Living Resources Committee

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REPORT OF THE

STUDY GROUP ON LIFE HISTORY OF *NEPHROPS*

by Correspondence

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1 INTRODUCTION

1.1 Background

The Study Group (SG) on Life Histories of *Nephrops* was established in 1994. The group last met in La Coruna in May 1998 and a report of the meeting was presented at the last annual conference (ICES, 1998). The report dealt with a range of biological issues and listed a series of recommendations for areas of future work. Some of these were considered by ACFM and Terms of Reference (TOR) were added to the schedule of work for the 1999 meeting of the ICES *Nephrops* Working Group. In addition, TOR were drawn up for the Study Group to consider by correspondence in the light of Working Group findings. Since, however, the meeting of the Working Group was fairly late in the year, there has been little time to take some of the issues forward.

1.2 Terms of Reference

Council Resolution C.Res.1998/2:55 states that The Study Group on Life Histories of *Nephrops* [SGNEPH] (Chair N. Bailey, UK) will work by correspondence in 1999 to:

a) continue work on biological reference points for *Nephrops*, the intercalibration of underwater TV surveys to estimate *Nephrops* biomass, the collection of data on biological parameters for stocks assessed by the *Nephrops* Working Group, and methods for the estimation of natural mortality;

b) plan cooperative research on the potential effects of the parasite *Hematodinium* on *Nephrops* stocks and fisheries;

c) obtain peer review of the Study Group report from a member of the Living Resources Committee prior to the Annual Science Conference;

d) Comment on the draft objectives and activities in the Living Resources Committee component of the ICES Five-Year Strategic Plan, and specify how the purpose of the Study Group contributes to it.

Attempts were made to address all the Terms of Reference, although progress on some was limited. TOR a) covers a number of aspects of the group's activities which are dealt with in Sections 3-6 of the Report. This TOR prompted several Working Papers to be written and these are referred to in the text and appear in Appendices 1- 4. TOR b) generated further discussion on the type of *Hematodinium* study regarded as being of most current value.

Section 7 of the report sets out the main conclusions of the Group on this subject but does not address the logistic questions associated with setting up such a project. TOR d) is covered in Section 8.

Sections 9 and 10 of the report deal, respectively, with the review of the report and with recommendations.

2 PARTICIPANTS

In order to maintain contact between a wide range of biologists with an interest in *Nephrops* and to ensure that dialogue on *Nephrops* matters is maintained, letters were sent to the following persons inviting contributions and comment. Responses were received from a limited number of people.

R.J. Atkinson	UK, Scotland
S. Baden	Sweden
N. Bailey, (Chair)	UK, Scotland
M. Bell	UK, England
A. Biseau	France
R. Briggs	UK, Northern Ireland
C. Brown	UK, England
A. Caramelo	Portugal
A. Cascalho	Portugal
H. Castro	Portugal
M. Afonso Dias	Portugal
H. Eiriksson	Iceland
C. Farina	Spain
I. Figueiredo	Portugal

J. Freire	Spain
H. Hallback	Sweden
P. Hillis	Ireland
J. Idoine	USA
P. Mallet	Canada
S. Marrs	UK, Scotland
R. Mohn	Canada
S. Munch Petersen	Denmark
A. Nicolajsen	Faroe Islands
F. Redant	Belgium
A. Shanks	UK, Scotland
C. Silva	Portugal
C Talidec	France
D. Taylor	Canada
S. Thomson	Ireland
I. Tuck	UK, Scotland
O. Tully	Ireland
S. Tveite	Norway
M. Ulmestrand	Sweden

3 BIOLOGICAL REFERENCE POINTS

Lengthy discussions at the 1999 meeting of the ICES *Nephrops* Working Group concluded that little further progress could be made using the range of biological reference points investigated at the 1998 *Nephrops* Study Group. Many of the standard reference points commonly calculated and employed during assessments of fish stocks were examined and calculated for those *Nephrops* stocks with adequate data– there was little uniformity or pattern across stocks and conclusions that could be drawn from the exercise were limited. Available assessments mostly indicate stability in stocks with little variation in recruitment. This lack of contrast in the data makes it more difficult to draw conclusions about critical points in a population's trajectories or dynamics. Questions also remain about the data and parameter values used in many of the assessments from which the reference points were calculated.

Furthermore, this year's Working Group questioned the reliance put on yield per recruit analysis in judging the state of stocks for which data are limited. The method provides no information on recruitment and can give a misleading impression of stock condition. Several reference points are derived from this kind of analysis, and $F_{\mathbf{max}}$ has been used in the provision of management advice. The wisdom of applying reference points of this type in the absence of additional information now seems questionable.

It was generally agreed that little progress on reference points would be made until new information or additional data became available and further discussion of the merits of specific reference points has not been attempted. It was also suggested that efforts to produce assessment models tailored to the biology of *Nephrops* would be worthwhile and that new reference points specific to *Nephrops* might arise from these.

In the meantime two important items of relevance to the subject of reference points are reported on. An effort to improve on the yield per recruit approach and increase robustness of the conclusions on growth overfishing is described in a Working Paper (Appendix 1). This paper is an exercise on yield and biomass modelling which incorporates a variety of plausible stock and recruitment relationships in order to draw conclusions about sustainable yield for the Farn Deeps stock. In addition the paper offers suggestions on how to combine male and female information which, up to now, have been presented separately. The paper concludes that using the modified approach, the prognosis (in terms of sustainable yield rather than yield per recruit) is less pessimistic and that the stock is probably not overfished. Various points are raised in discussion which merit further study including a more critical consideration of stock recruitment relationships and also the need to establish the importance of male stock health in the overall stock recruit relationship.

The setting up of a new study to investigate male reproduction and behaviour (Section 6) has a bearing on the reference point issue. In view of the high mortality on males, the importance of ensuring an adequate male population (both in terms of numbers and size composition) has been discussed previously and the use of reference points associated with sex ratio and male size composition have figured in earlier Study Group deliberations (ICES, 1998). No figures were available on which to base any judgements about the merits of such reference points and it was concluded that they could not at present be used. New data on the subject could improve this.

4 INDEPENDENT ESTIMATES

The use of fishery independent data and assessment methods continues to offer an approach which i) obviates the need for landings and effort information where these are suspected of being subject to mis-reporting and other errors and ii) provides value data for tuning traditional assessments. At the Working Group (ICES, 1999), further use was made of these methods in the context of *Nephrops* assessment. In this report two working papers describe, in more detail, recent findings from two methods applied in different areas.

4.1 Underwater Television

In Appendix 2 a description of a series of surveys in the Firth of Clyde Sea provides spatial information on density and the changes in distribution over a period of time. These are discussed in relation to recruitment and incidence of the disease *Hematodinium*. For the future, it may be possible to compare such distribution data with the distribution of fishery effort and to examine the extent to which fishermen target areas of highest abundance or highest quality *Nephrops*.

4.2 Stock estimates from back calculation of larval estimates

Appendix 3 provides a summary of the findings of an EU study on the back calculation of Irish Sea stock biomass from larval abundance. Some details of this were given at the 1998 Study Group and 1999 Working Group. Results from this study were encouraging and produced estimates of stock size which are quite close to those derived from VPA. Although the technique is relatively costly and might be difficult to apply over very patchy *Nephrops* grounds, it nevertheless appears to work well where the larval distribution is largely contained in one patch and the sediment distribution is similarly of a fairly simple configuration. The technique may provide a useful 'tuning' which could be carried out every few years.

5 BIOLOGICAL PARAMETERS

There was one contribution which potentially offers information on biological parameters. A new form of growth model was proposed based on results from radiometric work conducted on Bay of Biscay *Nephrops*. Appendix 4 describes the model in more detail. Since the method moves away from the von Bertalanffy growth model, the paper points out that a new slicing routine will need to be written into the assessment software in order to investigate the effects on assessment output.

In fact, the model predicts that growth in males gets faster and faster as age increases which represents a rather radical departure from observations derived from conventional tagging where a slowing down of growth is more common. The extent to which this is a direct result of applying a mean intermoult duration across all sizes (or ages) will need to be examined carefully. A model incorporating intermoult periods specific to different size groups of animals might be more robust.

6 REPRODUCTIVE BIOLOGY OF MALE *NEPHROPS*

In view of the high exploitation on male *Nephrops*, the Study Group has previously highlighted the need for studies of male reproductive biology and behaviour and made a series of recommendations (ICES, 1996). Despite this, progress on this important aspect of *Nephrops* biology has so far been slow. Recently, attention has been drawn to the potential risks of heavy exploitation on the male component in populations of Jasus edwardsii. MacDiarmid, Stewart and Oliver (1999) report that females exhibit impaired reproduction in populations deficient in males of appropriate sizes to ensure successful mating and fertilization.

The Study Group is happy to report that a proposal for a student research project to investigate male *Nephrops* reproduction and behaviour was successful in gaining funding in the UK. This work, commencing October 1999, will examine male age and size at maturity, reproductive output, behaviour of males during mating (and associated female behaviour) and the effects on reproductive success of differences in size between the sexes. It is hoped this study will also cast light on the levels at which populations with a heavily exploited male component cease to be viable owing to a shortfall in male reproductive product. Modelling, to investigate the implications of varying population size structure and sex compositions will be an important element of this work. It is hoped that this work will contribute new biological parameter values (eg size of first effective maturity in males) and new insight on biological reference points.

7 PLAN COOPERATIVE RESEARCH ON THE EFFECTS OF *HEMATODINIUM* ON *NEPHROPS* POPULATIONS

In its 1997, by correspondence report (ICES, 1997), the Study Group reported on the completion of a significant study of *Hematodinium* by workers at Glasgow University and the Marine Station, Millport, (Appleton *et al* 1997). The study, funded by MAFF Chief Scientists Group provided a 6 point summary and numerous conclusions. Of principle concern from a fishery perspective is the possibility that high prevalence of this disease leads to elevated mortality rates which may make the stock particularly vulnerable to exploitation. Although the findings did not lead directly to new estimates of natural mortality in *Nephrops*, the *Nephrops* WG attempted to incorporate some of the information in its assessments of the Firth of Clyde Stock (ICES 1997a and 1997b). Using elevated estimates of natural mortality, the stock biomass and recruitment were relatively high (a function of adding additional mortality) whereas LPUE and TV estimates from the period of high prevalence suggested a reduced biomass. It was pointed out (ICES 1997b) that more subtle adjustments to the assessment might actually be required - for example, if infected animals spend longer periods of time out of the burrow, it might be necessary to adjust catchability in the assessment rather than simply adjusting M.

For the present, work on the disease is fairly limited. A follow on project at Glasgow University is examining the behaviour and physiology of *Hematodinium* infected animals. This should point the way to how assessments might need to be adjusted to take account of the disease. In addition, monitoring for the presence of *Hematodinium* has continued in a number of countries, notably Sweden, UK Northern Ireland and UK Scotland

Monitoring for the disease in Irish Sea *Nephrops* was continued by Northern Ireland. During a survey in April 1999 the prevalence of *Hematodinium* in *Nephrops* was generally fairly low, ranging between about 3 and 10% in 10 routinely monitored stations. The new estimates represent a continuation of the drop from the high values of the mid 1990s reported in earlier reports (ICES 1997b). The decline is similar to that observed in the Clyde suggesting that the current downward trend in the cycle is common to a number of areas. Interestingly, highest values were obtained in stations located closest to the coast of Northern Ireland.

Against this background, responses to the call for planning a cooperative piece of work were mixed. Most respondents agreed that some kind of co-ordinated study was desirable but owing to the variable involvement with the disease so far, different members expressed different emphasis. The early studies have completed much of the preparatory work in identifying the disease, investigating elements of its life history and studying its effect on individual *Nephrops*. It is now necessary to apply some of this expertise in addressing key questions which affect exploited populations of this animal.

In a future study it would be desirable to see the following features:

- *Participation by scientists from most of the countries with Nephrops populations in their waters*. Since some workers have no experience of *Hematodinium*, an important early phase of the project would be expertise and technology transfer of diagnostic techniques etc.

- *A more complete description of the geographic and bathymetric distribution of the disease*. Numerous Study Group members are unclear about whether the disease is present in their waters. The study should provide this information and might answer more general questions such as whether the disease is confined to inshore enclosed areas, whether it has a wide depth distribution, whether it is present in open sea and shelf edge populations

- *Routine seasonal monitoring for prevalence over a period of at least 3 years (preferably 5 or longer).* It would be interesting to know whether patterns in the fluctuation of prevalence are common across *Nephrops* stocks from a wide areal distribution or whether there are no similarities. This might have an important bearing on understanding control mechanisms and providing a predictive tool. Relationships with other seasonally occurring phenomena would also be interesting.

- *A study of local, spatial distribution in relation to biotic or physical factors.* There is a need to ascertain how even the prevalence is across the distribution of a given *Nephrops* stock. This has a bearing on the nature of any long term monitoring and again may point to control mechanisms and causes of outbreak.

- *Further study on the possible vectors of the disease*. Various species have been implicated as possible vectors of the disease and the role of infected bycatch material consumed by *Nephrops* needs to be studied.

- *Modelling of the effects of the disease on the population dynamics of Nephrops*. Combining any new information with data from earlier studies and the existing behaviour/physiology study should help to describe the ways in which the disease could modify the dynamics of the *Nephrops* population.

- *An examination of the significance of the disease for Nephrops populations compared with the effects of other forms of mortality including fishery exploitation*. This is essential if we are to fully understand the impact of the disease and whether it is something which requires to be routinely included during assessment deliberations.

It was generally concluded that a more constructive dialogue on the logistics of setting up a project to investigate these subjects would be achieved through a meeting of the Study Group. It was also agreed that significant work is only likely to be possible with outside funding such as from the EU.

8 COMMENTS ON THE DRAFT OBJECTIVES AND ACTIVITIES IN THE LIVING RESOURCES COMMITTEE COMPONENT OF THE ICES FIVE-YEAR STRATEGIC PLAN

The Study Group was invited to comment on the draft objectives and activities in the Living Resources Committee component of the ICES Five –Year Strategic Plan, and to specify how the purpose of the Working Group contributes to it. The following draft of objectives (revised in January1999) available to the Chairman was circulated to Study Group members for comment.

Objective 1. Develop our knowledge of the life history and population dynamics of living resources populations.

Justification: In order to provide advice on the management of marine resources, basic biological information is required on life history, recruitment, growth, maturity and mortality. This information is used to model populations and their response to exploitation . Since populations interact with each other, this basic biology is needed for both target and non-target species.

Objective 2. Co-ordinate national programmes aimed at monitoring the abundance and distribution of marine populations.

Justification: most living resources in the ICES area are exploited by several countries, each with its own programme of research. Monitoring programmes are an essential element in research on population biology and the provision of management advice. ICES can substantially enhance national programmes by fostering co-operation through co-ordinated work. This reduces duplication of effort and enhances the utility of data collected to the benefit of all participants.

