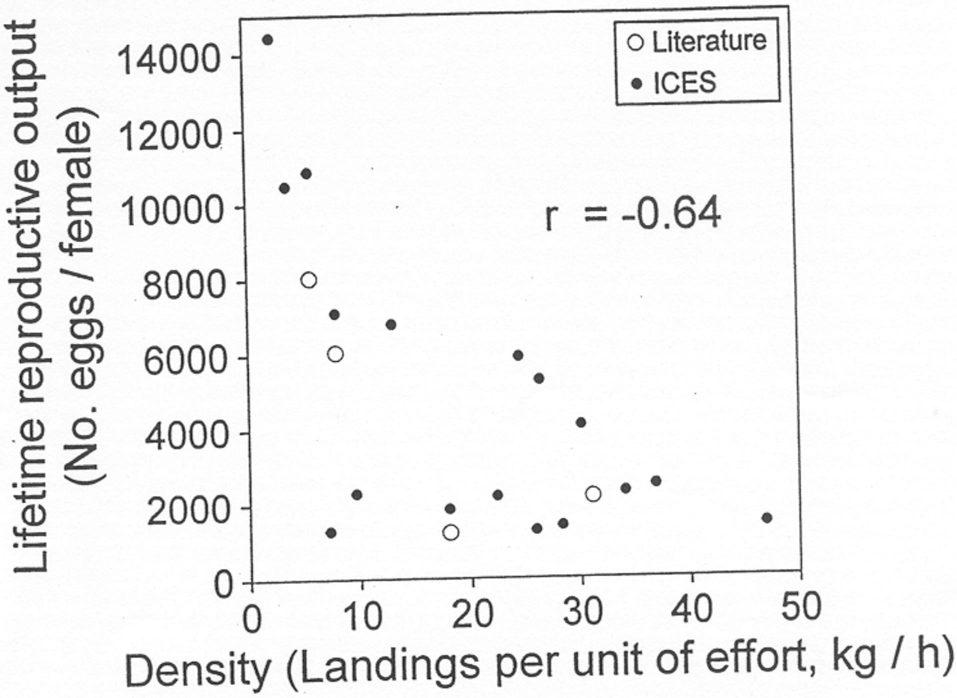

NE Atlantic
°N
-64
-56
-48
-40
Iceland
Scotland
Irish Sea
Bay of Biscay
N Spain
S Portugal
0
10
20
30
40
50
Density (Landings per unit of effort, kg / h)

Figure 6



Literature
ICES
r = -0.64
14000
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
Lifetime reproductive output (No. eggs / female)
Density (Landings per unit of effort, kg / h)

