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Report of the Benchmark Workshop on *Nephrops* (WKNEPH)

2–6 March 2009

Aberdeen, UK

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

The Benchmark Workshop on *Nephrops* assessment, held in Aberdeen, Scotland from the 2–6 March 2009, addressed the problems encountered while generating TAC advice for *Nephrops* in 2008. These problems arose from different approaches in handling uncertainty and potential bias when using underwater TV surveys to estimate the abundance of *Nephrops* populations in Functional Units (FUs = the subdivisional geographical scale on which *Nephrops* are assessed).

The Workshop focused FUs: 6 (Farn Deeps, Division IV), 7 (Fladen Ground, Division IV), 8 (Firth of Forth, Division IV), 9 (Moray Firth, Division IV), 11 (North Minch, Division VI), 12 (South Minch, Division VI), 13 (Clyde, Division VI), 15 (Irish Sea West, Division VIIa) and 17 (Aran Grounds, Division VIIb).

Experts on *Nephrops* stock assessment and life history, industry representatives, and a panel of three independent, external experts were present. The meeting was chaired by Kevin Stokesbury. The meeting opened with presentations covering the evolution of the *Nephrops* TV surveys, their use and recent developments in analysis and assessment, *Nephrops* life history and information on the fishery.

The first decision for the group was whether the TV survey indices should be used as relative or absolute indices of abundance. Initially the group considered using the surveys as a relative index thereby avoiding the estimation of bias correction factors. The bias for each FU is listed in a Table of Uncertainty. However this still requires some coupling of the survey to absolute TAC advice and no obvious route to making this link could be found. The uncertainty in historical landings information was critically limiting. The group therefore reverted to using the TV index as an absolute index and made initial estimates of the various potential sources of bias. For each survey, each potential source of bias was tabulated and quantified.

Previously the TV surveys were assumed to have the same selectivity as the fishery. A comparison of fishery dependent and independent data in the Irish Sea demonstrated that there was a portion of the population which was physically on the ground and available to fishing gear but does not appear in the sampled catches. These smaller *Nephrops* are capable of constructing their own independent burrows and this suggests that the TV survey likely observed burrows of individuals are considerably smaller than the fishery selects. Using a combination of expert knowledge and on-screen measurements, the group suggested a knife-edge detection selectivity of 17 mm for all areas. This revision of TV survey selectivity required a revision of the sustainable harvest rate. New harvest rates corresponding to fishing at $F_{0.1}$ and F_{max} were calculated for each Functional Unit.

Standard protocols for the handling of TV survey data and the generation of ICES catch option tables were produced and incorporated into the Stock Annexes for each Functional Unit. Research recommendations were provide that should improve the estimates of uncertainty in the next few years.

1 Opening of the meeting

The meeting opened with presentations covering the evolution of the *Nephrops* TV surveys, their use and recent developments in analysis and assessment, *Nephrops* life history and information on the fishery.

2 Adoption of the agenda

The agenda was adopted without question.

3 Background to meeting

Since 2001 there has been a progression of changes in the development of advice on *Nephrops* fisheries. (See text table below).

YEAR	ICES GROUPS	ADVICE BASIS	ADVICE	DEVELOPMENTS
2001	WGNEPH	Indicators / trends Inc XSA &ICA	Average landings	
2002	WGNEPH (a mixture of assessment and study group)	Indicators / trends Inc XSA	Advice for Areas VIII and IXa (FUs 23-31)	
2003	WGNEPH	Indicators / trends Inc XSA &ICA	Average landings	
2004	WGNEPH (a mixture of assessment and study group)	Indicators / trends Inc XSA	Advice for Areas VIII and IXa (FUs 23-31)	Evaluation of Predictions
2005	WGSSDS, WGNSDS, WGHMM, WGNSSK	Indicators/trends including XSA	Average landings	Mixed Fisheries MTAC - Age based VPAs were called into question
2006	WKNEPH (workshop on *Nephrops* maturity)			
	WGSSDS, WGNSDS, WGHMM, WGNSSK	STECF 0.1/TV harvest ratio Indicators / trends Inc XSA (for FUs without TV surveys)	No increase in effort	
2007	WKNEPHTV			Simulation of exploitation. Uncertainty tables in the context of using the survey as relative or absolute
	WGSSDS, WGNSDS, WGHMM, WGNSSK	Where UWTV surveys existed a 15% harvest rate was applied by ICES for most stocks	Predicted Landings -no increasing effort	
2008	WKNEPHBID			Survey evaluation Training, reference material
	WGSSDS, WGNSDS, WGHMM, WGNSSK	UWTV * Harvest Ratio Indicators / trends for FUs without TV surveys	Predicted Landings -no increasing effort	

Fisheries advice was generally based on an average of previous landings prior to 2006. However, for some of the most important/largest *Nephrops* fisheries notably the UK and Irish fisheries in ICES Areas IV, VI and VII, the accuracy of historical landings data prior to 2005 was questioned when new legislation on the documentation of sale was introduced between 2005 and 2007. The new national legislations for these fisheries improved the accuracy of recorded landings figures, but also indicated that the historic landings data were biased (underreported), although the magnitude of the bias was uncertain. As the historical landings data are uncertain this called into question advice that was based on previous landings. This lead ICES and STECF to propose Harvest Ratios (HR) based on the TV surveys, where such were available. There was some variation on what an appropriate HR might be for different stocks. The recent TV survey evaluations indicated that they could provide information on the abundance of *Nephrops* in surveyed FUs. A 2008 review of the WKNEPHTV report concluded that the results of the TV surveys would be useful but might be biased towards overestimating population abundance. ICES expert groups WGNSSK and WGNSDS provided draft advice in 2008 was mainly based on F0.1 harvest rates using the TV surveys as an absolute measure of abundance. The ICES advice drafting groups ADGNS and ADGCSE perceived that there might be differing levels of bias in the TV surveys for different FUs. These differences called into question the basis of the TV surveys as a catch independent method for setting the TACs, and it was not possible to reconcile these views in 2008. Catch advice for 2009 was based solely on recent catches.

This workshop was proposed with the ToR (Annex 2) to determine the most appropriate way to use the available data and to give catch options for *Nephrops* FUs for which TV survey data are available.

4 Comments from external reviewers

The issues leading to rejection of age-structured sequential population analysis as a basis for formulating management advice for *Nephrops* fisheries included bias in reported landings with an intervention effect in 2006–2007 as a consequence of a change in reporting requirements and dissatisfaction with the method of converting length to age for *Nephrops*. The recent approach advocated for provision of management advice makes use of survey-based estimates of standing stock multiplied by an $F_{0.1}$ harvest rate estimated from the fishery catch size frequency distribution. Through simulation it was demonstrated that harvest rate corresponding to $F_{0.1}$ can vary depending on fishery selectivity, growth characteristics, the age-range represented by the survey, and other features, many of which are different for the different *Nephrops* functional units. Although the recent approach applied does not rely as heavily on fishery information (*e.g.* catch (or landings) per unit effort patterns), it does make use of the same average growth-rate patterns used for age slicing to convert the fishery length distribution into age components and assumes the survey-based estimates of standing stock are unbiased and has the same size composition as caught by the fleet. Trawl survey information using smaller mesh than typically employed by the Irish fleet indicated a smaller average size distribution of *Nephrops* on those grounds than generally caught by the fishery. As a result, it is reasonable to hypothesize that the survey estimates of standing stock represent a different size composition than is impacted by the fleet. The robustness of the method for estimation of recent harvest rates relative to $F_{0.1}$ harvest rate requires further testing through simulation and experimental designs to test the hypothesis should be implemented. Estimation of the history of harvest rates by this technique is also influenced by bias in overall catch and biases in the estimates of standing stock from surveys. To the degree possible, experimental designs should be implemented to estimate and adjust for bias. Given lack of observations with which to quantify bias, realized harvest rate estimates should account for a plausible range of bias as identified by expert advice and used to characterize the uncertainty in the estimates. The process used for setting catch advice relative to $F_{0.1}$ (or other sustainable harvest rates), should take account of inter-annual variability and trend in survey estimated abundance, in order to mitigate risks of exceeding the intended harvest rate during the period for which catch advice is provided.

Issues of bias in reporting and variability of length-at-age are not unique to *Nephrops* as analysts providing management advice for other ICES stocks (and stocks worldwide) face similar concerns. Alternatives to age slicing exist which could better accommodate variability of length/age, and modelling formulations have been developed which allow for errors in catch, trends in catchability, or other hypotheses related to fishery and population processes. These are essentially embedded in more integrated statistical models which permit propagating variability of a way which also permits translating that scientific uncertainty into management advice (e.g. probability of exceeding established limit or target reference levels for a given level of TAC), which, in turn, permits more informed decisions on management of the fishery. These approaches can also admit broad array of fishery-dependent and fishery-independent information sets into an overall estimation scheme. The method proposed by Bell (Appendix 5) at this meeting, is movement in this direction and this or similar modelling approaches (e.g. CASAL, MULTIFAN-CL, SS3, etc), which can accommodate information sets with different levels of reliability, should be pursued. Providing there are sufficient data, the bias in key parameters, for instance reporting rates, can also be estimated in such models. As the data available for analysis of *Nephrops* stocks mature (e.g. VMS based catch effort information, longer time-series of consistent TV surveys, etc), application of these approaches would seem to provide an improved basis for providing scientific advice in view of a wide range of plausible hypotheses about the fishery and stock characteristics. Catch and discard length frequencies are currently estimated by port and observer sampling programmes, but the level of observer sampling is currently very low, less than 1% of trips. Because key signals on recruitment are likely to be seen in discards (and in the western Irish Sea in the fine mesh trawl survey) observer sampling rates should be increased substantially.

5 Recent Progress with UWTV

Work has been largely facilitated through the Working Group meetings with progress made in optimizing a common approach to collection and work up of data, as well reducing error and bias. Annual workshops have taken place since 2007.

5.1 2007: WKNEPTV Workshop on the Use of UWTV Surveys for Determining Abundance in *Nephrops* Stocks throughout European Waters

This was the first ICES workshop on the use of UWTV surveys, with participation of all the major UWTV survey groups. The following were addressed:

- Activity, equipment, methods and procedures in use were detailed for all the laboratories concerned (approximately 10 European laboratories).
- The various survey designs in use were reviewed.
- Survey methodologies were described. Counting procedures and methods were in general very similar between most laboratories. Also covered were; internal and external consistency of burrow counting, reduction in tow duration or the counted fraction of the tow, quality control, assurance, and data management.
- Calibration and training were highlighted as areas that needed to be addressed in a future workshop.
- Translating the survey results into abundance estimates and using them in assessments or in the provision of management advice was discussed. The main conclusion was that there are assumptions and potential biases in the surveys. Ideally the surveys should be used to calibrate an assessment that also uses fishery dependent data i.e. landings, discards, effort and length or age structure. In many *Nephrops* stocks, accurate data are not available as a consequence of misreporting, discarding, and limited sampling. In their absence the current approach advocated by some assessment WGs of using a harvest ratio based on the abundance estimate from the survey may need further work addressing some of the accuracy and bias issues, particularly edge effects and occupancy.
- UWTV surveys were promoted for studying both the benthic habitat and *Nephrops* stocks.
- In relation to the comparison of methodologies and sources of bias, a table of uncertainty was constructed based on source, cause, impact, magnitude and how it could be addressed. See Table 7.1, first 6 columns.

5.2 2008: WKNEPBID: Workshop and training course on *Nephrops* burrow identification

WKNEPHBID (ICES 2008e) was convened to address some of the sources of uncertainty in *Nephrops* burrow counting identified by WKNEPHTV (ICES 2007). The group focused on three main areas,

1) Training of personnel unfamiliar with the complexities of burrow counting.
2) Development of training and reference material.
3) Production of reference counts for standardization of counter performance.

- Footage from four main *Nephrops* grounds was viewed (Farn Deeps, Fladen Grounds, Western Irish Sea and the Kattegat), for a common consensus on burrow complex identification,
- Experienced counters went through the footage with less experienced counters in small groups for general training.
- The construction of training material was commenced to comprise, for each area, a general description of *Nephrops* burrow identification, characteristics of confounding burrowing species and still shots of burrow types.
- Reference counts were made for three functional units, FU6, FU7 and FU15 (Farn Deeps, Fladen Grounds, Western Irish Sea) and are now considered the standard against which the relative performance of counters is to be measured. The footage selected covered a range of visibility, *Nephrops* density and species complexes likely to be encountered in each area.

5.3 2009: SGNEPS

The Study Group met to look at progress and the state-of-the-art with respect to moving from relative abundance estimates of *Nephrops* from UWTV to absolute measurements. Progress up and from the Workshop:

- UWTV surveys for 2008 were reviewed.
- The 2008 Reference Material is being used as a standard practice for the main groups to check performance and control drift over time. Different groups use it in slightly different ways; highlighting discrepancies that will require recounts, applying correction factors to individual counters, removing counters from consistently problematical environments (e.g. low visibility, high density), highlighting re-training requirements. A ring test will be completed in 2009.
- Efforts have been made (and will continue) on reviewing previous (historical) estimates in light of better training/protocols/experience.
- Training material has been produced by CEFAS, with materials from other geographical areas still under development.
- Recounting protocols are being revised to reduce time spent on each station and free up time to be invested in recounting stations from previous years to ensure interannual consistency.
- Survey database developments will allow for a standardized minimum output for comparability and/or data exchange.
- Survey areas have been modified for better coverage as a result of new availability of VMS data in conjunction with sediment maps,
- Recent developments were reported on; edge effects (simulations and reworking existing footage), track over the ground (ships track, acoustic sled beacon, counting wheel), variable field of view (lasers and altimeter), water clarity (turbidity meters).
- The Table of Uncertainty from the WKNEPTV report has been updated (see Table 7.1) with the addition of progress since 2007. Some uncertainties have been worked on (see above), but some areas have not (particularly burrow occupancy, burrow size/edge effects, size of individuals) and will need research funding to make progress.
- Some experimental approaches have been used on the use of counts towards stock assessment.