Objective 3. Investigate the biological effects of non-commercial bycatch in fisheries on marine populations and the ecosystems

Justification: Most fisheries take a bycatch of non-target species or an unwanted size component of the target species. Frequently this bycatch is discarded at sea and will have a direct impact on the populations concerned. There will also be other indirect effects on the ecosystem by altering energy flows. Certain sea birds, for example, may benefit from discarded fish. Such effects on the ecosystem need to be understood and quantified so that the broader effects of fishing can be appropriately managed.

Objective 4. Investigate trophic relationships in marine ecosystems and develop multispecies models suited to management issues.

Justification: The development of an ecosystem approach to fishery management requires an understanding of how ecosystems function and how populations interact. It is, for example, important to understand the potential impact of fishing populations at the base of the food chain on higher trophic levels. ICES will support research on trophic relationships and multispecies modelling to assist the development of an ecosystem approach to management.

The *Nephrops* Study Group considered that given the range of living resources within the ICES remit and taking into account current issues facing managers and their advisors (eg ecosystem approaches to management), the objectives provide a fairly balanced plan. A plan incorporating these features should yield quantitative information on the dynamics of living resources and on the responses to exploitation of target and bycatch species, while also providing insight on ecosystem aspects. Aspects of some of the objectives have been prominent in the *Nephrops* Study Group's activities over the past few years, while others are areas into which the Study Group will need to move.

For a number of *Nephrops* populations certain basic biological information is sparse, this makes application of existing population models difficult and impairs development of new approaches. Attention to objective 1, should help to address these shortfalls. The emphasis on monitoring of abundance (objective 2) should facilitate continued progress in quantitative estimation of *Nephrops*. There are important *Nephrops* issues relating to objectives 3 and 4. For example discard bycatch is of particular relevance to *Nephrops* fisheries owing to the small mesh derogations available in many fisheries. It is very important that the 'ecological position' of *Nephrops*, and indeed the benthos in general, is understood and that these elements are not overlooked in the setting up of ecosystem models or the development of ecosystem approaches to management within the ICES area. In recent years there has been a tendancy to concentrate on fish assemblages, pelagic interactions and the role of top predators – attention paid to benthic components including *Nephrops* would provide a more holistic view.

The purpose of the *Nephrops* SG, as currently outlined in the TOR and Justification contained in the 1998 Council Resolution C. Res.1998/2:55, already contributes to some of the objectives of the 5 year plan. Recent meetings of the Group have reported on additional biological data and for some stocks knowledge is reasonable. Improvements in fishery data provision and the development of fishery independent survey data (from TV and larval surveys) have permitted the Study Group (and also the Working Group) to make progress in the assessment of the abundance of these animals. The Study Group has not, to date, spent much time addressing the issue of discarded bycatch (objective 3) although current EU funded studies will provide new material in the near future for review. Ecosystem issues have similarly not previously been considered by the Study Group but earlier work on cod/*Nephrops* interactions (Brander and Bennett) suggest that the role of *Nephrops* should be examined more closely and that they should figure more highly in multispecies modelling. In developing these studies there will be a need to consider length structured models and the group suggests that more attention should also be paid to spatial matters – incorporation of predator and prey distributions should lead to improvements on earlier models.

Although the objectives generally appear to highlight current and near future needs for living resources, it was felt that some additional points could be made to strengthen the plan. Firstly, there is a case for ICES to forge closer links with other forums or organisations involved in dealing with marine resources. Exchange of expertise on common problems would be an efficient development. Arguably, a shortfall in the ICES studies of *Nephrops* is the lack of formal contact with Mediterranean organisations which have information on populations covering the more easterley, southerly and deeper populations. Objective 1 would be strengthened if ICES not only highlighted the need for biological study of populations, but was more proactive in actually encouraging nations to be generous in their support for such studies; the Study Group has repeatedly pointed this out (eg ICES, 1996). To some extent the targeting of national programmes on *Nephrops* will depend on the economic, volume and population state of those fisheries – but progress will only be made in some cases if such support is forthcoming. Finally, the objectives make no mention of the potential effects of environmental factors. These effects have been highlighted in the past and there is a continuing need to recognise their potential importance. In the case of *Nephrops*, questions about the effects on recruitment (mediated through the larval, settlement or post settlement phases) and on catchability (arising from changes in emergence) regularly arise during the quantitative assessment of abundance and exploitation.

9 PEER REVIEW OF REPORT

Dr Colin Bannister, chair of the Living Resources Committee kindly agreed to review the by correspondence report.

10 RECOMMENDATIONS

10.1 Potential areas for work arising from the recent *Nephrops* WG and from suggestions within this report

The Working (ICES, 1999) recognised the need for a more critical examination of the correspondence between various stock indices and assessment outputs available for each stock – something which the tight constraints of the WG environment do not always allow. This kind of examination lends itself to approaches such as time series and other statistical methods and in order to improve the robustness of conclusions, participation by an expert(s) in this field should be encouraged. Time series analysis of the longer data sets available for some stocks might also help us to understand the variability of populations.

In recent times there has been considerable attention paid to the provision of biological reference points. The group considers that there is little point pursuing biological reference point work further unless new developments or data justify this. Methodological work tailored to *Nephrops* biology is considered to be a more fruitful avenue at this stage which may provide both improved assessment methods and also new insight on more relevant reference points.

A matter related to the reference point issue and to provision of medium and long term advice on stocks, is that of the likely stock recruitment relationship in *Nephrops*. It is sometime since this has been examined and some of the more recent data on abundance and distribution may help in formulating ideas from first principles on possible relationships between stock and recruitment (or the inverse).

With growing uncertainty about the quality of some fishery data and the need for independent data with which to compare or tune assessment methods, it is necessary to continue pursuing independent survey methodologies. Recently, greatest attention has been paid to TV work but there is room for development of other methods. During 1999 and early 2000, further progress on TV methods is expected and it is recommended that independent methodologies continue to figure in the TOR of the *Nephrops* Study Group.

There is an ongoing need to update, and indeed provide first estimates, of biological parameters used in assessments. Calls for studies to estimate values of these parameters are repeatedly made but the number of directed studies is limited. Nevertheless, an opportunity to discuss and implement new values needs to be available and one or two items are usually presented at most meetings.

Section 7 calls for a discussion of the logistics of establishing a project on *Hematodinium*. Several ideas were put forward during correspondence but the practical details of achieving this are best dealt with around a table. It has been pointed out that for a number of participants the exercise will be largely academic unless funding can be found from outside for monitoring or modelling of effects work.

In view of the derogations available for the use of smaller mesh nets in *Nephrops* fisheries and in view of the amount of effort now expended in those fisheries, concern is often expressed at the magnitude of and fate of discarded material including target species and bycatch. Reports from new studies on this field will become available during the year and it is recommended that these are considered by the *Nephrops* Study Group.

A number of the issues above are pertinent to the activities of the *Nephrops* WG and its ability to provide sound advice on the state of *Nephrops* stocks. Further progress in methodological development (including the use of survey data) and the need for a critical review of the consistency of different assessment indices available for a stock, will benefit from a meeting of the scientists concerned. Several of the items also have a bearing on wider marine issues which the objectives of the Living Resources Committee seek to address and given the current profile of diseases in marine organisms and bycatch levels, an opportunity to examine data on these subjects would be welcome. The Study Group therefore recommends that it meets in the year 2000.

10.2 Venue and Dates

At the most recent meeting of the *Nephrops* WG (Ostende 1999), an offer was received from Iceland to host the next meeting of the Study Group. In view of the need to make progress in advance of the 2001 *Nephrops* WG, it is suggested that a meeting of the SG takes place in 2000. It is proposed that this should be in Reykjavik for 4 days from May 2nd to 5th. The host institute has confirmed that this arrangement would be acceptable.

10.3 Proposed terms of reference

It is recommended that suitable items for inclusion as Terms of Reference could include some of those listed below although tackling all of them in a 4 day meeting would probably represent too great a workload.

- Comparison of trends in various assessment, fishery data and survey indices including the use of time series and other statistical techniques
- Review progress on the development of *Nephrops* specific assessment methodologies
- Attempt to define a likely stock and recruitment relationship for *Nephrops*
- Report on refinements in the use of independent methods and present spatial distribution data where available
- Develop logistical plans for cooperative work on *Hematodinium*
- Summarise available data on fate of discards and bycatch from *Nephrops* fisheries
- Present new data on the biology of *Nephrops* and on parameter values

11 REFERENCES

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APPENDIX 1

Sustainable yield and the stock-recruitment relationship in Farn Deeps *Nephrops*

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INTRODUCTION

One of the main tools used to interpret the state of exploitation in *Nephrops* stocks is yield per recruit analysis (ICES, 1999). A variety of biological reference points for *Nephrops* stocks have been considered, relating to both growth and recruitment overfishing (ICES, 1997, 1998, 1999). However, the only reference point that has so far been used explicitly or implicitly to inform management advice is the fishing mortality at which yield per recruit is maximised. This takes no account of the relationship between stock size and recruitment. Depending on stock status and the nature of the stock-recruitment relationship, the fishing mortality at which yield is maximised can be either higher or lower than that which maximises yield per recruit.

Shepherd (1982) showed how yield per recruit information can be combined with a stock-recruitment curve to draw conclusions about sustainable yield. The method has been applied to lobsters *Homarus gammarus* by Bannister & Addison (1986) and Addison & Bannister (1998), to crabs *Cancer pagurus* by Addison & Bennett (1992) and to *Nephrops* in the western Irish Sea by Bennett (1994). This paper describes an application to *Nephrops* in the Farn Deeps. It is an attempt to improve the robustness of conclusions about the current state of exploitation with respect to growth overfishing, and at the same time give some insight into the likelihood of recruitment overfishing. A plausible range of stock-recruitment curves for Farn Deeps *Nephrops* is derived using data and assumptions from Farn Deeps and other stocks. Yield per recruit analyses are currently performed separately for males and females, owing to very different levels of exploitation on the two sexes. The paper considers how best to combine male and female information on yield, recruitment and stock size.

METHODS

A model for stock and recruitment

Shepherd (1982) proposed a simple functional form to describe the processes of egg production and density-dependence which determine the relationship between recruitment (*R*) and the size of a spawning stock (spawning stock biomass, *SSB*):

$$R = \frac{aSSB}{1+\left(\frac{SSB}{K}\right)^{\beta}} \qquad (1)$$

Potential egg production is described by the parameter *a*, which is the slope of the stock-recruitment curve at the origin and has units of recruits per unit of *SSB*. The proportion of eggs that actually survive to recruit to the fishable stock is described by the parameter *K*, the threshold *SSB* above which density-dependent processes dominate, and the dimensionless parameter β which expresses the degree to which density-dependence compensates for increases in potential egg production as *SSB* increases. Values of β below 1 imply imperfect compensation, *i.e.* increases in *SSB* always accompanied by increases in *R*, whereas values above 1 imply overcompensation, *i.e.* at high *SSB* levels, increases in *SSB* are accompanied by decreases in *R*.

Recruitment and *SSB* estimates for Farn Deeps *Nephrops* are available from the XSA stock assessments performed by the ICES Working Group (ICES, 1999). Since exploitation patterns differ between the sexes, separate assessments are performed for male and female components of the stock, giving separate estimates of *SSB* and recruitment. Bennett (1994) modelled recruitment of western Irish Sea *Nephrops* in terms of female biomass expressed explicitly as egg production. Recruitment could depend in different ways on the male and female components of *SSB*. Assuming that reproductive success is not limited by the availability of males, egg production depends solely on female *SSB*, whereas both male and female *SSB* contribute to density-dependence. Equation 1 could be modified to use female *SSB* in the numerator and total *SSB* in the denominator. In practice, it was found easier to construct stock-recruitment curves using female *SSB* estimates only, with *K* scaled in relation to female *SSB* rather than total *SSB*. This should introduce biases only if seasonal exploitation patterns change; otherwise, male and female stock trends should be similar. Male and female recruitment estimates were summed to represent overall recruitment.

XSA estimates of recruitment and *SSB* for Farn Deeps *Nephrops* are available for the period 1985 to 1998. Given that the recruiting year classes make up a very small proportion of the total landings, the most recent two recruitment estimates are considered not to be reliable. These estimates depend unduly on assumptions about discarding, and were not included in fitting a stock-recruitment curve. Recruitment was compared with *SSB* lagged by one year, to account for the time difference between release of larvae and entry to the fishable stock. Thus, recruitment estimates for the years 1986 to 1996 were compared with *SSB* estimates for 1985 to 1995.

Recruitment and SSB estimates have been very stable over the assessed period, so that there is little information on the form of the stock-recruitment relationship (Figure 1). 'Observed' ratios of recruitment to SSB_{female} in the Farn Deeps do not offer much insight into a likely value for *a*, the initial slope of a stock-recruitment curve, unless we assume that density-dependence was of no importance in defining these ratios – not a safe assumption! The maximum ratio is 100 thousand recruits per tonne SSB_{female}. Thus, *a* cannot be less than this value.

Biological differences between stocks and their environments will mean that stock-recruitment relationships are not universal, but the range of variation in *R*/*SSB* may at least give a first idea of the likely range of values. Figure 2 shows the distribution of these ratios for all stocks assessed by XSA at the 1999 Working Group (most recent two years of recruitment omitted, *SSB* lagged by one year). The highest values were less than 350 thousand recruits per tonne SSB_{female}, and we may take this as a first estimate of *a*. In order to describe the possible range of variation in the form of the stock-recruitment relationship, a range of alternative values for *a* from 100 to 500 thousand per tonne was considered.

Stock-recruitment relationships may differ between stocks, but we may expect nearby stocks to be most similar. XSA estimates for three other North Sea stocks (Botney Gut, Firth of Forth and Moray Firth) were included with Farn Deeps estimates in fitting a stock-recruitment curve. It was assumed that egg production per unit of biomass, *i.e.* values of *a*, and degree of density-dependent compensation, *i.e.* values of β, are the same for all four stocks. The threshold *SSB* above which density dependence dominates, *K*, acts as a scaling parameter for each stock, proportional to unexploited stock biomass, or the total area occupied by the stock. Thus, the appropriate stock-recruitment model for the North Sea stocks is

$$R_{\text{total,stock}} = \frac{aSSB_{\text{female,stock}}}{1+\left(\dfrac{SSB_{\text{female,stock}}}{K_{\text{stock}}}\right)^{\beta}} \qquad \text{(1a)}$$

This model was fitted to the data using SAS PROC NLIN (SAS Institute Inc., 1989), assuming log-normal errors for recruitment.