Figure 7

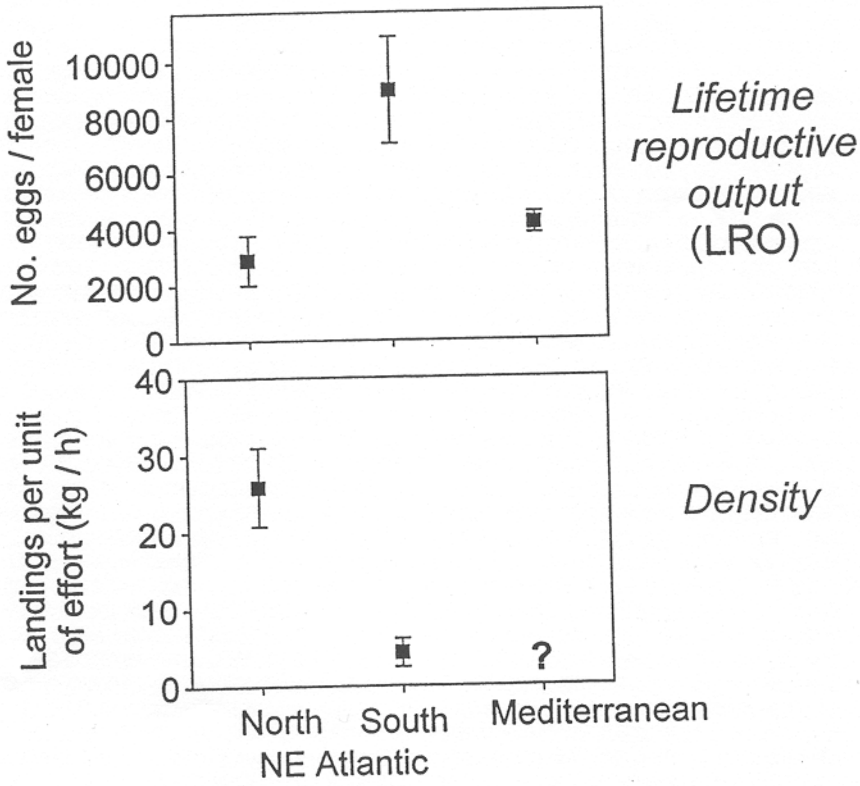
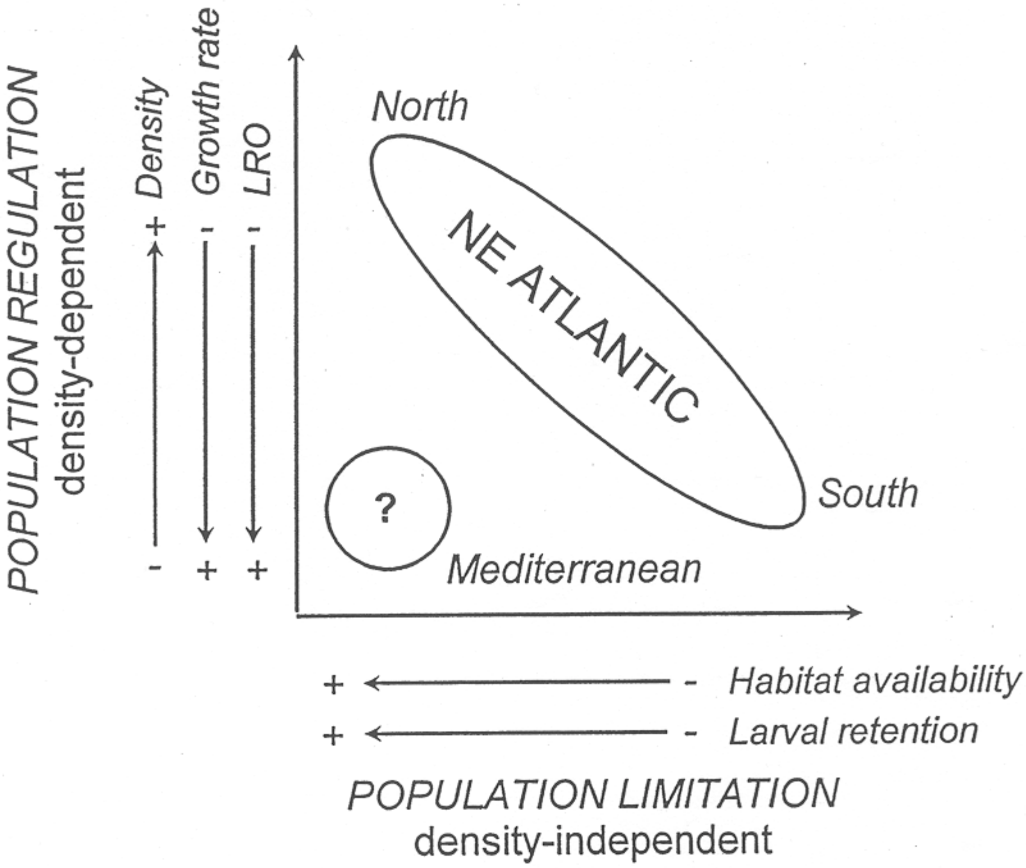

No. eggs / female
10000
8000
6000
4000
2000
0
Lifetime reproductive output (LRO)
Landings per unit of effort (kg / h)
40
30
20
10
0
Density
?
North
South
Mediterranean
NE Atlantic

Figure 8



POPULATION REGULATION
density-dependent
- + Density
+ - Growth rate
+ - LRO
North
NE ATLANTIC
South
?
Mediterranean
+ - Habitat availability
+ - Larval retention
POPULATION LIMITATION
density-independent