6 Alternative data sources

6.1 Fishery dependent

Fishery dependent data for each FU are discussed in the relevant stock annex.

6.2 Trawl Survey

Northern Ireland (AFBI) has performed *Nephrops* trawl surveys in the Western Irish Sea (FU15) during April and August since 1994. Since 2003 the August survey has been completed immediately prior to the collaborative UWTV survey with the Marine Institute (Ireland) and represents the season of maximum *Nephrops* emergence. In addition to providing time-series data on biological parameters such as sex ratio, maturity and mean size the trawl surveys allow an appraisal of *Nephrops* populations on the ground at the time of the UWTV survey. A fixed grid of trawl stations covering a range of depths throughout the western Irish Sea were established during the early nineties (Figure 6.1) and fished during each survey. Because of the sensitivity of *Nephrops* catchability to environmental factors such as tides, currents and daylight attempts were made to complete surveys at the same time of year and during neap tides in order to minimize environmental affects. Hauls at each station of 30–60 minutes duration and covering a distance of about 2 nautical miles were performed initially by *RV Lough Foyl*e and since 2005 by *RV Corystes.* The gear used was a custom built 20-fathom *Nephrops* trawl with a low headline height (approx 1.5 m) and of nominal mesh size 50 mm throughout. Catch bulk from each haul was quantified by counting baskets filled from the catch and sample baskets were sorted to provide an assessment of species composition. The *Nephrops* in a subsample from each catch were divided into male and female components and the ovary maturity stage of the females noted according to an arbitrary scale (Bailey, 1984; Briggs, 1988). *Nephrops* carapace length frequency distributions for both male and female *Nephrops* were measured to the nearest millimetre below using vernier calipers. The contribution of all bycatch species was quantified and their size compositions measured. Stratified sampling procedures were similar to those used during AFBI groundfish surveys which are coordinated by WGIBTS.

Although catch rates from trawl surveys are very sensitive to environmental factors there were significantly more *Nephrops* caught during August surveys (Figure 6.2) which is attributed to the different emergence rhythms of male and female animals. Ovigerous females remain in their burrows during winter while incubating their eggs. The selective properties of the 50 mm mesh trawlnet used in surveys results a larger proportion of small *Nephrops* being caught than occurs in the commercial fishery which uses nets of 70–80 mm mesh size (Figure 6.3). Temporal data demonstrates constant mean size and sex ratio suggesting that this stock is relatively stable (Figure 6. 4). More detailed examination of spatial data indicates variability of mean size within small geographic areas (Figure 6.5) and supports earlier studies performed from a commercial vessel (Briggs, 1995). As *Nephrops* is a burrow dwelling territorial species which is not known to migrate, it is likely that the observed variation in mean size is indicative of patchy recruitment or differences in growth rate between areas.

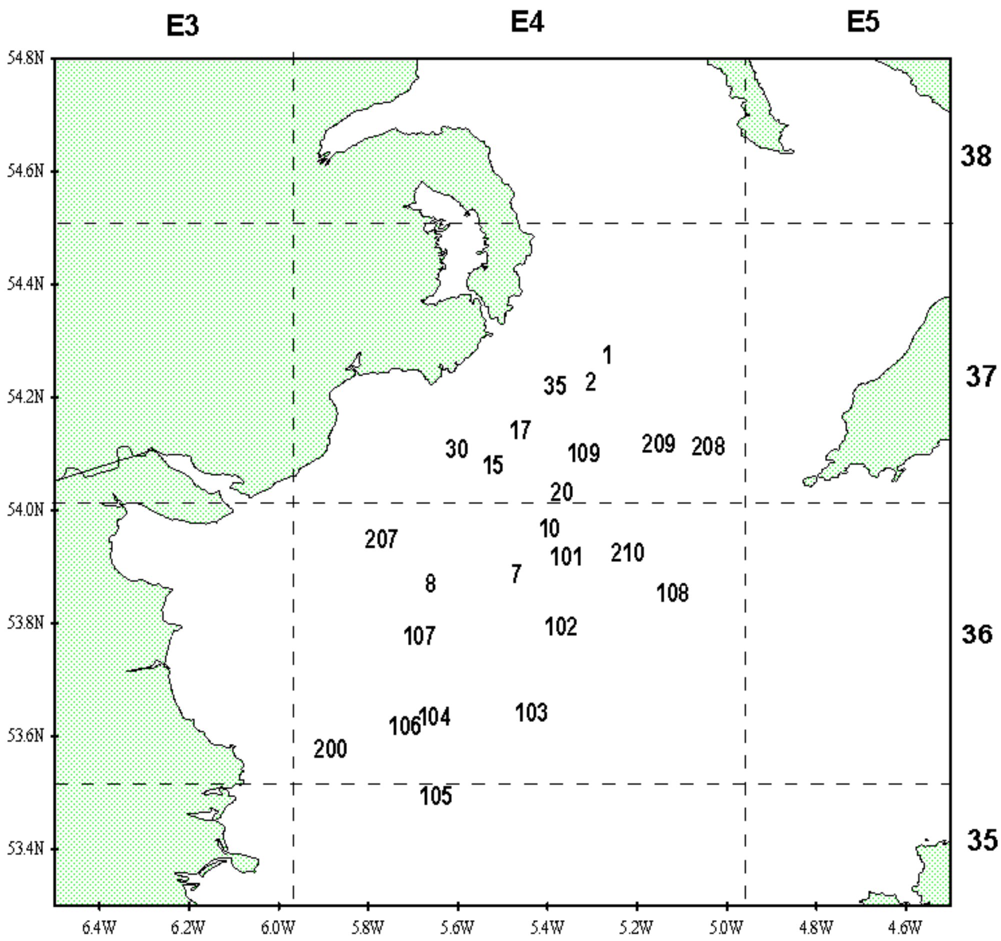


Figure 6.1: Western Irish Sea *Nephrops* stations.

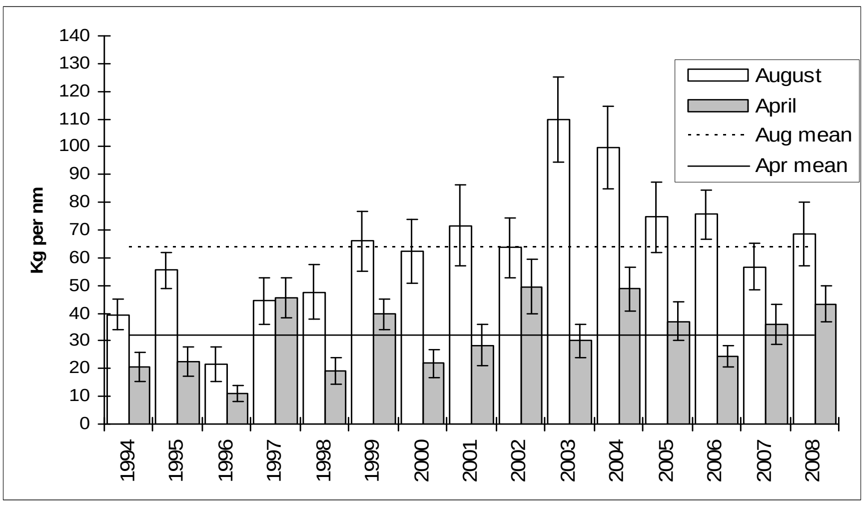


Figure 6.2: Trawl survey *Nephrops* catch rates expressed as kg per nautical mile (error bars = SE).

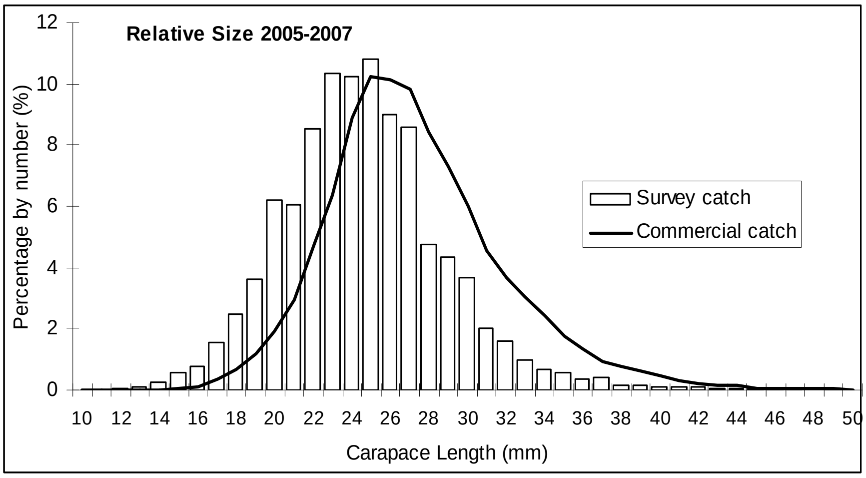
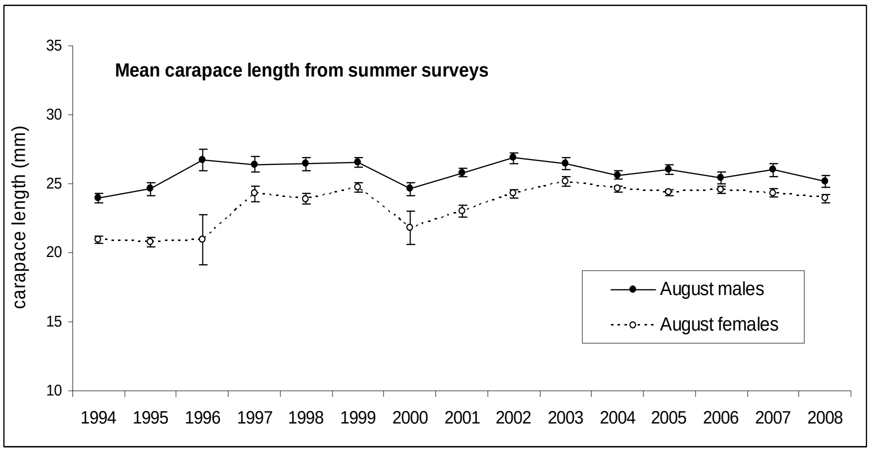


Figure 6.3: *Nephrops* size composition from August surveys 2003–2007 compared with commercial catch length composition over the same period

a)



b)

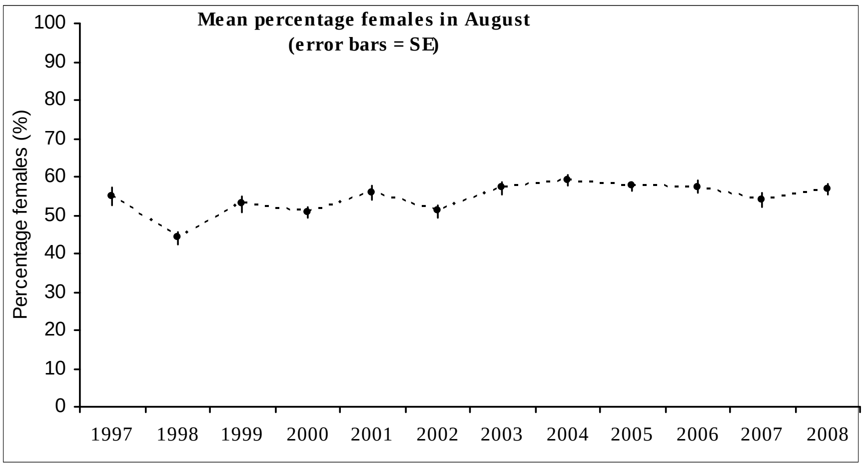
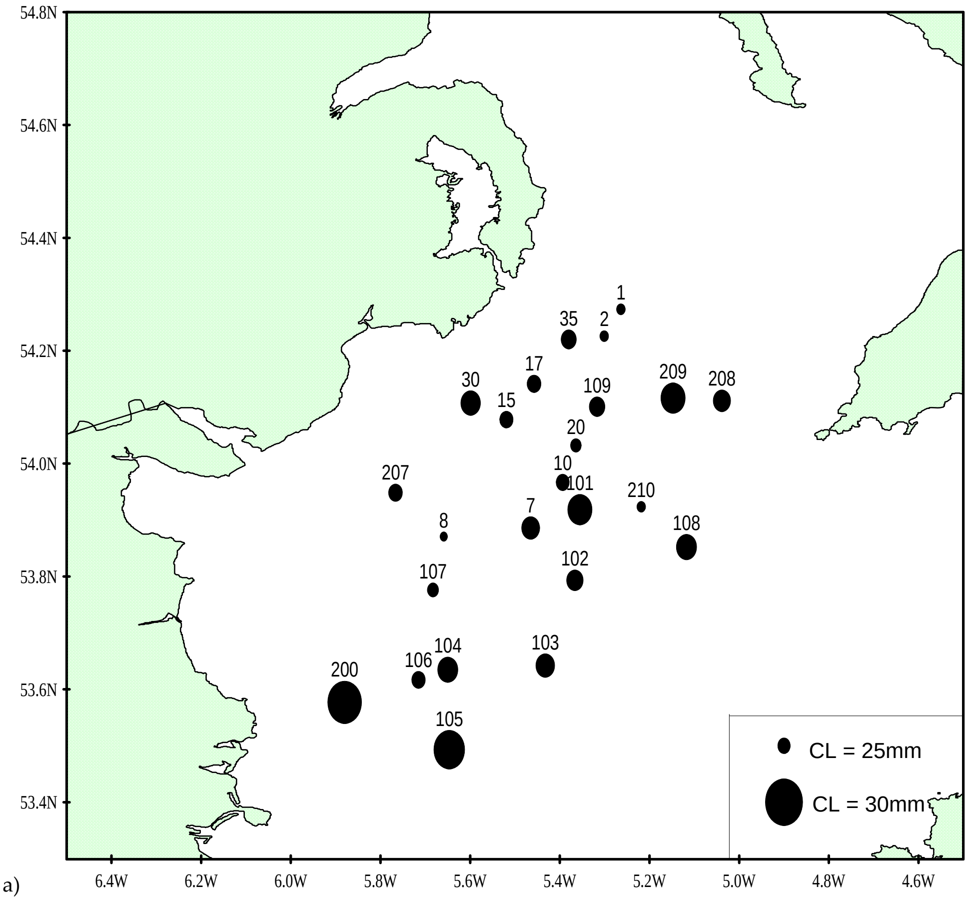
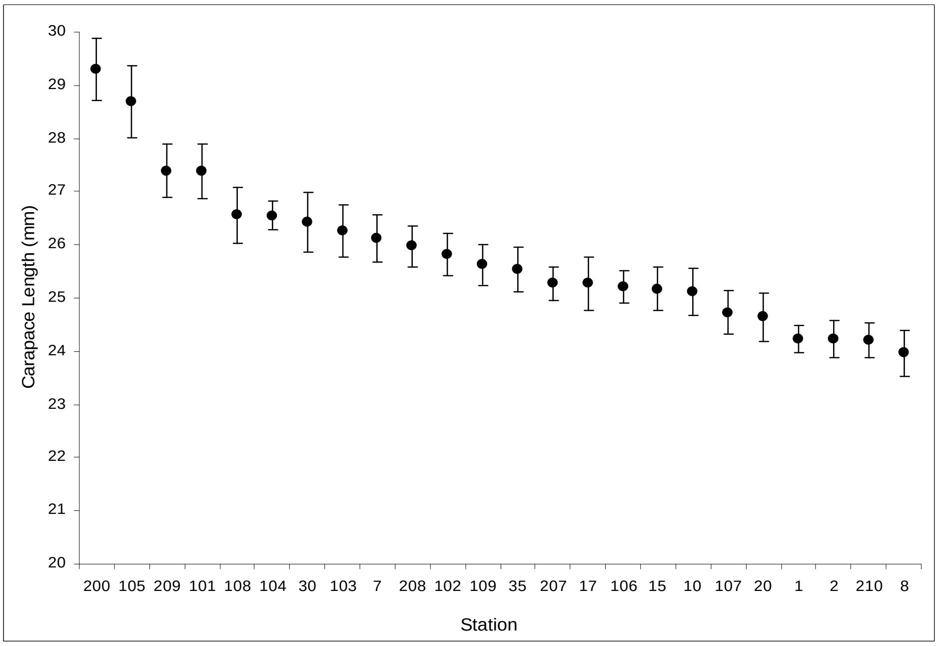