Modelling yield and biomass

The level of exploitation at which yield per recruit (*Y*/*R*) is at its maximum given prevailing growth, natural mortality and fishery selection at size/age is known as F_{max}. It is taken to represent the trade-off point between gains from harvesting the stock at an older/larger average age/size and losses from longer exposure to natural mortality. There is an implicit assumption that recruitment is independent of stock size, so that fishery yield is directly proportional to *Y*/*R*. In practice, this is unlikely to be true, but conversion of *Y*/*R* to yield requires knowledge of the stock-recruitment relationship. Shepherd (1982) showed how this can be achieved by combining spawning stock biomass per recruit (*SSB*/*R*) analysis with a stock-recruitment curve. Equation 1 is re-arranged to express *SSB* as a function of *SSB*/*R*:

$$SSB = K\left(aSSB/R - 1\right)^{\frac{1}{\beta}} \qquad (2)$$

For any value of *SSB*/*R* this allows calculation of recruitment from either Equation 1 or *SSB* divided by *SSB*/*R*, from which it follows that yield can be estimated as the product of *Y*/*R* and recruitment. *SSB*/*R* decreases monotonically with increasing fishing mortality, for any given combination of growth, natural mortality and exploitation patterns. Thus, sustainable yield and equilibrium *SSB* can be calculated for any exploitation level represented as *SSB*/*R*. Instead of $F_{\max}$, exploitation levels can be compared with F_{MSY}, the fishing mortality at which maximum sustainable yield (MSY) is achieved.

Given total recruitment modelled as a function of female *SSB* and separate *Y*/*R* and *SSB*/*R* analyses for the two sexes, some modification of Shepherd's method of yield estimation is required. Equation 2 is modified to

$$SSB_{\mathrm{female}} = K\left(aP_{\mathrm{female}}(SSB/R)_{\mathrm{female}} - 1\right)^{\frac{1}{\beta}} \qquad (2a)$$

where P_{female} is the proportion of recruits to the fishable stock that are female. Total recruitment is estimated from Equation 1 using SSB_{female}, and in turn is used to estimate yield and male *SSB*:

$$SSB_{\mathrm{male}} = P_{\mathrm{male}} R_{\mathrm{total}} (SSB/R)_{\mathrm{male}} \qquad (3)$$

$$Y_{\mathrm{female}} = P_{\mathrm{female}} R_{\mathrm{total}} (Y/R)_{\mathrm{female}} \qquad (4)$$

$$Y_{\mathrm{male}} = P_{\mathrm{male}} R_{\mathrm{total}} (Y/R)_{\mathrm{male}} \qquad (5)$$

These modifications are necessary to account for the difference between total recruitment, modelled by the stock-recruitment curve, and recruitment by sex in the denominators of *SSB*/*R* and *Y*/*R*.

Differences between exploitation patterns of male and female *Nephrops* occur because of a change of burrow emergence behaviour after sexual maturity in females. Since recruitment of females to the fishable stock occurs before sexual maturity, it is reasonable to assume that $P_{\mathrm{female}} = P_{\mathrm{male}} = 0.5$. *Y*/*R* and *SSB*/*R* analyses were performed for Farn Deeps *Nephrops* based on biological input values and fishing mortality estimates from XSA (Table 1). These analyses were used as the basis for modelling yield and biomass at varying levels of fishing effort.

RESULTS

Stock-recruitment relationship

With fixed values of *a*, there was enough information in the data for satisfactory estimates of *K* for each North Sea stock and a common value of β (Table 2). Figure 3 shows fitted curves for three values of *a*; the data points and curves have been scaled by *K* for each stock to allow comparison of all four stocks on the same plot. The curves vary from an almost straight line between the origin and the data points for *a*=100, to a steep curve and peak of recruitment well to the left of the data points for *a*=500. *a* could conceivably be even higher than 500 thousand per tonne, but *a*=500 already represents relative stock size as being very high for Farn Deeps and other North Sea stocks. In terms of informing management advice, it is more critical to explore the consequences of low stock sizes.

Y/*R* and *SSB*/*R* analyses

Figure 4 shows the results of *Y*/*R* and *SSB*/*R* analyses for Farn Deeps *Nephrops*, based on the inputs given in Table 1. Expressed as a proportion of current fishing effort, $F_{\max}$ for males is 0.79, but this represents only a 1% increase in *Y*/*R*. Because exploitation levels on females are much lower, 22% gains in female *Y*/*R* are possible, but at the unfeasibly high $F_{\max}$ of 24.4 times current effort. Overall *Y*/*R* is maximised at $F_{\max}$=1.23, but with a negligible increase of 0.5% over current levels. Thus, if maximising yield was a management objective, in the absence of information on the stock-recruitment relationship there would be no basis for revising current harvest levels in the Farn Deeps.

The *SSB*/*R* analyses are mainly of relevance as a measure of exploitation levels for use in the yield and biomass modelling, since there are no absolute criteria against which to judge the outcome. At current effort, male *SSB*/*R* is estimated to be at 31% of the virgin (unexploited) level, and female *SSB*/*R* is at 46%. Overall *SSB*/*R* is not a meaningful statistic and was not calculated.

Sustainable yield curves

Sustainable yield curves for Farn Deeps *Nephrops*, estimated by applying each of the fitted stock-recruitment curves to the *Y*/*R* and *SSB*/*R* estimates, are given in Figure 5. At effort levels up to 40% greater than current, the choice of stock-recruitment curve makes virtually no difference to sustainable yield. Above this level, the yield curves differ in the point at which yield declines and in the rate of decline. Under the most pessimistic view of stock and recruitment, *a*=100, yield declines rapidly above 1.5 times current effort, plunging to zero at an effort of about 1.7. At the other end of the scale, with *a*=500, yields are still high at five times current effort.

F_{MSY} is above current effort in all cases, but the gains from even substantial effort increases are likely to be small (Figure 6). F_{MSY} is higher than F_{max} in males and in total, but much lower than F_{max} in females. MSY increases with increasing value of *a*, but in the case of males the increase is negligible. Sustainable yield of males under current effort is very close to MSY. At most, with *a*=500, male MSY is 7% higher than current sustainable yield. Owing to lower current exploitation levels, up to 56% gains in female yield would be possible and choice of stock recruitment curve has much greater influence on the estimated value of MSY. Total yield is dominated by males, and there is a potential gain of 23% if *a*=500. This would, however, require more than three times the current effort.

Equilibrium spawning stock biomass

Equilibrium *SSB* curves are shown for males and females in Figure 7. The main influence of choice of stock-recruitment curve is the point at which the decline in *SSB* accelerates and plunges towards zero. This depends on the stock level at which the stock moves into the domain of positively correlated recruitment and *SSB*.

There is little difference between the curves at lower effort levels. It follows that the estimate of current *SSB* as a proportion of the virgin level is not strongly dependent on choice of stock-recruitment curve: estimates vary from 41% (*a*=500) to 50% (*a*=100) in males and from 61% (*a*=500) to 73% (*a*=100) in females. These levels are much higher than was estimated for *SSB*/*R*. Shepherd (1982) points out that virgin *SSB* is likely to be overestimated since natural mortality will be higher and growth slower in an unexploited population.

The estimated level of fishing mortality at which equilibrium *SSB* is zero is known as F_{crash} – the fishing mortality that results in stock collapse. In the worst case, a stock-recruitment curve with *a*=100, F_{crash} is at 1.72 times current effort (Table 3). At the opposite extreme, with *a*=500, effort could increase almost six times before the stock would collapse. Trials with differing values of *K* and β show that F_{crash} depends only on *a*, the initial slope of the stock-recruitment curve.

DISCUSSION

Stock-recruitment relationship

Applying common stock-recruitment parameters across all North Sea stocks is inevitably a gross approximation. We may expect these stocks to have more in common in terms of predation pressures and fecundity relationships than, say, Farn Deeps and Bay of Biscay stocks, but there must still be important differences in environment and genetic structure that will have consequences for stock-recruitment relationships. Nevertheless, the fitted stock-recruitment curves appear to be a satisfactory first description of the range of possible stock-recruitment relationships in Farn Deeps and other North Sea *Nephrops* stocks. In particular, the curves encompass the likely range of recruitment behaviour at stock levels below the observed values. Extrapolation above the range of observed stock levels is perhaps more contentious, involving decreases in recruitment in every case. However, we are more interested in the consequences of increased fishing effort, *i.e.* decreased stock sizes, so that it is the left-hand portion of the stock-recruitment curve that is relevant.

Nephrops populations are limited to the essentially two dimensional environment of the sea bed. The spatial extent of a population is also limited by the distribution of suitable muddy substrates. In many cases, such as the Farn Deeps, stock boundaries are clearly marked by the limits of a large scale mud patch. Thus, habitat availability should impose an upper limit on recruitment, and one would expect the value of β in Equation 1a to be at least 1. Density-dependence may further be of particular importance in *Nephrops* because adults are known to cannibalise juveniles at high stock densities. This should lead to strong overcompensation in the stock-recruitment relationship, *i.e.* values of β greater than 1. Estimates of β for the North Sea stocks were greater than 1 for every value of *a* tried. The 95% confidence interval for the favoured value of a=350 thousand per tonne is β=1.29 to 2.51. Shepherd (1982) suggested that β should lie in the region 0.5 to 2 for most exploited fish stocks.

Status of Farn Deeps *Nephrops*

This modelling exercise appears to offer reassuring conclusions about the status of the Farn Deeps *Nephrops* stock. Previously, the view based on Y/R had been that there is moderate growth overfishing of at least the male portion of the stock (ICES, 1999). The present results, based on a speculative but plausible range of variation in the stock-recruitment relationship, suggest that current effort levels may be below rather than above the optimum for maximising yield. Since growth overfishing sets in at a lower level of fishing mortality than recruitment overfishing, this also implies that the spawning stock is not endangered. Indeed, judged qualitatively, the current spawning stock appears to be a healthy proportion of its unexploited size.

The fishery could probably sustain modest increases in effort, but the gains in yield would be relatively small. Gains would be mainly female yield, which is not desirable from the point-of-view of conserving the spawning stock. Sustainable yield at current effort is close to MSY for males. Current landings from the Farn Deeps are about 2,200 tonnes, less than the estimates of sustainable yield at current effort – about 3,600 to 3,700 tonnes, depending on choice of stock-recruitment curve. This suggests that if effort stabilises at current levels catch per unit effort should increase until equilibrium is reached.

Even under the most pessimistic view of stock status with respect to a stock-recruitment relationship, substantial effort increases – 70% or more – could be sustained before stock collapse. However, sharply decreasing yield and biomass curves as F_{crash} is approached give grounds for caution: stock collapse could occur quite suddenly, with a relatively modest increase in effort.

Under the precautionary approach, management advice for the Farn Deeps *Nephrops* stock would be that fishing effort should be maintained at or below current levels. Current exploitation levels appear to be well within sustainable limits, but any increase in exploitation would be at the expense of the female spawning stock.

General conclusions

This modelling approach could usefully be applied in other *Nephrops* stocks. This should allow more robust conclusions about growth overfishing. More importantly, the exercise might identify stocks that are perilously close to collapse. The conclusions about the status of the Farn Deeps *Nephrops* stock appear to be robust to the assumptions about the stock-recruitment relationship. It does not follow that the conclusions about other stocks would be equally robust. This would depend on the current level of exploitation and on the location of the stock on a stock-recruitment relationship. However, the exercise does provide a context in which to examine the implications of various biological and fisheries data and assumptions. Bennett (1994) performed a similar analysis for *Nephrops* in the western Irish Sea, modelling female biomass and yield. In this case, there was greater uncertainty about the form of the stock-recruitment relationship since only a single pair of equilibrium recruitment and biomass estimates was available from length cohort analysis. Bennett (1994) concluded that, although effort increases might result in considerable increases in female yield, it was also possible that F_{crash} was as low as 40% above current effort levels.

More research is needed into the nature of stock-recruitment relationships in *Nephrops*. Stock and recruitment estimates from XSA assessments show an unexpectedly high degree of positive correlation in some stocks, such that 'observed' ratios of recruitment to *SSB* are relatively invariant (ICES, 1999). The usual interpretation for a fin-fish stock would be that it is highly vulnerable, close to collapse, but this has not yet happened in any *Nephrops* stock. Assuming that these stock and recruitment patterns are not artefacts of assessment, there are two types of explanation: (1) there are mechanisms that prevent low stock sizes from decreasing further; or (2) the functional relationship is a dependence of future *SSB* on current recruitment rather than *vice versa*. The second possibility could apply at high fishing mortalities if the spawning stock was composed largely of first-time breeders, particularly if breeding starts at a very young age. In either case, estimates of F_{crash} based purely on the shape of a stock-recruitment curve are likely to be over-pessimistic.

The rôle of male stock size in the stock-recruitment relationship introduces a further level of uncertainty about recruitment at low stock levels. Since copulation occurs during the limited time when a female *Nephrops* is newly moulted (Farmer, 1974), it is likely that reproductive success could be compromised at low male densities. This implies depensation in the stock-recruitment relationship at low stock levels, and might cause over-estimation of F_{crash}. There is no information on limiting sex-ratios or male densities for successful reproduction (ICES, 1998). Given relatively high exploitation rates on males, it may be critical to identify such limits.

Finally, it should be noted that modelling exercises of this type depend heavily on the quality of the inputs. There are some concerns about the application of standard assessment methodology to *Nephrops* (ICES, 1999). In particular, there is scope to improve the way in which male and female fishery data are combined. Currently, male and female stocks are assessed as if they were independent. The quality of female assessments is often poor, given low exploitation that are low in comparison with natural mortality, but estimates of female *SSB* are vital in any consideration of stock status with respect to a stock-recruitment relationship. The raw data are even more important than the assessment models. In particular, recruitment estimates depend on discarding data and information on the survival of discards. There is a moderate level of sampling of discards from the Farn Deeps in most years, but sampling of discards from some other stocks is poor or non-existent.

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TABLE 1. Farn Deeps *Nephrops* biological input data for modelling of yield and biomass. Fishing mortality values are estimates from XSA, averaged over 1996-98.

Age	Average Weight (g)	Proportion Mature	*F*	*M*
Males:				
1	4	1	0.0036	0.3
2	9	1	0.2468	0.3
3	18	1	0.3870	0.3
4	30	1	0.5434	0.3
5	45	1	0.5668	0.3
6	61	1	0.5632	0.3
7	75	1	0.5799	0.3
8	92	1	0.5129	0.3
9	107	1	0.5013	0.3
10	122	1	0.7191	0.3
+	152	1	0.7191	0.3
Females:				
1	4	0	0.0040	0.3
2	9	0	0.2301	0.3
3	13	1	0.0937	0.2
4	16	1	0.1028	0.2
5	19	1	0.1124	0.2
6	22	1	0.1395	0.2
7	25	1	0.1596	0.2
8	27	1	0.1935	0.2
9	31	1	0.2029	0.2
10	33	1	0.2430	0.2
11	37	1	0.2943	0.2
12	40	1	0.2726	0.2
13	42	1	0.4446	0.2
14	47	1	0.4950	0.2
+	57	1	0.4950	0.2

TABLE 2. Parameter estimates for Shepherd curves fitted to North Sea *Nephrops* stock and recruitment data. *a* is in units of thousands of recruits per tonne; *K* is in units of tonnes.