Figure 6.4: Mean carapace length (a) and proportion of female *Nephrops*, (b) in August survey catches (error bars = SE).



a)



b)

Figure 6.5: a) Spatial variability of mean size of male *Nephrops* sampled during August surveys by station 1994–2008 (mean values) and b) the same data ranked by mean size by station (error bars = ± SEs).

6.3 Life history and biological data sources

Nephrops has a wide geographical and bathymetric range. It is exploited from Iceland in the north to the Mediterranean and Canaries in the south, occurring at depths of 20–800 m, sometimes even shallower in Scottish sea lochs. It occupies distinctive burrows in muddy sediments that range from fine-grained muds through sandy muds and muddy sands to muddy gravel. Characteristics such as growth and population density vary in a manner that suggests links with sediment type, food availability and local hydrography. Some populations are characterized by dense populations of small animals: others comprise populations with a lower population density and a wider size range of animals including some of large size.

The life-history characteristics of *Nephrops* vary across its range, for example, in relation to the time of spawning, duration of egg incubation, timing of larval release, duration of planktonic phase, whether eggs are spawned annually or biennially, timing of moulting and mating, etc. Following the pelagic phase (three zoeal stages), post-larvae settle into the seabed, some at least connecting their burrows with those of adults. The lifestyle of juveniles appears to be burrow-oriented: they are poorly represented in catches (even those using fine-meshed gear) until after the pubertal moult. Little is known about the juvenile phase of the life cycle.

Nephrops are caught when they emerge from their burrows to forage. The timing of burrow emergence relates principally to environmental light levels and tidal currents: the control of such behaviour is still insufficiently understood. Ovigerous females normally remain within their burrows so are poorly represented in catches. Therefore, during this protracted period catches are male-dominated. In contrast, when the females re-engage in emergent behaviour after the ovigerous phase, catches may be female dominated. The size- and sex-composition of catches demonstrate geographical, seasonal and diel variations, complicating the investigation of *Nephrops* population parameters.

Reviews on the life history and biological parameters of *Nephrops norvegicus* are provided by Figueiredo and Thomas, 1967; Farmer, 1975; Chapman, 1980; Sardà, 1995 and Bell *et al.*, 2006. These comprehensive works include information on growth (growth curves, growth rates, moulting patterns etc.), reproduction (size at first maturity, reproductive cycle, fecundity, larval development), burrowing and emergence behaviour (diurnal activity patterns, seasonal patterns etc.), food and feeding, predation, mortality, fisheries and management. Data regarding Mediterranean *Nephrops* are collected in a monographic volume of Scientia Marina (Sardà, 1998). Specific information on behavioural and physiological rhythms is summarized in Aguzzi and Sardà, 2008, while Marrs *et al.*, 1996 provide a comprehensive analysis and review of burrow structure data (of *Nephrops* and other species occurring on the same grounds) as well as a general description of the appearance of *Nephrops* burrows on grounds of different sediment type. More area-specific information regarding the latter topic can be found in Afonso-Dias, 1998; Marrs *et al.*, 2000, 2002; Smith *et al.*, 2003; Leotte *et al.*, 2005 and Campbell *et al.*, 2008.

Literature sources regarding life history and biological parameters on a Functional Unit (FU) basis are summarized in Table 6.1.

Table 6.1. Literature sources regarding life history and biological parameters of *Nephrops norvegicus* on a Functional Unit (FU) basis.

FU	Fishery or Stock Area	Maturity		Length-weight relationship			Growth parameters			Mortality		
		Males	Females	Male	Female	Immature female	Male	Female	Immature female	Male	Female	Immature female
1	Iceland South coast		ICES (2000)	ICES (2000)			ICES (2000)			ICES (2000)		
2	Faroe Islands											
3	Skagerrak	ICES (2006a); Table 4.2	ICES (2006a); Table 4.3	ICES (2000)			ICES (2000)			ICES (2000)		
4	Kattegat											
5	Botney Gut - Silver Pit			ICES (2008d)			ICES (2008d)			ICES (2008d)		
6	Farn Deeps			ICES (2008d); Allan *et al.* (2009)								
7	Fladen Ground		ICES (2000)									
8	Firth of Forth		ICES (2006a); Table 4.3									
9	Moray Firth		ICES (2000)									
10	Noup											
32	Norwegian Deep											
33	Off Horn Reef											
11	North Minch	ICES (2006a); Table 4.2	ICES (2006a); Table 4.3	ICES (2008c); Allan *et al.* (2009)			ICES (2008c)			ICES (2008c)		
12	South Minch											
13	Clyde											
14	Irish Sea East			ICES (2008c); Annex 6			ICES (2008c); Annex 6			ICES (2008c); Annex 6		
15	Irish Sea West			ICES (2008c); Annex 7			ICES (2008c); Annex 7			ICES (2008c); Annex 7		
16	Porcupine Bank			ICES (2005)			ICES (2005)			ICES (2005)		

<table>
<tr><th>FU</th><th>Fishery or Stock Area</th><th colspan="2">Maturity</th><th>Length-weight relationship</th><th>Growth parameters</th><th>Mortality</th></tr>
<tr><td>17</td><td>Aran Grounds</td><td></td><td></td><td>ICES (2006b); Table 9.2.6</td><td>ICES (2006b); Table 9.2.6</td><td>ICES (2006b); Table 9.2.6</td></tr>
<tr><td>18</td><td>Ireland NW coast</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>19</td><td>Ireland SW and SE coast</td></tr>
<tr><td>20-22</td><td>NW Labadie, Baltimore and Galley (Celtic Sea)</td><td></td><td>ICES (2006a); Table 4.3</td><td>ICES (2008b); Annex 3</td><td>ICES (2008b); Annex 3</td><td>ICES (2008b); Annex 3</td></tr>
<tr><td>23</td><td>Bay of Biscay North</td><td rowspan="2">ICES (2006a); Table 4.2</td><td rowspan="2">ICES (2006a); Table 4.3</td><td rowspan="2">ICES (2008a); Table 11.4</td><td rowspan="2">ICES (2008a); Table 11.4</td><td rowspan="2">ICES (2008a); Table 11.4</td></tr>
<tr><td>24</td><td>Bay of Biscay South</td></tr>
<tr><td>25</td><td>North Galicia</td><td rowspan="4"></td><td rowspan="3">ICES (2000)</td><td>ICES (2006b)</td><td>ICES (2006b)</td><td>ICES (2006b)</td></tr>
<tr><td>31</td><td>Cantabrian Sea</td><td>ICES (2004); Table 4.1</td><td>ICES (2004); Table 4.1</td><td>ICES (2004); Table 4.1</td></tr>
<tr><td>26</td><td>West Galicia</td><td>ICES (2006b)</td><td>ICES (2006b)</td><td>ICES (2006b)</td></tr>
<tr><td>27</td><td>North Portugal (N of Cape Espichel)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>28</td><td>South-West Portugal (Alentejo)</td><td rowspan="2">ICES (2006a); Table 4.2</td><td rowspan="3">ICES (2006a); Table 4.3</td><td rowspan="2">ICES (2008a); Table 13.2.5</td><td rowspan="2">ICES (2008a); Table 13.2.5</td><td rowspan="2">ICES (2008a); Table 13.2.5</td></tr>
<tr><td>29</td><td>South Portugal (Algarve)</td></tr>
<tr><td>30</td><td>Gulf of Cadiz</td><td></td><td>ICES (2004); Table 4.1</td><td>ICES (2004); Table 4.1</td><td>ICES (2004); Table 4.1</td></tr>
<tr><td>34</td><td>Morocco Atlantic coast</td><td colspan="2">Orsi-Relini et al. (1998)</td><td></td><td>Mytilineou et al. (1998)</td><td></td></tr>
</table>

FU	Fishery or Stock Area	Maturity	Length-weight relationship	Growth parameters	Mortality
	Catalan Sea Alboran Sea Ligurian and N Tyrrhenian Sea				
	Adriatic Sea (FAO Area 37.2.1, GFCM GSA 17 & 18)	Froglia & Gramitto (1979); IMBC *et al.* (1994)	Froglia & Gramitto (1988); Sardà (1998)	Froglia & Gramitto (1988); IMBC *et al.* (1994); Sardà (1998)	Froglia & Gramitto (1988); IMBC *et al.* (1994); Marrs *et al.* (2000)
	Ionian Sea (FAO Area 37.2.2, GFCM GSA 20)				
	Aegean Sea (FAO Area 37.3.1, GFCM GSA 22)	Smith & Papadopoulou (2008)	Mytilineou *et al.* (1998); Smith *et al.* (2001); Smith & Papadopoulou (2008)	Mytilineou *et al.* (1998); Smith *et al.* (2001); Smith & Papadopoulou (2008)	Smith *et al.* (2001))

6.4 Modelling approaches

6.4.1 An age-structured simulation model

The age structured model described here was originally presented at the 2006 meeting of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK; Dobby and Bailey, 2006) then further developed in a WD to the Workshop on the use of UWTV surveys for *Nephrops* (WKNEPHTV; Dobby, 2007) and in an ICES ASC paper (Dobby *et al.*, 2007).

The model is essentially a seasonal age-based simulation model in which males and females (and mature and immature components of the population) are modelled separately. However, it also allows for some of the main biological process to be length dependent by using growth parameters to translate between age and length. The key features of the model are:

- An age range of 1–30+ with recruitment-at-age 1 consisting of an equal number of males and females.
- Mean length-at-age (length of midpoint of age interval) is calculated from a von Bertalanffy growth curve with FU dependent growth parameters with the usual assumption of separate growth parameters for mature female *Nephrops*.
- Maturity-at-length is assumed to be knife-edged with FU dependent transition lengths. The age at which individuals become mature is calculated from the mean length-at-age and the maturity-at-length ogive.
- Weight-at-age is calculated from the mean length-at-age and the appropriate FU dependent length-weight relationship.
- Natural mortality is independent of season, but dependent sex and maturity ($M=0.2yr^{-1}$ for mature females and $0.3yr^{-1}$ for all others).
- Fishing mortality is allowed to vary between quarters and sexes to account for differences in seasonal burrow emergence (while either carrying eggs or moulting, Bell *et al.*, 2006) and seasonal differences in fishing effort.

Fishing mortality is derived from a length-based selection curve (logistic) which is converted to an age-based exploitation pattern on the basis of the von Bertalanffy derived mean lengths-at-age. To incorporate the seasonal differences in fishing effort and burrow emergence, it is written as:

$$F_{s,a,q} = E_q Q_{s,q,a(l)} S_{a(l)}$$

where E_q is a quarterly fishing effort distribution multiplier, $Q_{s,q,a(l)}$ is a catchability multiplier to account for seasonal differences in the availability of males and females (mature and immature) and $S_{a(l)}$ is the age-based selection derived from the length-based selectivity curve. (*s:* sex, *q:* quarter, *a:*age, *a(l):* age derived from length).

This model was originally developed to investigate the robustness of $F_{0.1}$ and associated harvest ratio estimates to factors such as alternative exploitation patterns, timing of survey and assumed age of individuals whose burrows appear in the survey (survey selectivity). This followed the meeting of WKNEPH (ICES 2006) where a number of potential weaknesses with the LCA approach to deriving a combined sex $F_{0.1}$ were highlighted: in particular whether the combined sex yield-per-recruit had appropriately accounted for the likely different exploitation rates of males and females. To facilitate use at this meeting to investigate the sensitivity of $F_{0.1}$ harvest rates to assumptions of different TV survey selectivity at length, some assumptions had to be made about the distribution of lengths-at-age. It was assumed that within each age class, individuals are distributed uniformly across lengths.

Alternatively, the model can be used in non-equilibrium simulations (with stochastic recruitment) to investigate the application of particular harvest strategies. A range of different scenarios were investigated by Dobby *et al.*, 2007 which indicated a relatively low probability of resultant fishing mortality being above F_{max} when applying a harvest ratio of 20% (assuming that only the burrows of individuals aged 2+ were observed by the survey) to a population with moderate recruitment variability. However, if in fact the survey was assumed to be an absolute measure of all individuals aged 1 and above, then there was only a very low probability of F being below F_{max}.

Ahead of this meeting, the model was also used to consider the effect of a number of harvest strategies based on adjusting the current TAC with reference to a relative index of abundance (TV survey); one based on the gradient of the index and the other an interpretation of the harvest rule outlined in the Commission's non-paper. The harvest rule was applied to a population initially in equilibrium, assuming that the current catch levels are precautionary (i.e. a reasonable starting point from which to adjust the TAC according to the rule). A number of initial conditions were investigated (different equilibrium exploitation rate) and demonstrated how dependent the future risk of population depletion (defined as F(male) >2) is on the initial conditions highlighting the importance of initiating the harvest rule at a precautionary level.

6.4.2 SCA

An alternative to the commonly used Length Cohort Analysis (Jones, 1981) was presented to the group as a means of estimating potential reference points while simultaneously directly integrating the TV survey index into the assessment process. Model description and analyses for FUs 6, 7, 8, 9, 11, 12, 13 and 15 are in Annex 5.

7 Uncertainty and potential bias

WKNephTV 2007 compiled a table of factors which would contribute to both uncertainty and potential bias in the absolute estimates of abundance generated by the TV surveys. This "Table of uncertainty" has proven highly valuable for targeting and resolving a number of the issues. Progress against the various sources made by institutes and ICES groups are given in Table 7.1. Each institute and/or survey has described the potential impact of each factor, plus measures employed to minimize their influence and these are listed in Table 7.2.

The uncertainty factors with the greatest potential bias have been estimated for each of the FUs (Table 7.3). The cumulative bias estimate is the overall bias for that survey and is the correction factor to be applied to the abundance estimate in order to make it absolute. The FU specific bias correction factor is now part of the Stock Annex. These bias factors should be re-evaluated at subsequent benchmark groups or where specific changes to survey design or practice are invoked.

Table 7.1. Progress on sources of uncertainty in UWTV surveys.

NO.	USE OF SURVEY	SOURCE OF UNCERTAINTY	CAUSE	IMPACT OF UNCERTAINTY	PROBABLE MAGNITUDE	HOW ADDRESSED	PROGRESS SINCE ICES NEPHTV2007.
1	Relative index of burrows abundance	Field of view	Variability of camera altitude and angle	Noise, but likely to overestimate	Variable but potentially moderate	Measurement of camera altitude or new laser scaling technology	YES. Incoporation of lasers by main teams (CEFAS plans to improve lasers) and/or updated field of view parameters retrospectively (FRS), and related work on edge effects
2		Length of tow	Uncertainty in tow track	Noise	Variable but low, depending on method	Measurement systems	YES. Individual work on ships track, USBL positiioning systems. CEFAS and Marine Institute (MI) now use smoothing filters for positioning data. FRS still use odometer wheel viewed by a camera with good results.
3		Burrow detection	Visibility	Probable underestimate	Variable	Formal acceptability criteria	YES. Work in progress on turbidity sensors (CEFAS, MI and AFBI: use sledge mounted CTDs with a range of sensors including turbidity, FRS: has plans to use independent data loggers in 2009;)
4		"	illumination and camera angle	Probable underestimate	Probably fixed within survey	Identify optimum and maintain consistency between systems	Systems are fixed for survey. MI identified and maintain optimum settings
5		Burrow identification	Confusion caused by other species	Noise, but likely to underestimate at high density, and overestimate in areas with high abunadance of other burrowers	Variable but likely to be low	Training	YES. All teams (regular surveys and new/exploratory surveys teams) participated in ICES formal training WKNEPHBID08. CEFAS, MI, FRS and AFBI have produced Reference Count material for personnel training prior to surveys and for performance evaluation during surveys. CEFAS has produced the first training manual and FRS is producing one now. Reference count and training materials are planned for the Kattegat (Denmark and Sweden) and the deep clear water group (Portugal, Spain, Greece and Ireland) and the Adriatic (Italy and Croatia).
6			Detection of burrow systems	Probably underestimate at high density	Moderate	Knowledge of burrow structure (resin casting and observation)	NO. Although exploratory boxcorer resin casting is planned by FRS in 2009 to study burrow systems of various species

NO.	USE OF SURVEY	SOURCE OF UNCERTAINTY	CAUSE	IMPACT OF UNCERTAINTY	PROBABLE MAGNITUDE	HOW ADDRESSED	PROGRESS SINCE ICES NEPHTV2007.
7		Edge effects	Variability of burrow area, density and field of view	Overestimate	Moderate	Incorporate into workup and identify optiumum field of view	YES. Targetted studies, but still ongoing. FRS has published simulation tests (field of view, sled sinkage burrow size) to develop a Correction Factor while MI have investigated impact of burrow density (Hi, Med, Lo) on edge effects. New edge effects exercise is planned for 2009 with most teams agreeing to participate.
8	Absolute numbers	Burrow occupancy (100% assumed)	Empty burrows and multiple occupancy	Unknown	Moderate	Observation and experimental studies	NO. Although CEFAS has trialed and has plans to continue using landers to collect burrow occupancy and emergence data.
9		Area or boundary uncertainty	Differences between fished area, survey area and population area	Probable underestimate	Probably low, but area specific	Improved information on spatial distribution of population (survey coverage increased) and fishery	YES. Validation of, or modification to, survey areas from incoporation of VMS data and habitat mapping. Still ongoing.
10		Numbers outside survey area	Full population coverage lacking	Underestimate	Unknown, but area specific	As above	YES. Validation of, or modification to, survey areas from incoporation of VMS data and habitat mapping. Still ongoing.
11	Absolute biomass	Size distribution of animals contributing to burrow estimate	Difficulties in population sampling related to burrow emergence	Unknown, but using trawl catch size distributions likely to overestimate (owing to emergence and selectivity issues)	Unknown, gear and area specific, but probably the largest uncertainty	Investigations into emergence, bias caused by gear selectivity and other approaches (e.g.. measuring burrows from still images, although this still includes uncertainty)	NO. Although 1) CEFAS has trialed and has plans to continue using of landers to collect emergence data. 2) FRS has improved stock-specific length-weight relationships but recommendations under review. 3) AFBI has a trawl survey prioir to the UWTV survey and 4) Portugal use UWTV on the survey trawl
12		Sex distribution as above	As above, length weight varies with sex	Noise	Probably low	Trawl data	NO, with the exception of 1) MI now routinely acquire beam trawl samples during UWTV surveys (and planning to use a trawl mounted camera) and 2) Portugal use UWTV on the survey trawl. 3) AFBI has a trawl survey prioir to the UWTV survey

NO.	USE OF SURVEY	SOURCE OF UNCERTAINTY	CAUSE	IMPACT OF UNCERTAINTY	PROBABLE MAGNITUDE	HOW ADDRESSED	PROGRESS SINCE ICES NEPHTV2007.
13		Additional biomass of animals not covered above	Full population coverage lacking	Underestimate	Probably low	Observation and experimental studies	NO.
14		Biomass outside survey area	Full population coverage lacking	Underestimate	Unknown	Improved information on spatial distribution of population (survey coverage increased) and fishery	YES. Validation of, or modification to, survey areas from incoporation of VMS data. Still ongoing.

Table 7.2. Accounting for uncertainty: by area/survey setup.

NO.	SOURCE OF UNCERTAINTY	FARN DEEPS FU6	FLADEN FU7 FIRTH OF FORTH FU8 MORAY FIRTH FU9	NORTH MINCH FU11 SOUTH MINCH FU12 CLYDE FU13	IRISH SEA WEST FU15 IRISH SEA EAST FU14	ARAN GROUNDS FU 17
Relative index of burrows abundance						
1	Field of view	The camera angle and height is kept constant between surveys and the field of view is measured directly by recording an image underwater of a calibration grid lashed between the runners. No account is taken for the sledge sinking and only a subjective account is made when the sledge lifts. An altimeter is now being used on the sledge to record the perpendicular distance between the camera and the seabed. These measurements will be used to check and calibrate the field of view at each station. Consideration is being given to using lasers to project a known field of view onto the seabed with the intention of counting the systems within it. A new sledge, used for the first time in 2008 in the Farn Deeps will allow a greater field of view and Cefas intends to move to a wider field of view which will help reduce the impact edge effects.However to maintain continuity with previous surveys we first intend to calibrate the two different setups before making the commitment.	Camera height and angle has been consistant over all of FRS' UWTV surveys. Variations in the corrective lens angles have been accounted for. This has provided a field of view of around 1m. In softer sediments (e.g. central FU 7 and the Southern Trench in FU 9), the field of view narrows (down to 75 cm in worst case scenarios) as the sledge sinks in to the seabed, unlike in the areas of harder sediment found in FU 8. These variations are accurately calculated using a calibrated alitmeter.	FRS' has acheived a field of view of approximately 1m over all the UWTV surveys. This has been achieved by ensuring the camera is mounted on the sledge at the same height and angle on each occasion. A calibrated altimeter records the variable height the sledge is off the seabed. With this information and the focal angle of the camera and housing lens, the exact field of view is calculated every 3 seconds. The West Coast of Scotland experiences varying sediment densities, and softer sediments (found in the North of FU 13 and sheltered areas of FU 11) cause a narrowing of the field of view as the sledge sinks in to the seabed, whereas much of FU 11 and 12 has more compact sediment, reducing the sinking effect and edge effects.	The camera angle and height is kept constant between surveys. Since 2007 lasers have been used to directly indicate the field of view at the bottom of the screen for the Irish leg. An assumed field of view of 75 cm is used. For the NI leg an assumed field of view is used based on measuring a rope in water. Very soft sediments (~50% of stations) means the sledge does tend to sink in narrowing the field of view by up to 10%. This is partly compensated by an increasing edge effect bias.	The camera angle and height is kept constant between surveys. Since 2007 lasers have been used to directly indicate the field of view at the bottom of the screen which is approximately 75 cm. The sediment on the Aran grounds is relativly firm so sinking is not a issue. An assumed field of view of 75 cm is used and the variability on this is likely to be in the order of ~5%.

No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
2	Length of tow	In the Farn Deeps a USBL positioning system is used to log both the ordinal position of the sledge and ship over the ground for the period of the tow. To account for any noise in the logged positions the track is first smoothed using the spline function in R. The distance travelled is then calculated using spherical trigonometry. Account is taken for any periods along the track where visibility is lost to cloud and lifting.	Length of viewed track is measured by FRS using an odometer mounted at the rear of the sledge. Contact between the odometer wheel and the seabed is monitored by an additional TV camera mounted on the sledge, pointing at the wheel. The picture from this camera is fed to a monitor on the ship, from where the wheel can be raised or lowered depending on conditions to ensure the wheel is in constant contact with the seabed. This system is felt to give an accurate measurement of the distance covered.	Length of viewed track is measured by FRS using an odometer mounted at the rear of the sledge. Contact between the odometer wheel and the seabed is monitored by an additional TV camera mounted on the sledge, pointing at the wheel. The picture from this camera fed to a monitor on the ship, from where the wheel can be raised or lowered depending on conditions to ensure the wheel is in constant contact with the seabed. This system is felt to give an accurate measurement of the distance covered.	The distance over ground (DOG) has been calculated using a USBL on the sledge for the majority of stations since 2005. Prior to that ships DOG was used. Comparison with recent USBL data demonstrates that there can be significant difference between the ship and sledge when the vessel cannot tow in a straight line as a consequence of wind and tide. It is not possible to retrospectively correct for this but it may be worth down weighting suspicious stations in the overall estimates. To account for any noise in the logged positions the track is first smoothed using the spline function in R.	The distance over ground (DOG) has been calculated using a USBL on the sledge for the majority of stations since 2005. Prior to that ships DOG was used. Comparison with recent USBL data demonstrates that the variability is low~2%. To account for any noise in the logged positions the track is first smoothed using the spline function in R.
3	Burrow detection	Poor visibility could affect the number of burrow systems visible to the counter. To remove some of the subjectivity when choosing whether the quality of the footage is good enough, turbidity meters are used on the sledge for the Farn Deeps survey. The logged data will be compared with the video footage and could be used to score the quality and to set limits as to what visibility is acceptable.	Annual surveys have been timed to coincide with traditionally better weather conditions and reduced fishing activity. FU 7 provides some of the best water clarity, unlike the western reaches of FU8. Stations experiencing poor visibility as a consequence of organic matter and seabed disturbance are either repeated or extended in order to collect 10 minutes of viable footage. To date a 5 point reference key stages the water clarity. Trials with a turbidity meter are to take place in 2009.	Euphausids, seapens, seabed sediment disturbance and demersal species can obscure visibility in these FUs. In an attempt to gain acceptable footage, tows can be extended or the site is revisited later in the cruise. Minimal particulate disturbance is usually experienced in FU's 11 and 12, but organic interference is more frequent in FU 13. FRS has a 5 point key to grade visibility but following trials in 2009, this should be replaced by a turbidity meter.	Visibility can be poor despite timing the survey during neap tides. Most stations with poor visibility are repeated but in several parts of the ground the visibility can be persistently poor.	Visibility is generally good except when trawlers are close by. Often these stations are repeated later.