	K(S.E.)									
α	Botney Gut		Farn Deeps		Firth of Forth		Moray Firth		β(S.E.)	
100	2430	(69)	9034	(575)	4969	(298)	6558	(129)	4.97	(0.98)
150	1923	(94)	7184	(266)	3943	(132)	5138	(223)	2.92	(0.48)
200	1537	(122)	5773	(273)	3165	(133)	4097	(307)	2.37	(0.38)
250	1274	(136)	4798	(332)	2630	(168)	3391	(349)	2.13	(0.34)
300	1088	(142)	4107	(373)	2250	(193)	2896	(368)	1.99	(0.32)
350	952	(144)	3597	(397)	1971	(207)	2532	(374)	1.90	(0.30)
400	848	(143)	3207	(409)	1757	(215)	2255	(374)	1.83	(0.29)
450	766	(141)	2900	(414)	1588	(219)	2037	(370)	1.79	(0.28)
500	700	(139)	2651	(415)	1452	(220)	1861	(364)	1.75	(0.28)

TABLE 3. Levels of fishing mortality at which the equilibrium spawning stock biomass is zero: estimates of F_{crash} for *Nephrops* in the Farn Deeps under different assumptions about the stock-recruitment relationship. a is the initial slope of a Shepherd stock-recruitment curve.

a (thousand of recruits per tonne *SSB*)	F_{crash} (relative to current effort)
100	1.72
150	2.57
200	3.25
250	3.82
300	4.30
350	4.73
400	5.10
450	5.45
500	5.76

FIGURE 1. Stock and recruitment estimates from XSA of Farn Deeps *Nephrops*. Open symbols are the most recent two recruitment estimates (1997 and 1998).

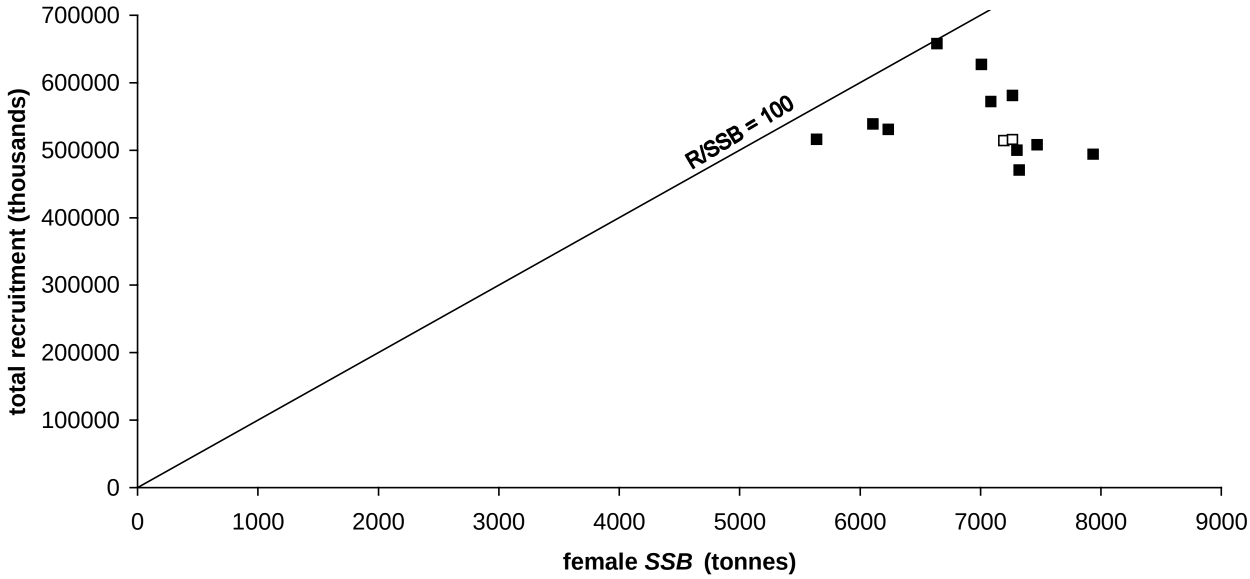


FIGURE 2. Distribution of total recruitment to female *SSB* ratios for all assessed *Nephrops* stocks.

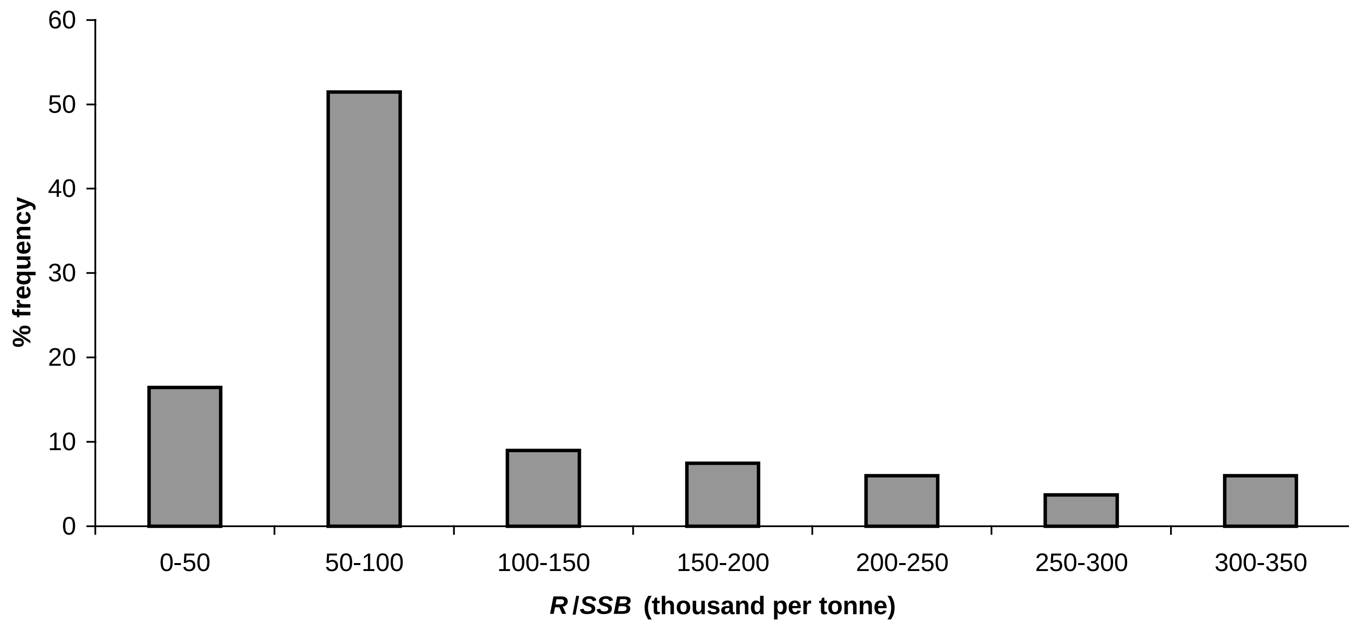


FIGURE 3. Relative stock recruitment relationships for *Nephrops* in the North Sea.

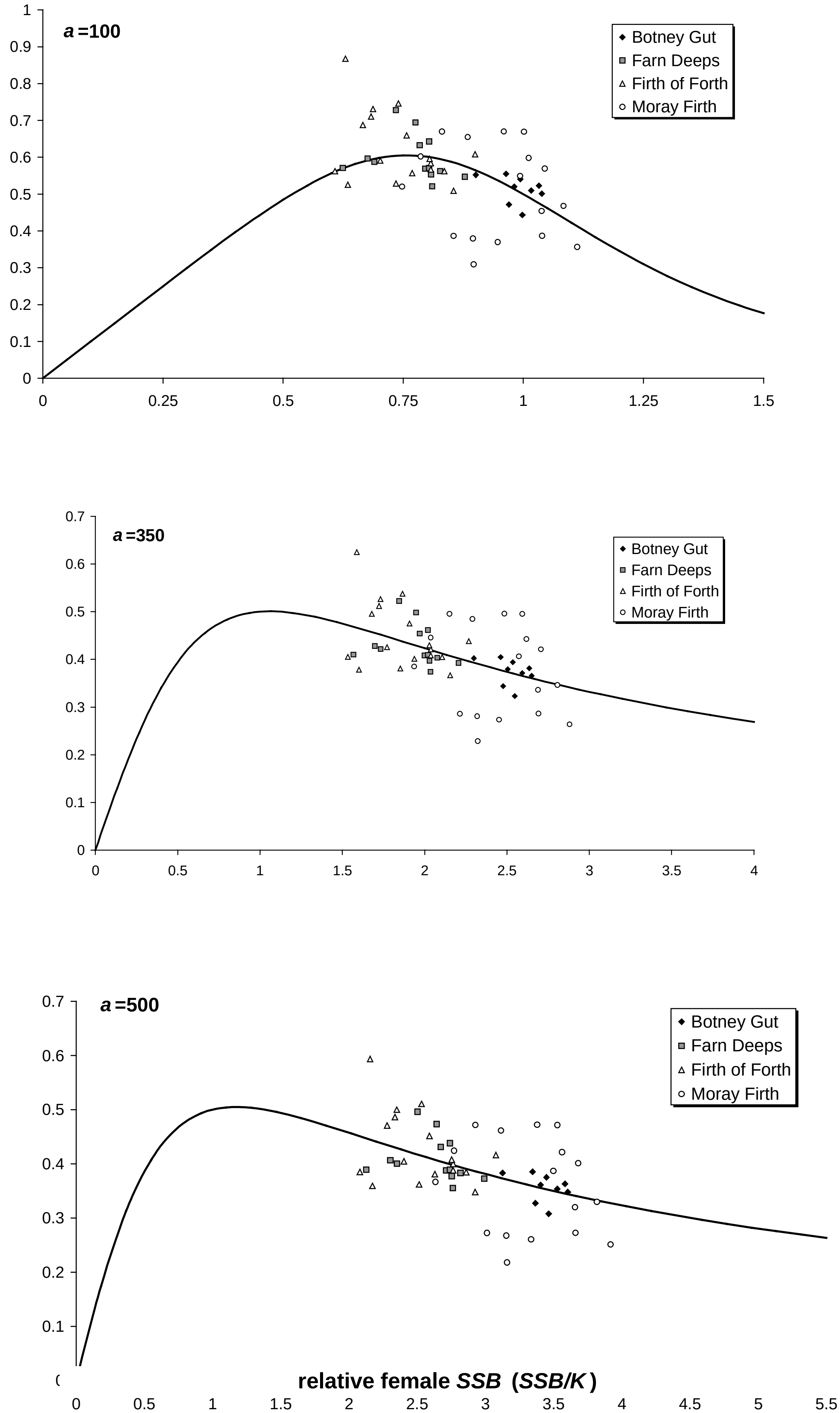
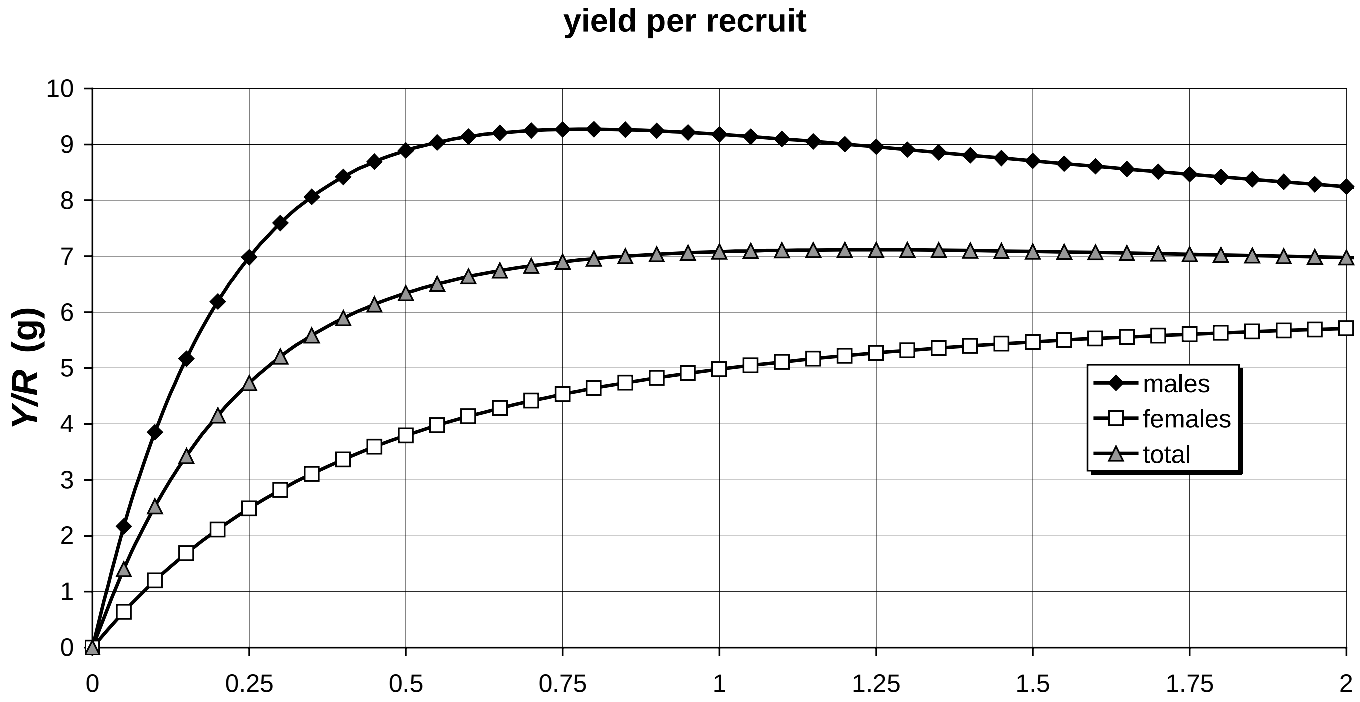


FIGURE 4. Yield per recruit and spawning stock biomass per recruit analyses for *Nephrops* in the Farn Deeps.