No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
4	Burrow detection	Lighting relative to camera angle has been consistent between surveys and maintained at an optimum. Any change to the camera setup may require an adjustment to the lighting. The aim is to project light to provide the contrast needed to make the burrow entrances apparent irrespective of the way they are facing.	Following trials in 1990s, an optimum height and angle for the video camera has been established and maintained for Scottish FU's. Although the specification of the lamps used has varied over time, their positioning has remained the same, providing sufficient illumination of the viewed area and creating the characterisistic crescent shadows at *Nephrops*' burrow entrances.	Following trials in 1990s, an optimum height and angle for the video camera has been established and maintained for Scottish FU's. Although the specification of the lamps used has varied over time, their positioning has remained the same, providing sufficient illumination of the viewed area and creating the characterisistic crescent shadows at *Nephrops*' burrow entrances.	Camera and angle has been consistent over time for the Irish survey. Lighting changed in 2008 no impact is expected. The camera and sledge on the NI leg has improved the quality of the footage significantly.	Camera angle has been consistent over time. Lighting changed in 2008 no impact is expected. In 2003 a digital camera was used and this reduced the quality of footage.
5	Burrow identification	Other burrowing organisms are prevalent in a few areas of the Farn Deeps and can cause some confusion. Reference material, including videos, has been collated and a training manual created. A programme is being developed to ensure each of the personnel involved in the counting is trained and re-trained and continually assessed. Their performance against reference sets prior to the survey can help the survey manager to set the level of their involvement in the recounts.	The frequency of non-*Nephrops* burrows varies greatly between FUs, as does the complex design and appearance. A peer reviewed reference set of videos from FU 7 are used in conjunction with a training manual, training sessions and assistance from an experienced verifier to educate and re-enforce burrow identification and protocols on a regular basis.	*Nephrops* burrows in FU's 11 and 12 tend to be similar in shape and size, with low to medium densities of other non-*Nephrops*' burrows; whereas FU 13 experiences high burrow densities of both *Nephrops* and other fauna. Training, protocols and expert guidance greatly improves burrow identification and accuracy. In preparation for 2009 cruises, reference material for FU's other than FU 7 will be made available, along with reference counts.	Densities of *Nephrops* and other burrowing species is very high making identification problematic. Training has been instigated in advance of the survey in recent years. Reference footage has been collated. A programme is being developed to train counters and assess their performance. Recounting previous footage in FU15 2003 and 2004 has demonstrated that counting crieria has changed. The footage for those years needs to be reviewed and interim years should also be checked.	*Nephrops* is the predominant species on the Aran grounds so confusion with other species is not a major issue. In the smaller Galway Bay patch there are many different burrowing species and mis identification could be a bigger issue. Reference footage has been collated. A programme is being developed to train counters and assess their performance.

No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
6		Identifying a burrow system is dependant on the counter seeing a number of features or ‘signatures’ typical of *Nephrops*, which includes the crescentic burrow entrance. Diver observations in shallow water Lochs have identified both atypical burrow systems created by *Nephrops* or other organisms creating systems similar to *Nephrops*. The number of entrances a system has also may not be clear and could lead to a misinterpretation of the number of the systems within the same field of view. The incidence of this in the Farn Deeps is not known but any bias would be expected to underestimate the number systems in high densities.	Burrow entrance and complex design can vary geographically, with large apparently well defined complexes in Fladen compared with denser, smaller complexes in the Firth of Forth. Based on this, and the guidance which ensures that only if a verifier is certain the complex belongs to a *Nephrops* should it be counted, t is more likely that some burrows maybe missed in the high density areas, especially as entrance orientation may make them difficult to identify.	Resin casting has been carried out in FU 11 in the past, but only at diveable depths and in *Nephrops* populations which are unlikely to be representative of all Scottish stocks. Present UWTV surveys work in deeper waters, and in areas where there are high (FU 11 and 12) to exceptionally high densities of burrows (FU 13). These complexes have not yet been mapped, although plans are underway to address this in 2009.	There is no information on burrow structure here. There are probably some burrows that are missed because of their orientation and the tendency to not count if in doubt.	There is no information on burrow structure here. There are probably some burrows that missed because of their orientation and the tendency to not count if in doubt.

No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
7	Edge effects	Edge effects can lead to an overestimate of between 4–55%, depending on the size of *Nephrops* burrow systems and the field of view of the TV camera (Campbell *et al.*, in press.). This probably contributes to one of the biggest uncertainties in the Farn deeps survey. Cefas is intending to move to a larger field of view which could reduce this effect. Cefas are also intending to collect images on each survey that can be used to measure relative burrow system size that would be used to correct this effect. Reanalysing video from previous surveys will provide the factors that can be used to correct historical abundances.	The impact of edge effects varies between FUs, with large complexes in FU 7 (~45%) increasing the overestimation effect and less overestimation of abundance in the areas with smaller burrow complexes such as FU 8 (20–25%). FRS utilizes a wide field of view, which in turn reduces the edge effects.Campbell, *et al.*, (in press) provide a correction factor which can be applied to adjust for edge effects.	Although variable, edge effects are reduced in area VI compared with Area IV, as burrow complexes tend to be smaller, most noticeably in FU 13 (~19%). This would result in lowering the overestimation of abundance. However it is proposed that in 2009 FRS review historical footage using an alternative method to establish the effect, and compare these results to the modelled outcomes provided in 'Investigating and mitigating uncertainties in the assessment of Scottish *Nephrops* norvegicus populations using simulated underwater television data', N. Campbell, *et al.*, in press	The edge effect bias is probably in the order of 20–30% as a consequence of the presence of smaller burrow systems. This needs to be examined further.	From observations the diameter of visible burrow systems suggest this might be an overestimation bias in the order of 30–40% but this has not been confirmed.
Absolute numbers						
8	Burrow occupancy (100% assumed)	The assumption for the Farn Deeps is that one *Nephrops* occupies one complex. To investigate this assumption Cefas have been trialling a 'lander' that will be placed over an identified burrow system and will record time-lapse video for a period covering at least one tide. This should provide information on occupancy and emergence behaviour.	At present it is assumed that one *Nephrops* occupies one complex, in all FU's. There are no plans in the near future to investigate this further in Area IV	At present it is assumed that one *Nephrops* occupies one complex, in all FU's. There are no plans in the near future to investigate this further in Area VI.	There is no information on occupancy. Fine scale VMS data gives information fishing activity and using a guestimate average net spread implys that the ground is swept around 7 times per year.	There is no information on occupancy. Fine scale VMS data gives information fishing activity and using a guestimate average net spread implys that the ground is swept around 6 times per year.

NO.	SOURCE OF UNCERTAINTY	FARN DEEPS FU6	FLADEN FU7 FIRTH OF FORTH FU8 MORAY FIRTH FU9	NORTH MINCH FU11 SOUTH MINCH FU12 CLYDE FU13	IRISH SEA WEST FU15 IRISH SEA EAST FU14	ARAN GROUNDS FU 17
9	Area or boundary uncertainty	The Farn Deeps survey area was mapped out in 1996 after consulting fishers and British Geological Survey sediment charts. When the 2006 VMS data became available this was used in 2007 to check the limits to the survey area. The fishing tracks of known *Nephrops* trawlers during the fishing season was demonstrated to fully occupy and stay within the limits of the survey area.	Discrepancies between data from particle size analysis samples taken on TV surveys and BGS maps indicate the BGS maps may not be wholly accurate. Historically the survey areas have been based on BGS data. In January 2009 an exploratory TV survey with spatial coverage based on VMS data suggested differences between the BGS defined survey area and stock distribution in FU9. This highlighted the need for further work in other FU's and that using VMS data may provide a better predictor of *Nephrops* distribution than BGS. This work will be continued in 2009.	The work carried out in January 2009 in FU9 confirmed that survey boundaries need to be re-examined according to VMS information. It is likely that this will have greatest effect in FU 11 where the survey area is currently less than the area of fishing activity as demonstrated in the VMS data. This will be investigated further in 2009.	Not a major issue. There are smaller patches outside the main trawled area fished by creeks but these do not account for much of the landings.	This is not a issue on the main Aran Grounds. There is uncertainty about the boundaries of the smaller *Nephrops* patches i.e. Slyne Head and Galway Bay.
10	Numbers outside survey area	As above	As above	As above	As above	As above
Absolute biomass						

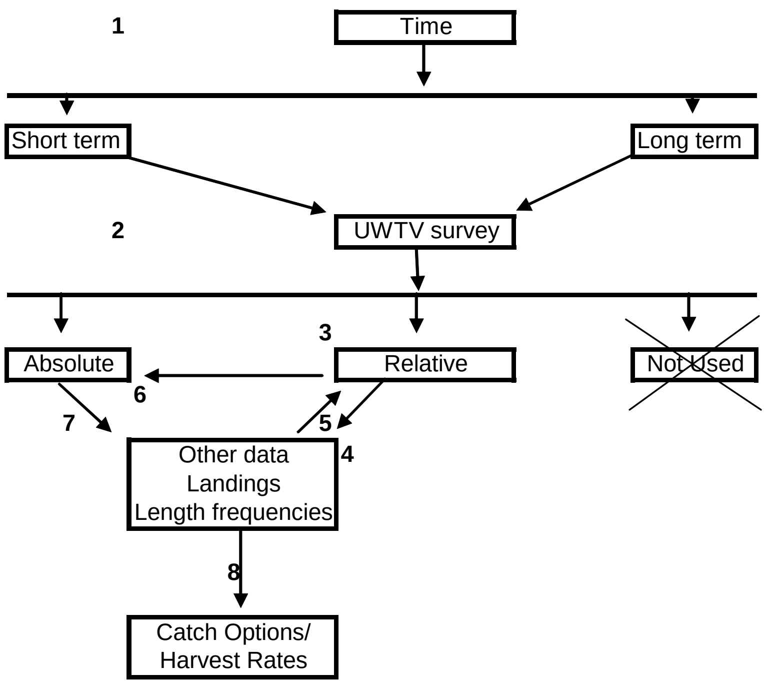
No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
11	Size distribution of animals contributing to burrow estimate	The harvest ratio approach requires the abundance estimate to be converted to a biomass. A rolling three year average LFD of the removals (based on samples from commercial catch samples (landings and discards)) has been used to represent the Farn Deeps burrowing population in the TAC year. If burrows of animals are being counted that are not fully represented in the length distribution then the final estimate is likely to be biased. The assumption is implicit that the selectivity of the commercial trawls matches the selectivity of the counter. The impact of this is unknown.	For all trawls in Area IV, sex and carapace length frequency data are recorded. In more recent surveys in addition to these measurements, further morphometric data has been recorded which includes whole and tailed weights. FRS is currently reviewing catch data which has been collected on previous UWTV surveys to analyse the length weight relationship by sex and functional unit within Area IV, and to compare these LFD's to commercial catches from comparable areas.	For all trawls in Area VI, sex and carapace length frequency data are gathered. In more recent surveys in addition to these measurements, further morphometric data has been recorded which includes whole and tailed weights. FRS is currently reviewing catch data which has been collected on previous UWTV surveys to analyse the length weight relationship by sex and functional unit within Area VI, and to compare these LFD's to commercial catches from comparable areas.	Survey trawl length distributions at survey time are significantly different from LFD from commercial catches. Selectivity of UWTV burrows counted is not known. Direct measurments of size on the UWTV survey has not yet been attempted.	Beam trawl length distributions at survey time in 2006 and 2007 are significantly different from LFD from commercial catches. Direct measurments of size on the UWTV survey has not yet been attempted.
12	Sex distribution as above	The size distribution is converted to a biomass using current weight length coefficients, and the sex ratio in the removals is assumed to be representative of the visible population. The length weight relationship is different for each sex so as above above if the sex ratio of the burrow systems is not represented in the catch there may be bias in the biomass estimate. The impact of this is unknown.	It is known that the length weight relationship for *Nephrops* is sex specific. FRS is currently reviewing catch data which has been collected on previous UWTV surveys to analyse the length weight relationship by sex and functional unit in Area IV. The sex distribution is assessed from landings and observer trip data and presented at WGNSSK.	It is known that the length weight relationship for *Nephrops* is sex specific. FRS is currently reviewing catch data which has been collected on previous UWTV surveys to analyse the length weight relationship by sex and Functional Unit in Area VI. The sex distribution is assessed from landings and observer trip data and presented at WGCSE.	There may be differences in size distributions and sex ratio across the ground. The impact is unknown.	There may be differences in size distributions and sex ratio across the ground. The impact is unknown.
13	Additional biomass of animals not covered above	Within this functional unit there appears to be very little *Nephrops* fishing outside the survey area however the VMS data are limited to vessels greater than 15 m.	FRS is not undertaking regular work in Area IV to address this issue at present, although FU 10 (Noup) and Devils Hole (Management Area H and I) have been surveyed opportunistically in the past.	FRS is not undertaking regular work in Area VI to address this issue at present, although Stanton Banks (Management Area C) has been surveyed opportunistically in the past.	Not an issue	Not an issue

No.	Source of uncertainty	Farn Deeps FU6	Fladen FU7 Firth of Forth FU8 Moray Firth FU9	North Minch FU11 South Minch FU12 Clyde FU13	Irish Sea West FU15 Irish Sea East FU14	Aran Grounds FU 17
14	Biomass outside survey area	The survey area has been checked against VMS data from known *Nephrops* trawlers during the 2006 spring and winter fishery. In this functional unit there is very little apparent fishing outside the survey area.	As discussed in point 9, the survey area based on BGS data appears to be smaller than that covered by the VMS data in FU 9 which may mean that biomass would be greater that at present estimated.	VMS plots have demonstrated fishing effort extends outside the present survey area for FU 11, which would imply an underestimate of stock biomass in that area. This will be addressed in future surveys, and the approach extended to FU 12 and 13, although fishing effort in FU 13 is more restricted as a consequence of the proximity of land to the fishing, which should minimize this issue. No work at present is being conducted to compare VMS effort between that which lies within and outwith the historical survey area.	Not an issue	Not an issue

Table 7.3. Bias estimates by source and FU. Cumulative bias estimate is now in each Stock Annex.