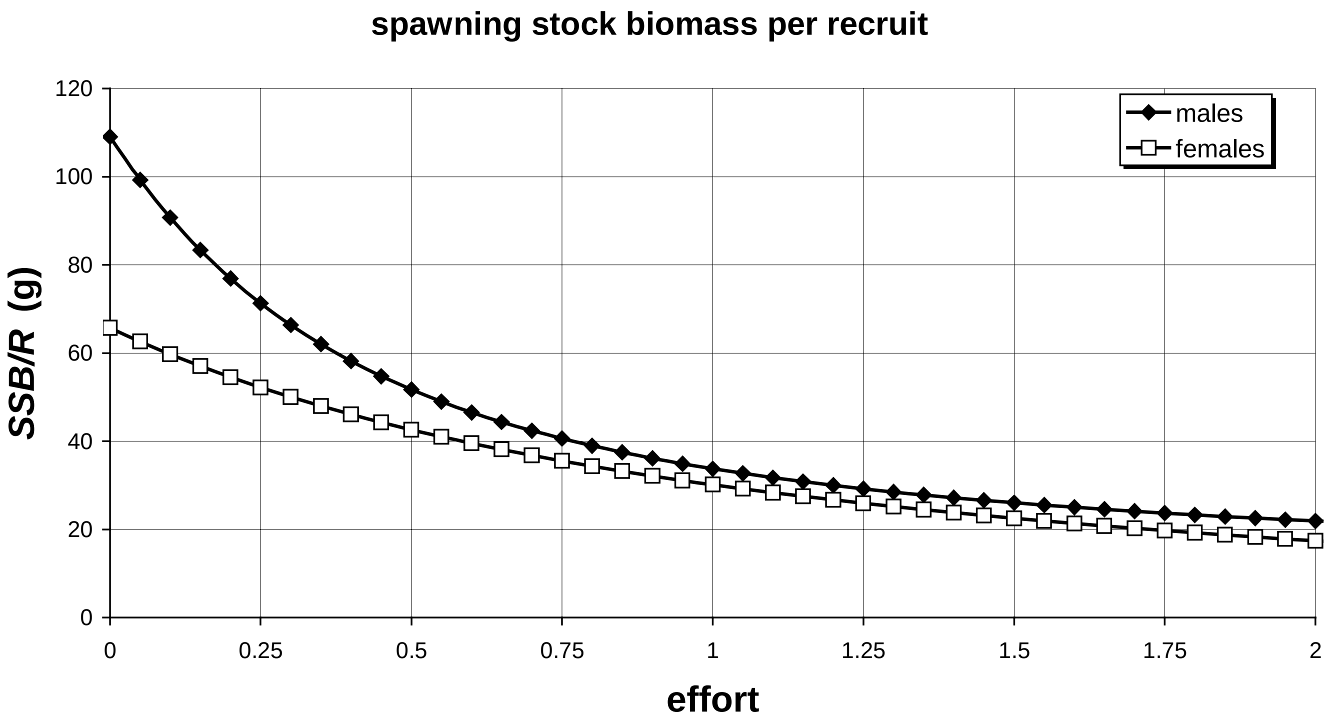
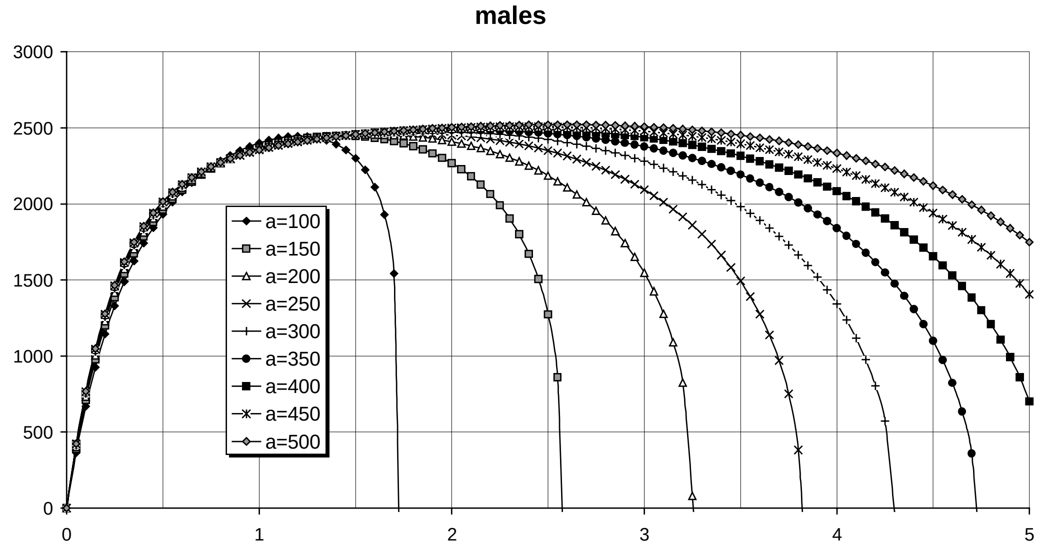
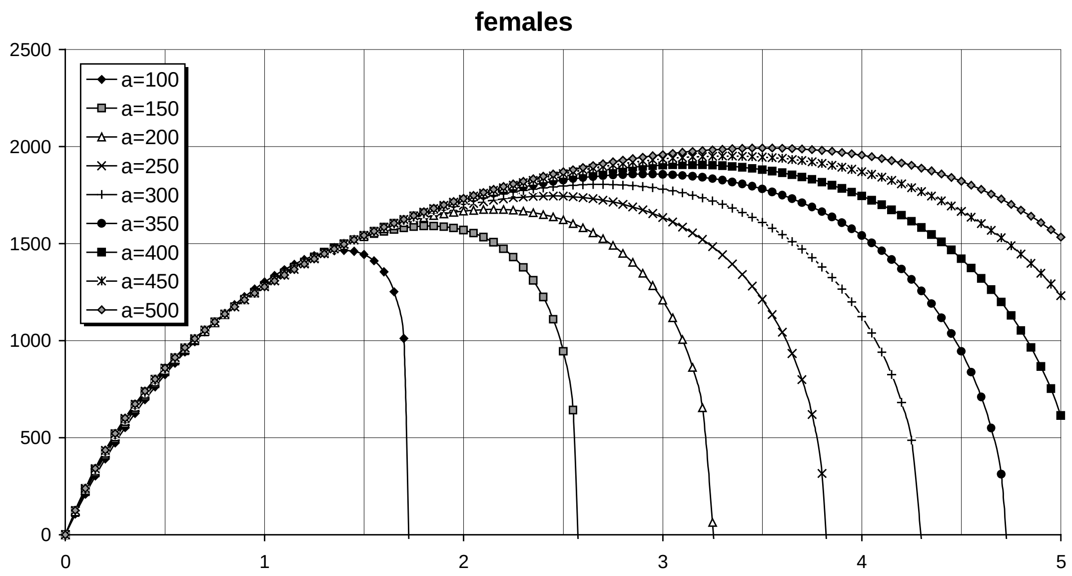


FIGURE 5. Sustainable yield curves for Farn Deeps *Nephrops* , under different assumptions about the stock-recruitment relationship.





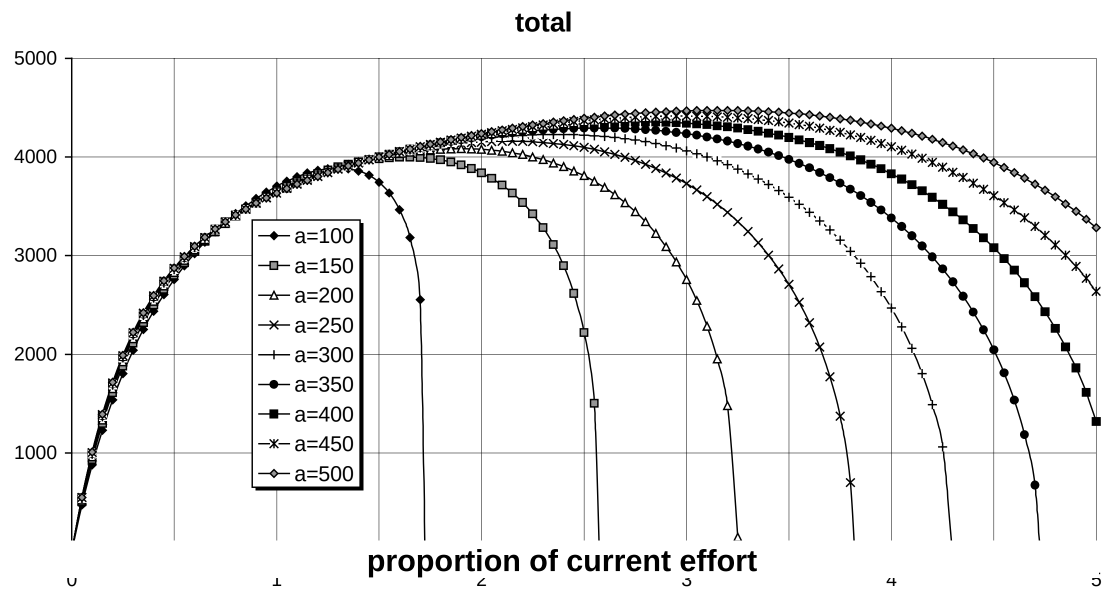


FIGURE 6. Maximum sustainable yield and the fishing effort required to achieve it.

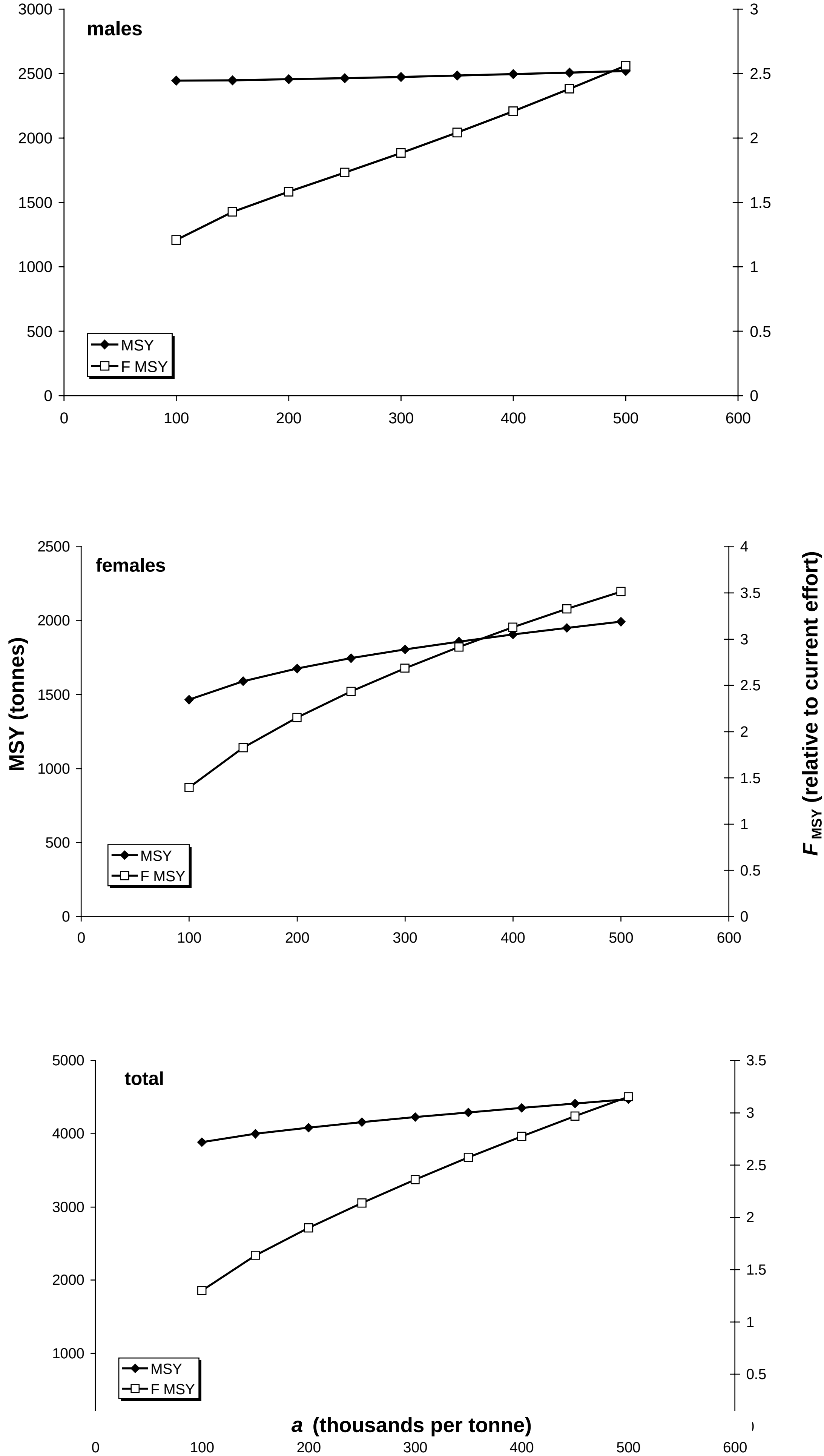
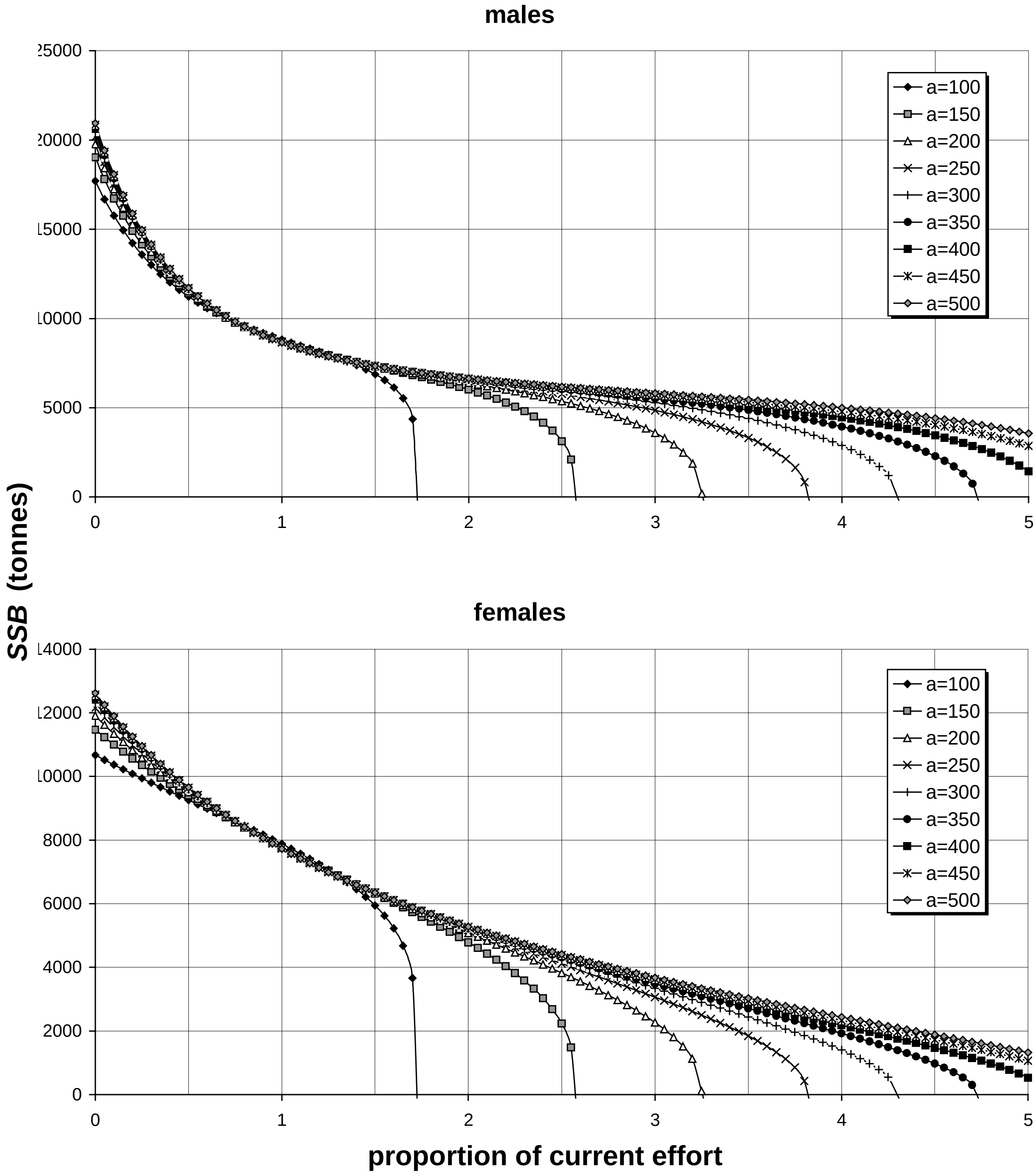


FIGURE 7. Equilibrium spawning stock biomass for Farn Deeps *Nephrops* under different assumptions about the stock-recruitment relationship.