FU	Area	Edge effect	detection rate	species identification	occupancy	Cumulative bias
6	Farn Deeps	1.3	0.85	1.05	1	1.2
7	Fladen	1.45	0.9	1	1	1.35
8	Firth of Forth	1.23	0.9	1.05	1	1.18
9	Moray Firth	1.31	0.9	1	1	1.21
11	North Minch	1.38	0.85	1.1	1	1.33
12	South Minch	1.37	0.85	1.1	1	1.32
13	Clyde	1.19	0.75	1.25	1	1.19
15	Irish Sea West	1.24	0.75	1.15	1	1.14
17	Aran	1.35	0.9	1.05	1	1.3

8 Methodology for determination of stock status



Flow chart of decisions based on Terms of Reference for Benchmark Workshop on *Nephrops*, with UWTV surveys (Aberdeen, UK, 2–6 March 2009).

This flowchart describes the steps and decisions followed by the working group to achieve the first Term of Reference. The first term of reference states:

"Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the Text Table below. The evaluation shall include consideration of fishery-dependent, fishery-independent (in particularly UWTV surveys), and life-history data currently being collected for use in the current assessment work and the proposed assessment."

The steps taken were:

1) Divide time into short-term, representing immediate decisions, and long term, future decisions that will have more information available. The group focused on the short term as the ToR states.

2) The group focused on the use of the Underwater T.V. (video based) dataset.

3) After review the three UWTV protocols conducted by England, Scotland and Ireland, and discussing the procedures, errors, and biases the working group debated using the UWTV survey as a relative survey (i.e. comparable with itself but not producing a number or biomass of *Nephrops* per unit area). These concerns are detailed in the Table of Uncertainty (Table 7.1) and in the description below.

4) The group then discussed the implications of treating the UWTV data as a relative survey taking agreed or proposed management plans into account for the stocks using the other available fisheries and life-history data.

5) As described below the combination of the UWTV relative indices and the lack of a landings data time-series (data from landings are only reliable for 2006 and 2007) resulted in the group being unable to provide a means of estimating historical Harvest Rates or Catch Options.

6) The group then considered using the UWTV survey data as an absolute estimate of *Nephrops* abundance provided that biases were estimated for each of the uncertainties. These biases were compiled based on preliminary experimentation, simulation models and expert opinions (Table 7.3).

7) The size frequency information from the fishery landings and from the independent fishery trawl survey conducted by the Irish and Northern Irish were examined and incorporated into simulation models with the UWTV survey data as an absolute estimate.

8) Using the UWTV as an absolute estimate permitted the use of $F_{0.1}$ as a proxy and the estimation of harvested rates and catch options (refer to the section below for a complete description).

8.1 Survey as a relative index

The workshop considered that using the surveys as relative indices would not provide a sufficient assessment of the stock without consideration of other information on stock dynamics. The key concerns about using an index of abundance as the sole piece of information for an assessment were the inability to determine an appropriate level of harvest using explicitly derived harvest rates, to determine appropriate reference points, to understand the relationship between changes in indices and changes in harvest rate and to understand other key aspects of *Nephrops* population dynamics such as recruitment. These issues would be solved were the index to be used in an assessment framework that incorporated other information, such as the SCA model presented at the workshop, integrated assessments such as CASAL and StockSynthesis, or indeed assessment models used by ICES in the past, and was able therefore to estimate a survey *q*. Unfortunately, the same central issue that led to the abandonment of the XSA assessment uncertainty about historical catches, will remain a confounding factor for multiyear assessments for some time to come.

Any harvest control rule that used an index alone would have to be robust to these uncertainties and, particularly would have to be able to determine a TAC in the absence of an explicit application of a harvest rate to stock size. The harvest control rules outlined in the Commission’s non-paper were considered to be inappropriate to *Nephrops*, because they would ignore long-term trends of less than ± 20% pa. which have previously been seen in *Nephrops* and would, further, assume that recent catch levels are precautionary? This is not an appropriate assumption given the apparent declines in TV survey index in Area VIa which follow the increases in catch and quota in 2006 (see below). The current management practice of disregarding the spatial structure (FUs) and giving whole-division TACs results in effort disproportionate to stock level at the FU level.

Relating the Commission’s rules to a fixed reference point (for instance using a rule operating on ± 20% change in index from a reference index rather than the most recent indices) and with allowance for a greater reduction in TAC than 15% to allow for stock rebuilding, would potentially solve this problem and could be used as an index based control rule, but some knowledge is essential to understand what TV survey reference year would be appropriate (i.e. would relate to a precautionary target reference point, equivalent to Bpa) and currently this knowledge is lacking.

Taking all these issues into consideration, the workshop concluded that using the surveys as relative indices did not take all available information into account and was unlikely to provide sufficient precaution at this time.

8.2 Survey as an absolute index

The workshop considered that use of the TV surveys as absolute estimates of biomass, without explicit consideration of the bias associated with the surveys, would not be a sufficient approach. Experience with other fisheries (e.g. NEA mackerel) has demonstrated that while biases in survey results may sometimes balance themselves out, the assumption of continuing balance is risky and ill-advised.

In 2005 the MHSAWG evaluated the assessment for mackerel in the context of biased catch and survey indices. The fishery information on NEA mackerel is similar to *Nephrops* in as much as the catch data prior to 2006 is acknowledged to be in error as a consequence of underreporting of landings. The mackerel assessment also depends on a short time-series of single value surveys. For mackerel, the survey is an egg survey giving estimates of numbers of females, through estimates of fecundity and atresia, and is usually expressed as SSB. As with the *Nephrops*, there is potential for bias in the survey. MSHAWG evaluated the use of the survey in the ICA assessment comparing the use of the survey as either a relative or absolute index of abundance. They evaluated the use of the survey in the ICA assessment for estimating stock biomass and mean fishing mortality for conditions of underestimation of catch and negative bias in the survey, but the results are probably applicable for positive survey bias as well. This study demonstrated that if the bias was less than 15% it was preferable to use the index as an absolute measure, if however, the bias exceeded 15% use of the survey as in index gave better management information.

In VIa there has been a decrease in survey estimate across all three functional units in 2007. This is coincident with an increase in advised Harvest Ratio (to 20%) and subsequently landings. The decrease in *Nephrops* abundance may be linked to either a reduction in recruitment levels and/or the actions of the fishery.

Taking explicit note of the likely biases in the surveys may at least provide an estimate of absolute abundance that was more accurate but no more precise. The workshop analysed key bias contributions for each of the FUs (Table 7.1.). Overall these suggest that in order to be used as absolute estimates of biomass within an assessment the survey data should be adjusted, on an individual FU basis, for the combined bias estimated in the Table.

A similar correction is required to harvest rates. Harvest rates in the North Minch, South Minch and Clyde, calculated for 2006 and 2007 when catches are anticipated to be more accurately reported (after the implementation of the buyers and sellers scheme) have been at or above 20% in these two years, are coincident with a reduction in the TV survey estimate. Although a causal link between the increase in catch limit in these FUs and the reduction in TV survey estimate is not proven, these coincident events provide at least some evidence these harvest rates are too high for these FUs. On the other hand, the Firth of Forth abundances appear to remain stable at harvest rates greater than 20%. FU6 has experienced a lower harvest rate and the TV survey index has declined to the lowest observed level commensurate with a decline in the fishery. Other FUs, with harvest rates below 20%, appear to have stable TV survey trends. Therefore, in a similar way to the bias correction for the TV survey estimates, harvest rates should be applied individually to FUs.

Recommendation: Combining the stock harvests rates from specific grounds within a Functional Unit to produce a TAC that is then allocated without spatially explicate harvest requirements will continually result in some areas being overfished. This is not a sustainable approach and should be reconsidered.

9 Agreed methodology for production of catch options

9.1 Step process for generation of catch option table in WG reports

The group formulated an eight step process for the generation of catch option tables for each FU which has a TV survey.

1) Survey indices to be worked up annually. The methodology for raising up the index is not specified as the various surveys are suited to different raising procedures (e.g. geostatistics or stratum- based raising). As these indices are to be produced annually there is the potential that ICES could move to the provision of catch advice for *Nephrops* on an annual basis.

2) Adjust index for bias. The stock annex for each FU will contain a table of estimates for the major potential sources of bias (see Section 7). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

4) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

5) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

6) Multiply the survey index by the harvest ratios to give the number of total removals.

7) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_{l} N_L}{\sum_{l} N_L + \left(\sum_{l} N_D \times S_D \right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

8) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

			Implied fishery	
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

9.2 Assumptions regarding survey selectivity

Previously there had been the implicit assumption that the UWTV surveys shared the same selectivity as the fisheries in the various functional units. The Workshop considered this to be unrealistic because it would imply different selectivities for the same survey equipment and that burrows of individuals of up to 30 mm carapace length went undetected in some instances. There was considerable debate within the Group regarding the likely range of survey selectivity (i.e. Carapace L50 for detection of the corresponding burrow). There are technological limitations on the smallest burrow entrance that could be observed corresponding to pixel size and MPEG4 compression used in the DVD footage collected. The diameter of the main chambers of *Nephrops* burrows are approximately the same as the carapace length, however the entrance to the burrow is typically flared thus increasing the likelihood of detecting the burrows of small individuals. The Group consensus was that survey selectivity had an L50 of 17 mm (knife edge selection with a likely detection range of 15–20 mm). Further experimental work could be undertaken to further refine this estimate.

The change in perception of survey selectivity resulted in the need to revisit harvest ratios, particularly the harvest ratios equating to the candidate reference points $F_{0.1}$ and F_{max}. The revised selectivity estimate means that the TV survey is counting individuals of a size not available to the fishery. The proportion of the perceived stock which is available to the fishery therefore becomes smaller and the observed harvest ratio reduces accordingly. Correspondingly the harvest ratio relating to any candidate reference points would also need to be revised. Two modelling approaches were used to derive harvest ratios equating to the candidate reference points under the new assumption of survey selectivity (see Section 6.4). Both approaches used the same growth, maturity and fishery selectivity data and were cross checked for consistency in the determination of the candidate reference points. The different assumptions in the models governing the length distributions at the time of the survey resulted in different harvest ratios for the given values of $F_{0.1}$ and F_{max} (Table 9.1 and Figure 9.1). Both modelling approaches appear to be reasonable simplifications of a complex system and as such there is no *a priori* reason to believe that either model is more correct than the other. The Group therefore decided that, for each candidate F-reference point, the mean harvest ratio between the two approaches should be taken for the point estimate for that FU (Table 9.2). It is proposed that as re-evaluation of $F_{0.1}$ and F_{max} will only be undertaken at every benchmark meeting, the associated harvest ratios will also remain constant. The implicit assumption here being that the selectivity of the fishery will not change in the intervening years.

9.3 Assumptions regarding discard proportion

In order to produce the number of individuals landed from the number of removals it is necessary to account for discarding. The proportion of individuals discarded in any year will depend upon a number of factors. Increased recruitment will result in a larger proportion of undersized *Nephrops* and therefore a higher discarding rate. Conversely a poor recruitment will lead to a lower discarding rate. Changes in F will also change the discarding rate; in an equilibrium situation, higher rates of F will produce higher discard rates and vice versa. What is required is an estimate of discarding proportion in the TAC year, however at present there is no mechanism for predicting this and we must rely upon some historical discard estimate.

Using the discard rate calculated at the time of the benchmark assessment restricts the ability of the TAC to follow changes in recruitment level. If a large recruitment enters the system and the burrow count rises, the total predicted removals (in number) rise. Applying the equilibrium discard rate will underestimate the discarding and therefore recommend a higher landing level finally resulting in a fishing mortality which exceeds the expected level. Using the most recently observed discard level does not necessarily improve the situation. There is a 2 year lag between observation data and the TAC to be determined, during which *Nephrops* will have moved through the discarding size and into the main fishable population. A large recruitment event in year t-1 would result in higher levels of discarding and would feed through to a lower landing rate in year t+1 resulting in the fishing mortality target being undershot. Of more concern to stock management, a poor recruitment in year t-1 would result in lower observed levels of discarding and therefore an increased landing component in year t+1. The net result of this would be a significant overshoot of the fishing mortality reference targets.

Interannual changes to the discard pattern resulting from changes in F are somewhat compensated for by the model. An increase in F would increase discarding and therefore feed through to a lower landing proportion (and vice versa). Long term changes in recruitment (i.e. regime shift) would take at least three years to become apparent and therefore the use of the benchmark discard rate would be appropriate in this case.

Given the lack of an obviously more appropriate assumption it was agreed that the discard rate should be fixed at the value calculated at the benchmark assessment. Further work on the impact of changes in discarding rate upon the resulting TAC advice is required.

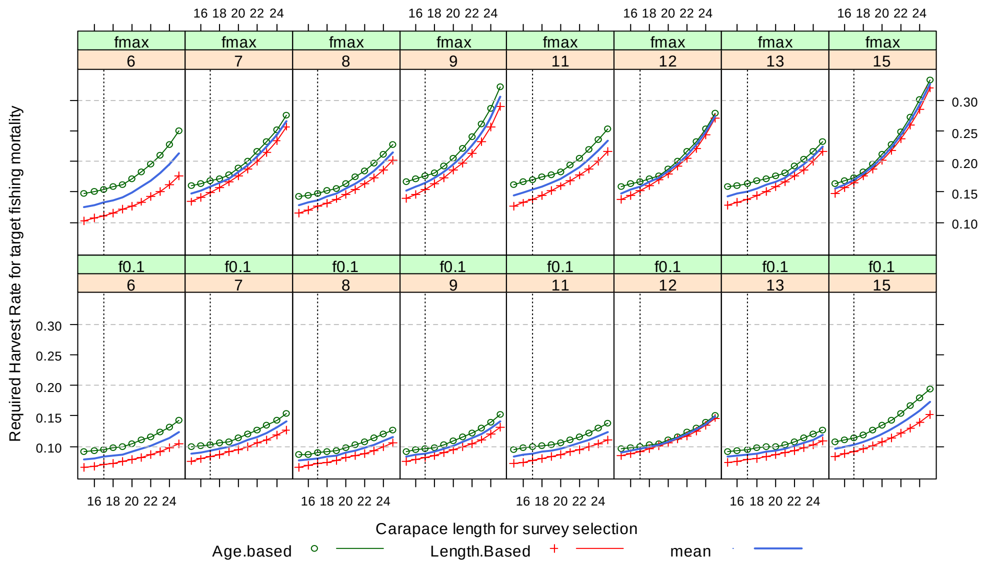


Figure 9.1. Harvest rates equating to F_{max} (top row) and $F_{0.1}$ (bottom row) from the two modelling approaches for each Functional Unit (columns) under a range of assumptions regarding the selectivity length of the TV survey.

Length based (SCA)

Survey min length(mm)

F0.1 Harvest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	6.5%	7.6%	6.6%	7.5%	7.2%	8.4%	7.3%	8.4%
16	6.8%	7.9%	6.9%	7.8%	7.4%	8.8%	7.6%	8.8%
17	**7.0%**	**8.3%**	**7.2%**	**8.2%**	**7.7%**	**9.2%**	**7.8%**	**9.2%**
18	7.3%	8.7%	7.4%	8.5%	8.0%	9.6%	8.1%	9.6%
19	7.6%	9.1%	7.8%	8.9%	8.3%	10.1%	8.3%	10.1%
20	7.9%	9.5%	8.1%	9.4%	8.7%	10.6%	8.6%	10.7%
21	8.2%	10.0%	8.5%	9.9%	9.1%	11.1%	9.0%	11.4%
22	8.7%	10.5%	8.8%	10.4%	9.4%	11.8%	9.3%	12.1%
23	9.1%	11.1%	9.3%	11.1%	9.9%	12.5%	9.8%	13.0%
24	9.7%	11.8%	9.9%	12.0%	10.4%	13.5%	10.3%	14.0%
25	10.4%	12.7%	10.5%	13.1%	11.0%	14.7%	10.9%	15.1%

Fmax Havest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	10.3%	13.4%	11.5%	13.9%	12.7%	13.7%	12.8%	14.8%
16	10.7%	14.1%	12.0%	14.7%	13.2%	14.4%	13.3%	15.7%
17	**11.1%**	**14.9%**	**12.6%**	**15.5%**	**13.8%**	**15.2%**	**13.9%**	**16.6%**
18	11.6%	15.7%	13.2%	16.4%	14.5%	16.0%	14.5%	17.6%
19	12.1%	16.6%	13.9%	17.4%	15.2%	16.9%	15.1%	18.8%
20	12.7%	17.7%	14.6%	18.5%	16.0%	18.0%	15.8%	20.2%
21	13.4%	18.8%	15.4%	19.8%	16.8%	19.2%	16.7%	21.8%
22	14.2%	20.0%	16.3%	21.3%	17.7%	20.5%	17.6%	23.7%
23	15.1%	21.5%	17.3%	23.2%	18.8%	22.2%	18.7%	25.9%
24	16.3%	23.4%	18.6%	25.7%	20.0%	24.3%	20.0%	28.6%
25	17.7%	25.7%	20.2%	29.0%	21.6%	27.1%	21.7%	32.0%

Age based

F0.1 Harvest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	9.1%	9.9%	8.6%	9.2%	9.5%	9.6%	9.2%	10.8%
16	9.3%	10.1%	8.7%	9.4%	9.7%	9.8%	9.3%	11.0%
17	**9.5%**	**10.3%**	**8.9%**	**9.6%**	**9.9%**	**10.0%**	**9.5%**	**11.3%**
18	9.7%	10.5%	9.1%	9.8%	10.1%	10.2%	9.7%	11.9%
19	9.9%	10.8%	9.3%	10.3%	10.3%	10.4%	9.9%	12.6%
20	10.4%	11.3%	9.7%	10.9%	10.5%	11.0%	10.0%	13.4%
21	11.0%	12.0%	10.2%	11.5%	11.0%	11.6%	10.3%	14.3%
22	11.6%	12.7%	10.7%	12.2%	11.6%	12.3%	10.8%	15.4%
23	12.3%	13.4%	11.3%	13.0%	12.2%	13.0%	11.3%	16.6%
24	13.1%	14.3%	12.0%	14.0%	12.9%	13.9%	12.0%	17.9%
25	14.2%	15.4%	12.7%	15.2%	13.7%	15.0%	12.7%	19.4%

Fmax Havest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	14.7%	16.0%	14.2%	16.7%	16.2%	15.9%	15.8%	16.3%
16	15.0%	16.4%	14.5%	17.2%	16.6%	16.3%	16.1%	16.8%
17	**15.4%**	**16.8%**	**14.8%**	**17.7%**	**17.0%**	**16.7%**	**16.4%**	**17.3%**
18	15.8%	17.2%	15.2%	18.2%	17.4%	17.2%	16.8%	18.3%
19	16.2%	17.8%	15.6%	19.2%	17.8%	17.7%	17.2%	19.6%
20	17.2%	18.9%	16.4%	20.6%	18.3%	18.8%	17.6%	21.1%
21	18.3%	20.1%	17.4%	22.2%	19.4%	20.1%	18.1%	22.8%
22	19.6%	21.6%	18.5%	24.0%	20.6%	21.6%	19.2%	24.9%
23	21.0%	23.3%	19.7%	26.1%	21.9%	23.3%	20.4%	27.3%
24	22.7%	25.2%	21.2%	28.7%	23.5%	25.3%	21.7%	30.1%
25	25.0%	27.6%	22.8%	32.3%	25.3%	27.9%	23.3%	33.3%

Table 9.1. Harvest Ratios equating to F0.1 and Fmax for the two modelling approaches for each Functional Unit under a range of assumptions regarding the selectivity length of the TV survey. The row in bold (17 mm) is the value chosen by the group considered to the most likely selection length for the TV surveys.

Mean Harvest Ratios between the two models

Survey min length(mm)

F0.1 Harvest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	7.8%	8.7%	7.6%	8.3%	8.4%	9.0%	8.3%	9.6%
16	8.0%	9.0%	7.8%	8.6%	8.6%	9.3%	8.5%	9.9%
17	**8.2%**	**9.3%**	**8.0%**	**8.9%**	**8.8%**	**9.6%**	**8.7%**	**10.2%**
18	8.5%	9.6%	8.3%	9.2%	9.1%	9.9%	8.9%	10.8%
19	8.7%	9.9%	8.5%	9.6%	9.3%	10.3%	9.1%	11.4%
20	9.1%	10.4%	8.9%	10.1%	9.6%	10.8%	9.3%	12.1%
21	9.6%	11.0%	9.3%	10.7%	10.0%	11.4%	9.6%	12.9%
22	10.1%	11.6%	9.8%	11.3%	10.5%	12.0%	10.1%	13.7%
23	10.7%	12.3%	10.3%	12.1%	11.0%	12.8%	10.6%	14.8%
24	11.4%	13.1%	10.9%	13.0%	11.6%	13.7%	11.1%	15.9%
25	12.3%	14.0%	11.6%	14.2%	12.3%	14.9%	11.8%	17.3%

Fmax Havest Ratios	FU6	FU7	FU8	FU9	FU11	FU12	FU13	FU15
15	12.5%	14.7%	12.8%	15.3%	14.4%	14.8%	14.3%	15.5%
16	12.9%	15.2%	13.3%	15.9%	14.9%	15.4%	14.7%	16.2%
17	**13.3%**	**15.8%**	**13.7%**	**16.6%**	**15.4%**	**16.0%**	**15.1%**	**16.9%**
18	13.7%	16.5%	14.2%	17.3%	15.9%	16.6%	15.6%	18.0%
19	14.2%	17.2%	14.7%	18.3%	16.5%	17.3%	16.1%	19.2%
20	15.0%	18.3%	15.5%	19.6%	17.1%	18.4%	16.7%	20.6%
21	15.9%	19.5%	16.4%	21.0%	18.1%	19.7%	17.4%	22.3%
22	16.9%	20.8%	17.4%	22.6%	19.1%	21.1%	18.4%	24.3%
23	18.1%	22.4%	18.5%	24.6%	20.4%	22.7%	19.5%	26.6%
24	19.5%	24.3%	19.9%	27.2%	21.8%	24.8%	20.9%	29.4%
25	21.3%	26.7%	21.5%	30.7%	23.4%	27.5%	22.5%	32.6%

Table 9.2. Final values for the Harvest Ratios (being the mean of the two approaches in Table 9.1). The row equating to a TV selectivity of 17 mm is the value to go to the Stock Annexes and subsequently be used by the Working Groups in the generation of catch option tables.

10 Future research needs

Future research needs identified by the group fall into four major thematic areas.

1) Work to improve data from the visual count process.

Factors highlighted in the bias table (Table 7.1), prioritized by expert judgement include: Edge Effect, Burrow Detection, Burrow Identification and Burrow Occupancy. Size of animal in relation to burrow size (relating sled counts to animal size distribution) was also highlighted and although the level of bias could not be ascertained it remains a key factor. While some previous important studies have been undertaken (in particular Marrs *et al.*, 1996) these were primarily on shallow, sheltered untrawled populations and it is recommended that a large cooperative research project be funded to address these issues on a wide variety of commercial grounds. As also noted by ICES 2008e, given the depths of most of the *Nephrops* fishing grounds, this should include research using sledge, technical diving, landers, and ROVs, to undertake observations, high-resolution fine-scale mapping and resin casting.

Over the next few years the time-series of reliable catch data and TV indices will increase, and investigations of bias, detailed above, will give more information on the sources and magnitude of bias. As this information develops, the way in which bias is handled in the provision of advice is expected to change. Where bias can be identified and quantified is should be incorporated into the estimates. If uncertainty in some biases remain these may be dealt with through relating historical catches to TV abundance and accounting for bias in a fitted model.

2) Work on biological parameters to improve the assessment process.

Factors include growth and natural mortality. Again work has been undertaken in various areas in the past, but growth parameters need to be updated for many FUs and targeted studies carried out with international coordination was thought to be the way forward. ICES 2006a acknowledging both the critical data limitations in growth rates within FUs and lack of national funding to the required scale, recommended a coordinated approach to the European Commission be made. The NephBench expert group also felt that both these factors could be addressed through a cooperative tagging programme across a number of commercial grounds to obtain estimates for different areas.

3) Work to improve and standardize video storage and processing procedures.

Work should continue on the development of standardized training techniques and protocols. A key focus is to computerize the counting procedures so that burrows counts are spatially explicit and can be overlaid on the original video footage, for example a form of X-Y grid. This would greatly increase quality control and facilitate counting and recounting. Further it would allow spatial statistical analysis. Computer game programs exist that may be adaptable to easily achieve this and should be investigated. Advice from a computer programmer is the immediate way forward.

4) Improving VMS data and sediment mapping.

Work should continue on defining the *Nephrops* grounds based on fishing fleet VMS data and sediment mapping. Estimates on sample size for a particular level of relative error can be made and stratified verses systematic survey designs can then be re-evaluated based on updated data.

5) 5. Estimating discard survival.

FU-specific data on survival of discarded *Nephrops* is required for the adjustment of catches in the assessment. Research funding should be sought to estimate survival from trawling (different trawling conditions, different exposures on deck, etc) and discarding process (return to the seabed), size distribution of the discard fraction and area of discarding (non-*Nephrops* ground).

6) Alternative modelling approaches.

Issues of bias in reporting and variability of length-at-age are not unique to *Nephrops* as analysts providing management advice for other ICES stocks (and stocks worldwide) face similar concerns. Alternatives to age slicing exist which could better accommodate variability of length/age, and modelling formulations have been developed which allow for errors in catch, trends in catchability, or other hypotheses related to fishery and population processes. These are essentially embedded in more integrated statistical models which permit propagating variability of a way which also permits translating that scientific uncertainty into management advice (e.g. probability of exceeding established limit or target reference levels for a given level of TAC), which, in turn, permits more informed decisions on management of the fisheries. These approaches can also admit broad array of fishery-dependent and fishery-independent information sets into an overall estimation scheme. The method proposed by Bell (Annex 5) at this meeting, is movement in this direction and this or similar modelling approaches (e.g. CASAL, MULTIFAN-CL, SS3, etc.), which can accommodate information sets with different levels of reliability, should be pursued. Providing there are sufficient data, the bias in key parameters, for instance reporting rates, can also be estimated in such models. As the data available for analysis of *Nephrops* stocks mature (e.g. VMS based catch effort information, longer time-series of consistent TV surveys, etc), application of these approaches would seem to provide an improved basis for providing scientific advice in view of a wide range of plausible hypotheses about the fishery and stock characteristics.

7) Observer sampling.

Catch and discard length frequencies are currently estimated by port and observer sampling programmes, but the level of observer sampling is currently very low, less than 1% of trips. Because key signals on recruitment are likely to be seen in discards (and in the western Irish Sea in the fine mesh trawl survey) observer sampling rates should be increased substantially.