APPENDIX 2

Changes in *Nephrops* density in the Clyde Sea area, from underwater TV survey data.

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INTRODUCTION

Underwater TV surveys of Scottish *Nephrops* grounds are carried out annually, providing a fishery independent estimate of stock size. *Nephrops* burrow counts are made from known areas of seabed, and densities are averaged over strata, and raised to the total area of the ground, to provide a stock size estimate. Full details of the technique have been described previously (Bailey *et al*., 1993), and the estimates provided have been found to be similar to analytical estimates (Tuck *et al*., 1997a). Random stratified underwater TV surveys have allowed investigation of *Nephrops* density (through estimation of burrow density) without the complications introduced by daily and seasonal emergence patterns, which cause trawl catch rates to vary considerably.

MLA first carried out TV survey work for stock assessment in 1992, at the Fladen Ground. The numbers of stocks examined was increased in following years, and an annual survey has been carried out in the Clyde Sea area since 1995, by either the Fisheries Research vessel *Scotia* or *Clupea*. Prior to this, although full survey coverage of the Clyde is not available, TV work was carried out by the UMBSM research vessel *Aora*, and burrow density data is available for a limited number of stations for 1991, 1992 and 1993. A summary of the data is provided in Table 1.

This work examines the changes in the patterns of *Nephrops* density in the Clyde Sea area, using the information provided by the TV burrow density estimates.

Results

Maps of the spatial pattern of burrow density are shown in Fig. 1. In these figures the size of the dots represent burrow density. Changes over the time period of the surveys, in the mean density for the three sediment strata examined, are shown in Fig. 2 and Table 2. This figure also shows the male recruitment estimated by XSA.

The TV work carried out in 1991 was part of a study examining variability in the *Nephrops* populations in the South of the Clyde, and therefore only examined locations to the South of Arran (Fig 1). Densities measured were highest on the muddy sand (1.479 m^{-2}), slightly lower on the sandy mud (1.219 m^{-2}), and considerably lower on the mud (0.552 m^{-2}). The 1992 and 1993 TV stations were more widespread, but included some of the locations visited in 1991. A similar pattern of densities was noted between strata (highest density on the coarsest sediment), but the densities recorded were considerably lower than in 1991 (0.328 – 0.058 m^{-2}; Fig. 1). This was the case for new stations to the North, and those repeated from 1991. No data is available from 1994, but for 1995 onwards, the data are from surveys specifically designed to estimate stock numbers, and spatial coverage is far better. In 1995 densities appeared to have increased overall from 1993 (0.215 – 0.436 m^{-2}), although they were lower on the muddy sand strata. In 1996 the density on the mud remained similar to the previous year, but increased for both the coarser strata (sandy mud and muddy sand). Although mean density for the muddy sand strata (0.678 m^{-2}) was about half that of 1991, the 1991 density was based on only one station, in the south of the Clyde Sea area. Both 1997 and 1998 surveys found similar burrow densities to 1996 for the sandy mud and muddy sand strata, but increasing densities on the mud, with these latest estimates for the mud (0.558 – 0.776 m^{-2}) the highest in the series. Overall the burrow density appears to have dramatically reduced after 1991, and then steadily increased. Recruitment showed a generally increasing trend through the same time period.

Table 2 also shows the mean burrow density for each strata broken into northern and southern regions, divided at roughly the southern limit of the Isle of Arran. These data are plotted in Fig. 3. Each of the strata show a similar pattern over time, with densities declining after 1991, and increasing from 1995. However, while the mud and muddy sand strata showed no difference in burrow density between regions, the densities on the sandy mud were consistently higher in the southern region than in the north.

Conclusions

One of the main assumptions underpinning the use of underwater TV surveys to assess the size of *Nephrops* stocks is one of burrow occupancy. In order to convert burrow densities to animal densities, one must make certain assumptions about the numbers of animals per burrow. It is unknown what proportion of animals maintain more than one burrow, or what proportion of burrows have multiple occupants, but provided these proportions do not vary between strata or over time, then the TV series provides a robust relative index of *Nephrops* density.

The pattern of *Nephrops* density identified in 1991 conformed to the pattern previously noted over the sediment types associated with Scottish stocks, with density inversely related to % silt & clay in the sediment (Chapman & Howard, 1988). Despite the dramatic decline in density in the following two years, this pattern was maintained. The drop in density in 1992 coincided with reduced *Nephrops* landings in the Clyde (ICES, 1999), and a peak in the prevalence of the parasitic *Hematodinium* infection (Field *et al*., 1998), which is thought to increase *Nephrops* mortality (Field *et al*., 1992). Burrow densities increased after 1995, and since then catch rates (measured as LPUE of Scottish *Nephrops* trawlers; ICES 1999) have been the highest in a decade. Large numbers of small individuals are being caught, supporting the indication from the XSA that recruitment has increased (Fig. 2). It is important to identify how dependent burrow counts are upon recent recruitment. It has previously been suggested that TV survey biomass estimates may be biased by use of too large a mean size (ICES, 1997), because animals responsible for some of the burrows counted are smaller than those caught through trawling. By examining the size distribution of burrows, and further investigating the relationship between animal size and burrow size (Marrs *et al*., 1996), it may be possible to estimate the size distribution of animals in the population, and therefore the influence of recent recruitment on burrow densities.

From the 1998 data there appears to be little difference in *Nephrops* burrow density between strata, although we are presently unclear as to the influence recent recruitment may have had on densities, or the effects subsequent juvenile mortality will have in the different habitats. Previously, lower densities on finer muddy strata were associated with higher growth rates for *Nephrops* in the Clyde Sea area (Tuck *et al*., 1997b). If growth is density dependent, then increased density may lead to slower growth in these areas.

It can be seen from Table 2 that station coverage of the muddy sand strata in the northern region has been poor. For Clyde Sea area TV surveys, stations are allocated in a random stratified manner, based on three sediment strata. Since there is very little muddy sand strata in the northern region, the number of stations allocated is low. Although this strata does not appear to show the same regional difference in burrow density as the mud and sandy mud, it may be worth allocating more stations to this strata in this region in the future.

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Table 1. Summary of TV survey data available for the Clyde Sea area.

Year	No. of Stations	Vessel	Breakdown[†] M	MS	SM	Source
1991	6	*Aora*	2	3	1	Tuck 1993
1992	6	*Aora*	3	2	1	MAFF funded research
1993	9	*Aora*	5	3	1	IMBC 1994
1994	No data					
1995	28	*Scotia*	11	10	7	MLA survey
1996	38	*Clupea*	14	14	10	MLA survey
1997	31	*Clupea*	13	12	6	MLA survey
1998	38	*Clupea*	13	14	11	MLA survey
	20	*Aora*	9	6	6	EC funded research

[†] - Breakdown by sediment strata : M – mud, MS – muddy sand, SM – sandy mud.

Table 2. Mean burrow density by strata[†] for Clyde Sea area, and broken into northern and southern regions[‡].

Year		Overall			South			North		
		M	SM	MS	M	SM	MS	M	SM	MS
1991		0.552	1.219	1.479	0.552 (2)	1.219 (3)	1.479 (1)	-	-	-
1992		0.058	0.075	0.328	-	0.127 (1)	0.328 (1)	0.058 (3)	0.024 (1)	-
1993		0.074	0.239	0.472	-	0.324 (2)	0.472 (1)	0.074 (5)	0.060 (1)	-
1994		-	-	-	-	-	-	-	-	-
1995		0.337	0.436	0.215	0.512 (5)	0.744 (5)	0.211 (8)	0.175 (9)	0.110 (1)	0.130 (1)
1996		0.332	0.594	0.703	0.345 (4)	1.155 (6)	0.650 (11)	0.306 (11)	0.243 (7)	0.610 (1)
1997		0.558	0.822	0.678	0.580 (5)	1.130 (7)	0.680 (6)	0.550 (8)	0.390 (5)	-
1998	C*	0.711	0.740	0.716	0.580 (5)	0.917 (9)	0.716 (11)	0.790 (8)	0.420 (5)	-
	*A**	0.776	0.625	0.600	0.933 (4)	0.827 (3)	0.485 (5)	0.649 (5)	0.423 (3)	0.618 (1)

[†] - Breakdown by sediment strata : M – mud, MS – muddy sand, SM – sandy mud.
[‡] - Demarcation between Northern and Southern regions set at latitude of 55.45°N (55° 27’N)

- - Surveys were carried out by both *Clupea (C)* and *Aora* (*A*) in 1998.

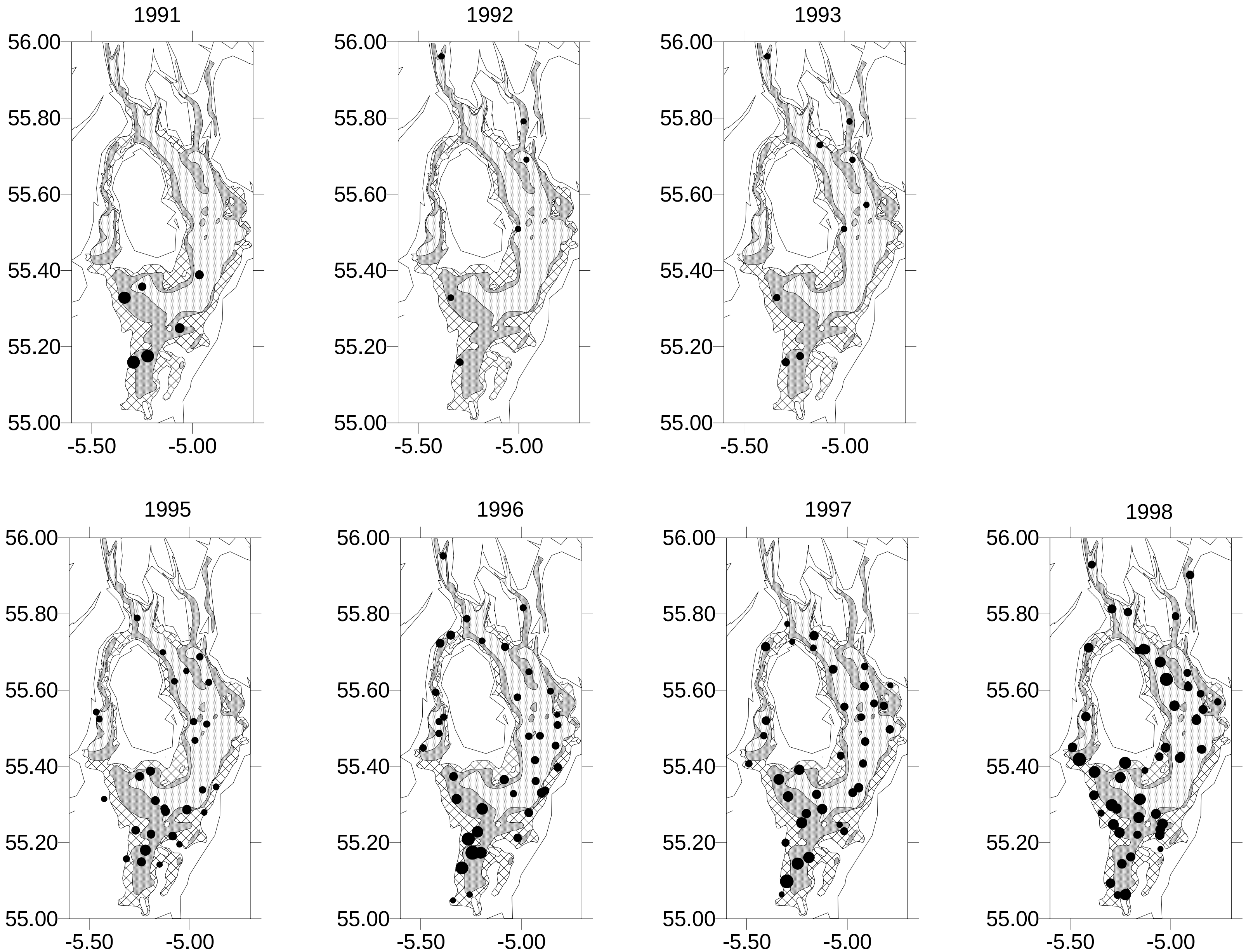


Figure 1. Maps of *Nephrops* burrow density for 1991, 1992, 1993, 1995, 1996, 1997 and 1998. Mud – lightly stippled, Sandy mud – heavy stipple, Muddy sand – cross hatched.

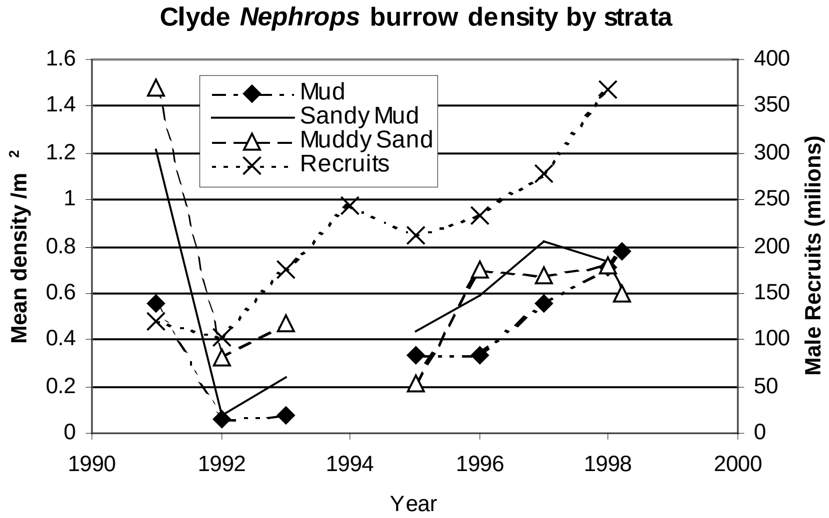
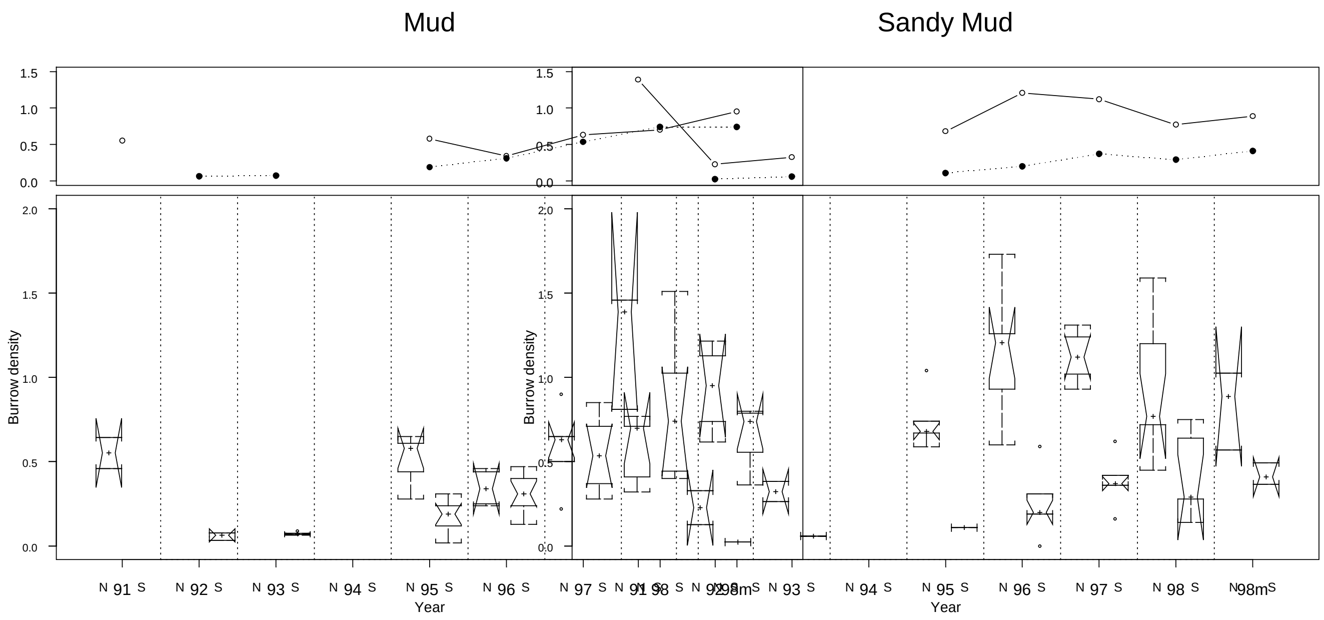


Figure 2. Overall mean *Nephrops* burrow density by strata for each survey, and male recruitment from XSA assessment.



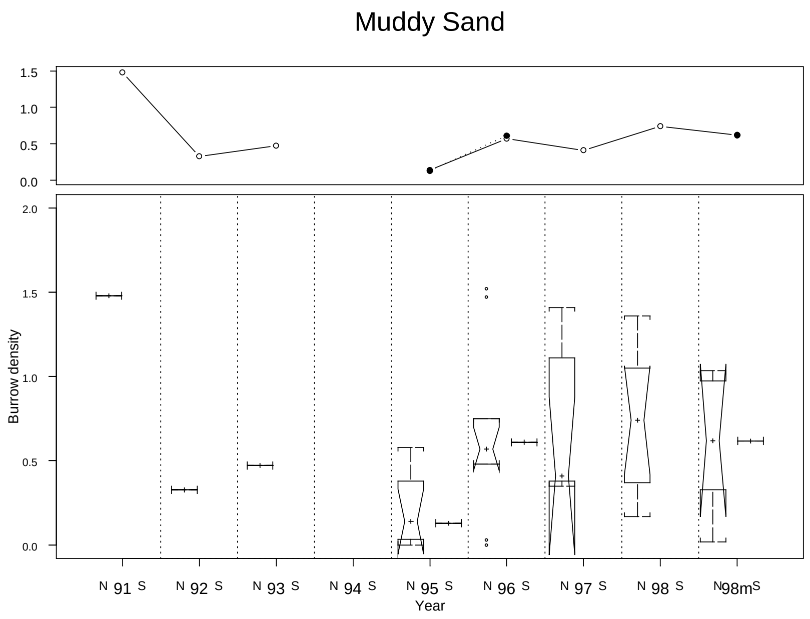


Figure 3. Box plots of mean *Nephrops* burrow density for mud, sandy mud anc muddy sand (lower panels), along with the time series for the median value for each survey. Box-plots are arranged in pairs in order of time (survey), with the Southern region on the left for each pair.

The notches in the boxes indicate 95% confidence intervals of the median. If the intervals around two population medians do not overlap the population medians can be considered significantly different ($P < 0.05$). The dashed lines represent whiskers and extend to the largest observation that is less than or equal to the upper quartile plus 1.5 times the interquartile range (or the smallest observation that is greater than or equal to the lower quartile minus 1.5 times the interquartile range).

APPENDIX 3

Survey Estimates of Biomass of *Nephrops* in the Irish Sea

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This contribution is from the FINAL REPORT (updated) on EU project: DGXIV 1995/086 (Anon., 1999). The paper describes a study coordinated by The Department of Agriculture (NI), in collaboration with The Queen's University of Belfast (C-MAR), The University of Liverpool (PEML) and the Marine Institute in Dublin (FRC).

Overview

Nephrops is the target of the most important Irish Sea fishery with average international annual landings of over 8,000 tonnes and first-sale value of over 14 million Euros. The *Nephrops* stocks are assessed biennially by ICES which provides advice to EU fishery management bodies. The analytical methods used in these assessments are adapted from procedures developed for finfish that exhibit very different biological characteristics from crustaceans. Although the advice ensuing from these assessments appears adequate for some stocks such as in the western Irish Sea stock, limitations in data restrict the application of analytical methods to other stocks including the one occurring in the eastern Irish Sea. An EU-funded project to explore the use of the annual larval production (ALP) method was established to assess *Nephrops* spawning stock biomass (SSB) in the Irish Sea. The ALP method estimates the biomass of mature females required to produce the observed annual production of planktonic larvae. This requires a series of plankton surveys to estimate the annual larval production and concurrent sampling of the *Nephrops* population to estimate of the number of eggs per unit weight of female at the time of hatching (the realised fecundity, F_r). Calculation of total spawning stock biomass of males and females requires estimates of sex ratio in the population of mature *Nephrops*:

$$SSB = \frac{ALP}{F_r * R}$$

where ALP is the annual larval production and R is the proportion of SSB comprising mature females. Maturity in male *Nephrops* cannot be established using macroscopic criteria thence R was specified as the ratio of female SSB to combined biomass of mature females and all males, to allow total biomass of males to be estimated.

Annual larval production

The annual larval production ALP was estimated from a series of ichthyoplankton surveys carried out as part of an earlier EU contract (AIR3-CT94-2263). The surveys were designed for estimating annual egg production of several stocks of fish in 1995, and therefore were not optimal for estimating *Nephrops* larval production. However, sampling took place throughout most of the period of hatching of *Nephrops*. Each survey comprised a stratified grid of sampling stations covering the full area where eggs of the target fish species were expected. In most surveys this also covered the main distribution of *Nephrops* larvae. Laboratory estimates of larval stage duration as a function of temperature were used to calculate daily larval production from estimates of abundance. Annual larval production was estimated for stage I and stage II larvae only, as larvae were not successfully reared through stage III to stage IV. The laboratory estimates of duration of stage I larvae were consistent with the time lag between production of stage I and II larvae in the plankton. The annual production of stage I and II larvae was obtained by integrating the survey estimates over time using several different methods for comparison. Larval mortality was estimated from the decline in production between stage I and II assuming a simple exponential decay model, allowing the estimation of production at age zero (i.e. at hatching). It was not possible to investigate the appropriateness of the exponential model. A decline in standard deviation of the seasonal production cycles between stage I and II larvae indicates that mortality rates could increase over time during the hatching season or increase at low densities of larvae.

Fecundity estimates

Fecundity and larval development were studied by establishing a hatchery at the Centre of Marine Resources and Mariculture (C-Mar) in Portaferry, Northern Ireland. Adult female *Nephrops* collected by trawling and creeling were successfully maintained in individual containers over the 9-month incubation period to examine aspects of fecundity and hatching success. An important observation made during these studies was the extrusion of eggs in captivity which provided an estimate of mean potential fecundity in the population of 104.3 eggs g^{-1} (SE = 2.7; n = 50). There was no significant correlation between specific fecundity and carapace length.

Loss of eggs during incubation was investigated from sequential samples of ovigerous females collected by trawling and also by monitoring egg loss and hatching in the *Nephrops* maintained in captivity. Specific fecundity of trawl-caught *Nephrops* appeared to decline linearly with time between spawning and hatching. The average loss of eggs during the incubation period was estimated to be 36.7 eggs g^{-1} (SE = 3.3), assuming the same quantity of eggs was lost during each trawling exercise. Ovigerous females caught by trawling during the spawning period and maintained in the laboratory were estimated to have lost 42.5 eggs g^{-1} during incubation although initial fecundity was lower than the potential fecundity because eggs were lost during transportation to the laboratory. The field estimates of egg loss during incubation were subtracted from the estimated potential fecundity to give an estimate of mean realised fecundity at hatching of 67.6 eggs g^{-1} (SE = 4.3).

Egg loss during trawling was estimated to be 12 eggs g^{-1} or 11.5% of potential fecundity by comparing the mean fecundity of ovigerous females trawled in August with the potential fecundity of females caught during the same survey but which extruded their eggs in captivity. This estimate of egg loss is small compared with the losses during the incubation period, and is within the range of some previous estimates for Scottish *Nephrops*.

Sex ratio

Historical data series held by QUB, CEFAS and the Marine Institute in Dublin were collated to estimate sex ratio *R*. During winter months ovigerous female *Nephrops* stay in their burrows while they incubate their eggs and few ovigerous females are caught in commercial trawls during this time. The most reliable trawl-based information on the mature female population is from catches made during the summer months. Emergence of mature females from the burrows was consistently found to be highest during the month of July. Sex ratios were derived from both the Northern Ireland and Republic of Ireland data using the formula:

$$R = C_f/(C_f + C_m)$$

where Cf is the biomass of mature females in the catches during July and C_m is the biomass of all males. This form of sex ratio was adopted merely to provide estimates of total biomass of males for comparison with the estimates produced by ICES using virtual population analysis (VPA) or length-based cohort analysis (LCA). Mean *R* of 0.53 (SE = 0.019) was estimated from samples collected in July from Northern Ireland and Republic of Ireland commercial catches of *Nephrops* over the period 1983-1996. No significant trend in *R* was recorded over these years. The estimate of *R* remains biased because of gear selectivity. However, similar results were obtained from research trawl surveys using 40mm mesh trawls compared with 70mm in the commercial fleet, reflecting the shallow selection ogive in *Nephrops* stocks.

Estimates of spawning stock biomass

Estimates of SSB are given in the text table below, together with coefficients of variation of the means. The biomass of female *Nephrops* in the western Irish Sea is estimated to be 14 times greater than in the eastern Irish Sea (95% confidence range 5-24).

	Western Irish Sea		Eastern Irish Sea	
Parameter	Mean	CV	Mean	CV
ALP (x 10^{-6} larvae)	431,000	0.170	30,000	0.260
Fg (eggs g^{-1})	104.3	0.026	104.3	0.026
Fr (eggs g^{-1})	67.6	0.063	67.6	0.063
R	0.53	0.034	0.53	0.034
Female SSB (t)	6,375	0.181	444	0.267
Female SSB + total male biomass(t)	12,028	0.189	838	0.273

Maturity Ogive

Maturity ogives, calculated from the proportion of females with eggs or developing ovaries, could only be calculated for the western Irish Sea stock which contributes over 90% to the annual landings from the Irish Sea. Mature female *Nephrops* appear in catches during the winter but are generally small and unlikely to become ovigerous in that year. Maturity ogives were therefore generated from both NI and ROI data for the summer months when sex ratio is at its highest and female *Nephrops* contribute to about 50% of the catch. These ogives were similar to those already published for the Irish Sea with a 50% maturity size of L_{50} = 23mm carapace length. As found in other stocks of *Nephrops*, approximately 10% of mature females were not in a reproductive state during the year.

Comparison with ICES estimates of SSB

Annual estimates of SSB of *Nephrops* in the western Irish Sea were obtained by the ICES *Nephrops* assessment working group in 1999 using VPA tuned with data on commercial catch per unit effort. The analysis was re-worked to give SSB at the time of peak hatching of stage I larvae. The estimated female SSB in 1995 from the VPA was 27% lower than the ALP estimate, but just within the 95% confidence limits of the latter. (Fig. 1):

	ALP	VPA[1]	LCA[2]	LCA[3]
Female SSB (t)	6,375	4,643	4,242	4,466
Total males (t)	5,653	12,821	12,736	12,736
Total (t)	12,028	17,464	16,978	17,202

[1]1995 SSB, based on knife-edge maturity for females [2] Mean SSB for 1996-1998, based on knife-edge maturity in females [3] Mean SSB for 1986 - 1996, based on new maturity ogive.

The VPA estimates for females are based on a knife-edge maturity at age three and hence reflect a different pattern of maturity to the one implicit in the ALP estimates. A comparison of length cohort analysis estimates using knife-edge selection at 24mm (adopted by ICES for this stock) and the maturity ogive from the present study, indicates a possible under-estimate of female SSB of about 5% using knife-edge selection. The estimates from VPA and LCA are biased because they are dependent on values of natural mortality *M* which are assumed and not estimated. A change in *M* on mature females from 0.2 to 0.275 yr^{-1} is sufficient to increase the LCA estimate of female SSB for 1995 to the ALP estimate (Fig. 2). Males and immature females are assumed to experience *M* of 0.3 yr^{-1}. The VPA estimate of total biomass of males in 1995 is 127% higher than the ALP estimate, and gives a sex ratio of 0.27 compared with the value of 0.53 obtained from trawl samples in July. This partly reflects the effect of gear selectivity in the trawl samples indicating that a valid comparison between the ALP and VPA estimates of biomass of males is not possible.

The estimated annual larval production at hatching in the western Irish Sea in 1995 ($431*10^9$ larvae; CV=0.17) was not significantly different from an equivalent estimate of $520*10^9$ larvae obtained by CEFAS during surveys of the western Irish Sea in 1982. The mortality rate estimated during the 1982 surveys (0.035 d^{-1}, based on numbers at stage I - III) was not significantly different from the estimate of 0.04 d^{-1} (SE=0.016) obtained for the western Irish Sea in the present project. Using only the data for stage I and II from the 1982 surveys gives an estimate of mortality of 0.031 d^{-1} and an annual production at hatching of $493x10^9$ larvae. Applying the estimated realised fecundity from the present project gives 1982 SSB of female *Nephrops* in the western Irish Sea of 7,115 - 7,690 t for larval mortality rates estimated using stages I-II and stages I-III respectively, compared with the 1995 estimate of 6,375 t.

Conclusions

This project has shown that the annual larval production method can be applied successfully to *Nephrops* stocks, and that survey designs for estimating fish biomass using the annual egg production method could also provide data for *Nephrops* with a comparatively small amount of extra sampling. The project succeeded in developing techniques to study the *Nephrops* life cycle in captivity under controlled conditions. Egg extrusion and hatching were observed and both potential and realised fecundity were estimated. Larval development rates in laboratory conditions were found to be similar to the estimates from some previous studies. Methods of determining annual larval production from plankton survey data were explored and results used to provide estimates of *Nephrops* SSB in the Irish Sea. The estimates of SSB of females were of similar order to the estimates from ICES assessments based on analyses of commercial catches, indicating that the ICES estimates of fishing mortality may not be seriously in error.

The major weaknesses of the ALP method appear to be the estimation of realised fecundity and the pattern of larval mortality from the point of hatching onwards. Estimates of daily larval production are sensitive to assumed stage durations which could differ in the wild from estimates obtained in the laboratory if mortality rates are linked to larval development and population effects. Further work on realised fecundity and larval dynamics of *Nephrops* would lead to more confident application of the ALP method. Extension of the ALP method to estimate biomass of male *Nephrops* will require novel methods of sampling to ensure that the male and female components are equally catchable to the sampling gear used.

Reference

Anon., 1999. Survey estimates of biomass of *Nephrops norvegicus* in the Irish Sea**, Final Report: EU funded** Project: DGXIV 95/015, pp109

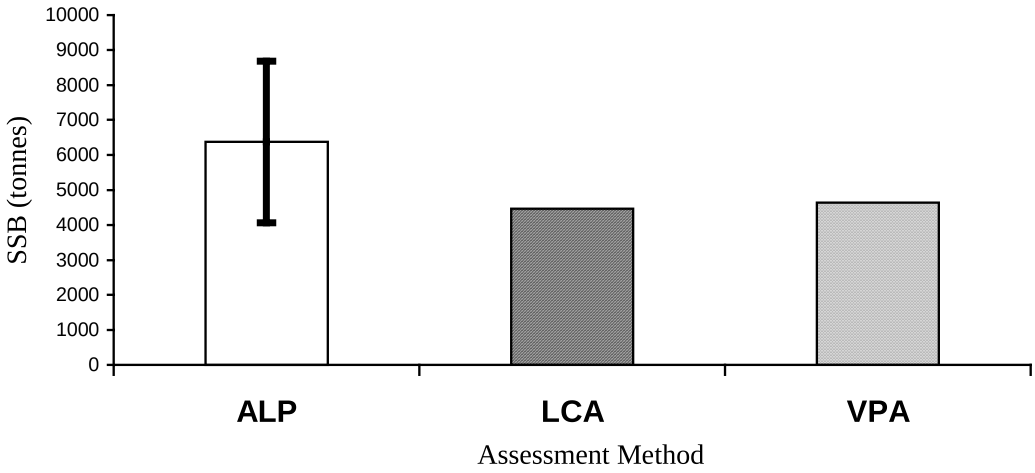

Figure 1
Female *Nephrops* Spawning Stock Biomass estimates from different methods
(vertical bar = 95% confidence range)

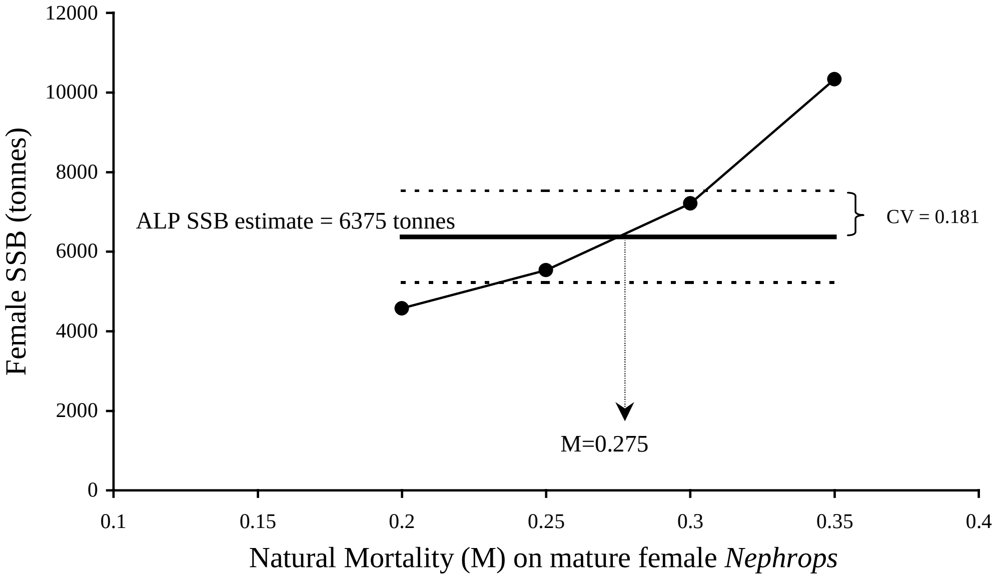

Figure 2

Female SSB from *LCA* for a range of natural mortality values (M). The ALP estimate of 6,375 tonnes is also shown. The ICES Working Group (1999) derived female SSB with M=0.2 was 4,466t and becomes comparable to the ALP estimate if M is increased to 0.275.

APPENDIX 4

A Growth Model for Nephrops

By

Marion Verdoit, Dominique Pelletier and Catherine Talidec

Introduction

A student in bio mathematics has worked on Nephrops growth modelling, from results of radiometric experiments on Nephrops from the bay of Biscay. For the record, measuring natural isotopes in the carapace gives its age, that is to say time elapsed since the last moult, provided that the Nephrops was about to moult.

Intermoult duration and moult increment were modelled separately, and for each sex.

The moult increment model was fitted from published data and supposed to be a linear function of cephalothoracic length, according to Hiatt (1948) equation.

Intermoult duration is supposed to depend only on sexual maturity length for females, and for males a constant intermoult duration is considered. The model was fitted from radiactivity measurments.

The bootstrap method was used to validate different paramater estimates, taking into account the uncertainty in intermoult duration measurements.

Then estimates were used to simulate the growth of 500 *Nephrops*, taking into account estimates uncertainty, in order to build an length age key.

1. Moult increment model

Data used are those of Charuau (1977), which were obtained by re-immersion of ready to moult individuals, in the north of bay of Biscay. Pre-moult lengths and post-moult lengths were obtained for 55 males and 73 females, in a length range of 20.5 to 45.5 mm.

Post moult cephalothoracic length (CL) was modelled as a linear function of pre-moult CL, according to Hiatt model (1948) as follows :

(1) Y mi = a +b x0i +ei

with Y mi = post-moult CL (mi for moult increment), x0i = pre-moult CL, a and b are constants and ei is the error term according to N(0,s2).

2. intermoult model

- males

Radiometric measurements have shown that males moulted twice a year. Calculating a simple mean t bar on the data sample was chosen to link intermoult duration to CL.

- females

A model in two parts, one for mature and the other for immature, was chosen. Fits were done by weighing each individual with its probability of being mature, using the maturity ogive from Morizur (1980).

At a CL of 29 mm, 100% of females are mature, at a CL of 23.5 mm 50% of females are mature, and at a CL of 18 mm all females are immature.

Two weighted averages were calculated, one for the mature part, using individual weights corresponding to the percentage of maturity, and one for the immature part, using individual weights corresponding to the percentage of immaturity

3. Parameters estimation

- **moult increment**

The L.T.S (Least Trimmed Squares regression) regression technique was used to fit the linear model. It is a robust technique which minimize the sum of the q squared smallest residuals, q being slightly greater than half the sample size). The standard error around regression parameters was estimated by the bootstrap technique.

- **intermoult duration**

Following estimation of mean intermoult durations, the bootstrap method was applied to the 3 samples (males, mature and immature females), in order to assess measurement uncertainty on means. Actually, the simple weighted mean variance cannot been estimated by classical methods (Central limit theorem and normal approximations) because the hypothesis of normal distribution of samples is not complied :

- the male sample is small
- measurement uncertainty are calculated according to the exponential law of radioactivity, that gives non symetric confidence intervals.

In this case, using the non parametric bootstrap which does not make any hypothesis on error distribution, allows to assess the quality of statistic estimates. In this way, by integrating an uncertainty of 15% into activity ratios of measured isotopes, the bootstrap estimate of the sample mean is calculated.

4. Growth simulation and estimating a growth curve

- **growth simulation**

Previous estimates were used to simulate the individual growth of 500 *Nephrops*, taking into account uncertainty on intermoult durations and moult increments.

Initial pre-moult CL to start the simulation is the theoretical recruit length of 15 mm. At this length, the age is supposed to be 9 months : this value is used as the initial intermoult duration. In other respects, the simulation starts by a moult increment, because available data concern ready to moult *Nephrops*.

In order to take into account moult increment individual variability at a given length, a number is drawn at random, the probability distribution of which follows a normal law with a mean of ymi (cf. equation (1)) and a variance of v(y mi). The number value is added to the initial pre-moult length L0 and the result named L1. The same procedure is repeated from this new value L1 and iterations go on until a sufficient number of growth monitoring years (around 15 years).

A similar procedure is applied to intermoult durations, with also drawing a number at random, the probability distribution of which follows a normal law with a mean of t bar and a variance of v(tbar). Two distributions are needed for females, because t bar is not the same according the maturity stage.

- **estimating the growth curve**

Confidence intervals are determined from all the growth curves obtained. The percentiles method is used to get the three curves L5%, L95% and L50%, for which 5% of length obtained for each year are greater than L5%, 95% are lower than L 95%, and 50% are lower than L50%. An length age key is calculated for monthly or yearly intervals from the initial date, and its variability. Then the annual number of moults since recruitment is calculated.

5. Results

- models

Results of intermoult duration fits are presented in table 1.

	Observed			Bootstrap with measurement error		
	Mean	Standard error	CV	Mean	Standard error	CV
Males $\bar{t}_M$	5.97	0.58	0.097	6.02	0.63	0.105
Mature females $\bar{t}_{MF}$	8.80	0.32	0.036	8.75	0.55	0.063
Immature females $\bar{t}_{IF}$	5.39	0.31	0.057	5.32	0.48	0.090

Table 1. Parameter estimates for intermoult period.

For males and immature females, average intermoult durations of 5.97 months and 5.39 months were obtained, that is in agreement with what was expected.

For mature females, the intermoult duration of 8.79 mois is lower than the one expected. This could be due to the fact that *Nephrops* sampling for isotope measurements has always been taken place at the beginning of moult periods. Intermoult durations would have certainly been greater for a sampling at the end of the moult period.

Figure 1 presents the synthesis of moult increment fits results, using the robust L.T.S regression.

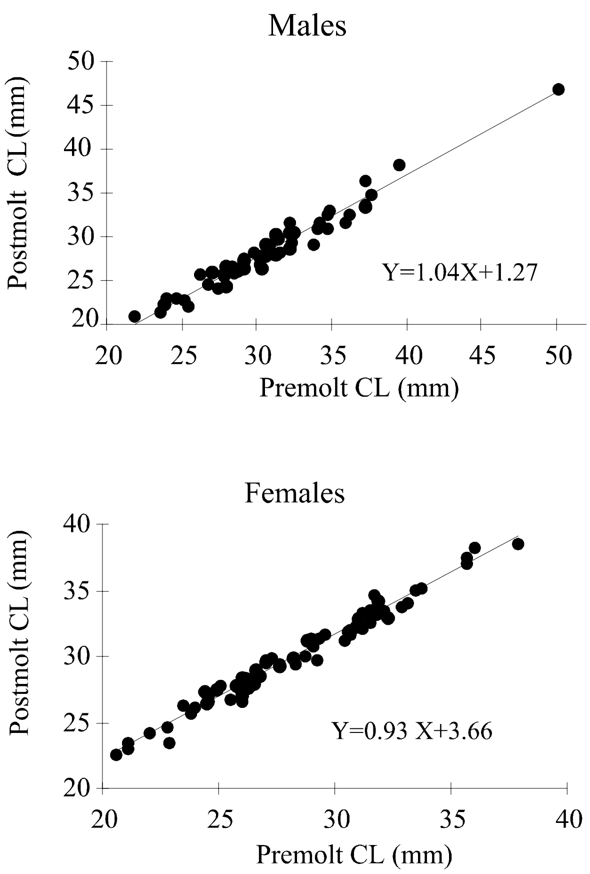

Figure 1. Fit of MI data by LTS regression based on eq. (3), for males (top) and females (bottom). Dots correspond to data points.

- **Simulation**

The length age key simulation results are presented in table 2.

Age (years)	Males	Females	Length-age key					
			Males			Females		
	Mean number of moults	Mean number of moults	$CL_{5\%}$	$CL_{50\%}$	$CL_{95\%}$	$CL_{5\%}$	$CL_{50\%}$	$CL_{95\%}$
1	1.4	2.0	15.3	18.0	21.5	18.8	20.0	21.1
2	3.4	4.0	18.8	22.7	26.6	23.1	24.4	25.6
3	5.4	5.7	22.6	27.2	32.0	26.1	27.8	29.1
4	7.4	7.0	27.0	32.2	37.5	28.8	30.0	31.1
5	9.4	8.2	32.0	37.6	44.4	30.7	31.8	33.4
6	11.4	9.8	36.5	43.9	53.2	32.9	34.3	35.6
7	13.4	11.0	41.6	51.5	67.3	34.6	35.9	37.3
8	15.4	12.4	46.7	61.3	82.0	36.0	37.6	39.3
9	17.4	13.9	54.5	74.1	102.5	37.6	39.3	41.0
10	19.4	15.2	63.2	89.0	130.5	38.8	40.5	42.7
11	21.4	16.6	74.2	107.1	161.4	40.0	42.1	44.4
12	23.4	18.0	87.4	133.4	202.7	41.2	43.4	46.0
13	25.4	19.3	104.2	160.9	269.1	42.3	44.6	47.5
14	27.4	20.7	123.7	203.2	352.6	43.4	46. 1	49.1
15	29.4	22.1	152.9	249.9	453.3	44.3	47.3	50.5

Table 2 : estimates obtained from statistics based on simulated growth curves. Results correspond to January estimates.

Those estimates are quite different from the length at ages calculated with the von Bertalanffy curves used for the assessments, as shown below in table 3:

Years	Length at the end of the year males	females
0	15	15
1	22.96914764	22.96914764
2	29.89719177	29.89719177
3	35.92014399	33.71336426
4	41.15624711	36.03487095
5	45.70829647	38.11455588
6	49.66565807	39.97760863
7	53.10602297	41.64659488
8	56.09693253	43.14172974
9	58.69710438	44.48112258
10	60.9575852	45.68099641
11	62.92275281	46.75588434
12	64.63118746	47.71880564
13	66.11642919	48.58142341
14	67.40763632	49.35418586
15	68.53015788	50.04645283

6. Conclusion

The direct use for assessment will consist in writing another slicing software than those in use at present which is based on the von Bertalanffy growth curve, and in testing the effect of this new growth model on *Nephrops* stock assessment.

This work has been the subject of a publication submitted to the ICES Journal of Marine Science.

An extension for the Celtic sea is planned, provided that isotopes measurements give results as good as in the bay of Biscay.