Annex 1: List of participants

Name	Address	Phone/Fax	Email
David Agnew	Imperial College London Silwood Park Campus SL5 7PY UK	Phone +447905713572 Fax obsolete	david.agnew@mrag.co.uk
R. Jim A. Atkinson	University Marine Biological Station Millport KA28 0EG Isle of Cumbrae Scotland UK	Phone 442890255003 Fax 442890255004	r.j.a.atkinson@udcf.gla.ac.uk
Nick Bailey	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 1224 295398 Fax +44 1224 295511	n.bailey@marlab.ac.uk
Ewen D. Bell ICES Coordinator	Centre for Environment, Fisheries and Aquaculture Science Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk UK	Phone +44 1 502 524 238 Fax +44 1 502 562 244	ewen.bell@cefas.co.uk
Hocine Benchikh	National University of Ireland Cork Zoology and Animal Ecology Distillery Fields North Mall Cork Ireland	Phone +353 Fax +353	ciaolho@yahoo.fr
Mette Bertelsen ICES Secretariat	International Council for the Exploration of the Sea H. C. Andersens Boulevard 44–46 DK-1553 Copenhagen V Denmark		mette@ices.dk
Richard Briggs	Agri-food and Biosciences Institute 18a Newforge Lane BT9 5PX Belfast UK	Phone +44(0)28 90255503 Fax +44(0)28 90255004	richard.briggs@afbini.gov.uk

Name	Address	Phone/Fax	Email
Neil Campbell	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 1224 295693 Fax +44 1224 295511	n.campbell@marlab.ac.uk
Sarah Clarke	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 1224 295 427	Clarkes@marlab.ac.uk
Helen Dobby	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 1224 876544 Fax +44 1224 295511	h.dobby@marlab.ac.uk
Jennifer Doyle	Marine Institute Rinville, Oranmore Co. Galway Ireland	Phone 353 91 387200 Fax 353 91387201	jennifer.doyle@marine.ie
Jon Elson	Centre for Environment, Fisheries and Aquaculture Science Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk UK	Phone +44 1 502 524 243 Fax +44 1 502 562 244	jon.elson@cefas.co.uk
Colm Lordan	Marine Institute Rinville, Oranmore Co. Galway Ireland	Phone +353 91 387200 Fax +353 91 387201	colm.lordan@marine.ie
Carlos Mesquita	Fisheries Research Services PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 Fax +44	c.mesquita@marlab.ac.uk
E. Betulla Morello	National Research Council Institute of Marine Science Largo Fiera della Pesca, 2 IT-60125 Ancona Italy	Phone +390712078869 Fax +3907155313	b.morello@ismar.cnr.it

Name	Address	Phone/Fax	Email
Sten Munch-Petersen	National Institute of Aquatic Resources, Section for Management Systems Charlottenlund Slot Jægersborg Alle 1 DK-2920 Charlottenlund Denmark	Phone 45 33963390 Fax 45 33 96 33 33	smp@aqua.dtu.dk
Nadia Papadopoulou	Hellenic Centre of Marine Research (HCMR) POBox 2214 71003 Heraklion Crete Greece	Phone 302810337827 Fax 302810337822	nadiapap@her.hcmr.gr
Heather Philp	Marine Research Institute Skúlagata 4 IS-121 Reykjavík Iceland	Phone +354 Fax +354	heather@hafro.is
Pieter-Jan Schön	Agri-food and Biosciences Institute 18a Newforge Lane BT9 5PX Belfast UK	Phone +44 28 90255015 Fax +44 28 90255004	pieter-jan.schon@afbini.gov.uk
Gerald Preston Scott Invited Expert	National Marine Fisheries 75 Virginia Beach Drive Miami FL 33149 United States	Phone +1 Fax +1	Gerry.Scott@noaa.gov
Cristina Silva	IPIMAR Avenida de Brasilia PT-1449-006 Lisbon Portugal	Phone +351 213 027 000 Fax +351 213025948	csilva@ipimar.pt
John Simmonds	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen UK	Phone +44 1224 876 544 Fax +44 1224 295511	j.simmonds@marlab.ac.uk
Chris Smith	Hellenic Centre of Marine Research (HCMR) POBox 2214 71003 Heraklion Crete Greece	Phone 302810337752 Fax 302810337822	csmith@her.hcmr.gr

Name	Address	Phone/Fax	Email
Kevin Stokesbury Invited Expert and Chair	University of Massachusetts Dartmouth School for Marine Science and Technology DFO 838 South Rodney French Blvd. New Bedford MA 02744-1221 United States	Phone +1 508 910-6373 Fax +1 508 910-6396	kstokesbury@umassd.edu
Adrian Weetman	Fisheries Research Services FRS Marine Laboratory PO Box 101 AB11 9DB Aberdeen Torry UK	Phone +44 1224 295354	A.Weetman@marlab.ac.uk

Annex 2: Agenda

WKNEPH

2008/2/ACOM33 A **Benchmark Workshop on *Nephrops*, with UWTV surveys** (Chair: Kevin Stokesbury (USA) and ICES coordinator Ewen Bell (UK)) will be established and will meet in Aberdeen, UK, 2–6 March 2009 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the Text Table below. The evaluation shall include consideration of fishery-dependent, fishery-independent (in particularly UWTV surveys), and life-history data currently being collected for use in the current assessment work and the proposed assessment;

b) Agree and document preferred method for evaluating stock status and (where applicable) short-term outlook and update the assessment handbooks as appropriate;

c) Develop recommendations for future improving assessment methodology and data collection.

NEPHROPS STOCK	ASSESSMENT LEAD
Nephrops in Division IVb (Farn Deeps, FU 6)	Jon Elson
Nephrops in Division IVa (Fladen Ground, FU 7)	Adrian Weetman
Nephrops in Division IVa (Firth of Forth, FU 8)	Adrian Weetman
Nephrops in Division IVa (Moray Firth, FU 9)	Adrian Weetman
Nephrops in Division VIa (North Minch, FU 11)	Adrian Weetman
Nephrops in Division VIa (South Minch, FU 12)	Adrian Weetman
Nephrops in Division VIa (Firth of Clyde, FU 13)	Adrian Weetman
Nephrops in Division VIIa (Irish Sea West, FU 15)	Colm Lordan
Nephrops in Division VIIb (Aran Grounds, FU 17)	Colm Lordan

The Benchmark Workshop will report for the attention of ACOM by 3 April 2009.

Annex 3: References

Afonso-Dias, M. 1998. Variability of *Nephrops norvegicus* (L.) populations in Scottish waters in relation to the sediment characteristics of the seabed. PhD Thesis, University of Aberdeen, 282pp.

Aguzzi, J. and Sarda, F. 2008. A history of recent advancements on *Nephrops norvegicus* behavioral and physiological rhythms. *Rev. Fish. Biol. Fisheries*,18: 235–248.

Allan, L., Campbell, N., Weetman, A. and Dobby, H. 2009. Analysis of Scottish *Nephrops* length-weight data by sex and functional unit. ICES Working Document for the *Nephrops* WG, March 2009. 17pp.

Bell, M.C., Redant F. and Tuck I. 2006. *Nephrops* species. In: Phillips BF (ed) *Lobsters: biology, management, aquaculture and fisheries.* Blackwell Publishing, Oxford, pp 412–461.

Campbell, N., Allan, L., Weetman, A. and Dobby, H. 2008. Investigating the link between *Nephrops norvegicus* burrow density and sediment composition in Scottish waters. *ICES CM 2008/G:06*.

Chapman, C.J. 1980. Ecology of juvenile and adult *Nephrops*. In: Cobb JS, Phillips BF (eds) *The biology and management of lobsters*, Vol. II. Academic Press, New York.

Dobby, H and Bailey, N. 2006. Harvest rates for *Nephrops*. Working Document for the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak, 5–14 September, 2006.

Dobby, H, Bailey, N. and Campbell, N. 2007. The use of underwater TV surveys in the provision of advice for *Nephrops* stocks around Scotland. ICES CM 2007/O:23.

Dobby, H. 2007. Deriving appropriate harvest rates for the *Nephrops* stocks around Scotland. Working Document for the Workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters, 17–21 April, 2007.

Farmer, A.D.S. 1975. Synopsis of biological data on Norway lobster *Nephrops norvegicus* (Linneo 1758). *FAO FIRS/S112*.

Figueiredo, M.J. and Thomas, H.J. 1967. *Nephrops norvegicus* (Linnaeus, 1758) Leach: a review. *Oceanogr. Mar. Biol. Ann. Rev.*, 5: 371–407.

Froglia, C. and Gramitto, M.E. 1979 An estimate of the fecundity of Norway lobster (*Nephrops norvegicus*) in the Adriatic Sea. *Rapp. Comm. int. Mer Medit.*, 25/26 (4): 227–229.

Froglia, C. and Gramitto, M.E. 1988 An estimate of growth and mortality parameters for Norway lobster (*Nephrops norvegicus*) in the Central Adriatic Sea. *FAO Fish. Rep.*, 394: 189–203.

ICES 2000. Report of the Study Group on the Life History of *Nephrops*. *ICES 2000 CM:G06*.

ICES, 2006. Report of the Workshop on *Nephrops* stocks. ICES CM 2006/ACFM:12.

ICES. 2004. Report of the Working Group on *Nephrops* Stocks, 28 March–1 April 2004, Lisbon, Portugal. *ICES CM 2004/ACFM:19*. 441 pp.

ICES. 2005. Report of the Working Group on the Assessment of Hake, Monk and Megrim (WGHMM), 10–19 MAY 2005, Lisbon, Portugal. Diane. 67 pp.

ICES. 2006a. Report of the Workshop on *Nephrops* Stocks (WKNEPH), 24–27 January 2006, ICES Headquarters. *ICES CM 2006/ACFM:12*. 85 pp.

ICES. 2006b. Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 9–18 May 2006, Bilbao, Spain. *ICES CM 2006/ACFM:29*. 776 pp.

ICES 2007. Report of the Workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters (WKNEPHTV). ICES CM: 2007/ACFM: 14 Ref: LRC, PGCCDBS.

ICES. 2008a. Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM), 30 April–6 May 2008, ICES Headquarters, Copenhagen. ICES *CM 2008/ACOM:07*. 613 pp.

ICES. 2008b. Report of the Working Group on the Assessment of Southern Shelf Dermersal Stocks (WGSSDS), April 30–May 6, 2008, Copenhagen, Denmark. *ICES CM 2008/ACOM:12*. 552 pp.

ICES. 2008c. Report of the Working Group on the Assessment of Northern Shelf Demersal Stock (WGNSDS), 15–21 May 2008, Copenhagen, Denmark. *ICES CM 2008/ACOM:08*. 757 pp.

ICES. 2008d. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak-Spring and Autumn (WGNSSK), 7–13 May and, ICES Copenhagen and by Correspondence. Diane. 921 pp.

ICES 2008e. Report of the Workshop and training course on *Nephrops* Burrow Identification (WKNEPHBID). ICES CM: 2008/LRC: 03 Ref: ACOM.

IMBC, UMBSM and IRPEM. 1994. *Nephrops norvegicus: stock variability and assessment in relation to fishing pressure and environmental factors*. Final Report to the Commission of the European Communities, Contract XIV.1/MED/91/003, 84 p + figures and appendices.

Leotte, F., Guerra, M., Silva, C. and Gaudêncio, M.J. 2005 Preliminary work into the characterisation of bottom sediment on *Nephrops norvegicus* grounds off the SW and SE coast of Portugal. *ICES CM 2005/O:42*.

Marrs, S.J., Atkinson, R.J.A., Smith, C.J. and Hills, J.M. 1996. *Calibration of the towed underwater TV technique for use in stock assessment of Nephrops norvegicus*. Final Report to the European Commission Contract 94/069, Study Project in support of the Common Fisheries Policy (XIV/1810/C1/94). 155pp.

Marrs, S.J., Tuck, I.D., Arneri, E., Atkinson, R.J.A., Santojanni, A., Stevenson, T.D.I. 2000. *Improvement of Nephrops stock assessment by use micro-scale mapping of effort and landings*. Final Report EC Study Contract 97/0100.

Marrs, S.J., Tuck, I.D., Arneri, E., La Mesa, M., Atkinson, R.J.A., Ward, B. and Santojanni, A. with technical support from Stevenson T.D.I. and Belardinelli, A. 2002. Technical improvements in the assessment of Scottish *Nephrops* and Adriatic clam fisheries. Final Report to the European Commission. Reference 99/077. Study Project in support of the Common Fisheries Policy (call 99/OJ C122). 277pp + appendices.

Morello E.B., Froglia C. and Atkinson R.J.A. 2007. Underwater television as a fishery-independent method for stock assessment of Norway lobster, *Nephrops norvegicus*, in the central Adriatic Sea (Italy). *ICES J. Mar. Sci.*, 64: 1116–1123.

Mytilineou Ch, M Castro, P Gancho and A. Fortouni 1998b. Growth studies on Norway lobster, *Nephrops norvegicus* (L.) in different areas of Mediterranean Sea and adjacent Atlantic. *Sci. Mar.* 62 (suppl.1): 43–60.

Orsi-Relini L, Zamboni A, Fiorentino F, Massi D. 1998. Reproductive patterns in Norway lobster *Nephrops norvegicus* (L.), (*Crustacea Decapoda: Nephropodidae*) of different Mediterranean areas. Sci Mar 62 (suppl.1): 25–41.

Sardà, F. (Ed.). 1998. *Nephrops norvegicus* (L). Comparative biology and fishery in the Mediterranean Sea. *Sci. Mar.*, 62 (Suppl.1).

Sardà, F. 1995. A review (1967–1990) of some aspects of the life history of *Nephrops norvegicus*. *ICES Mar. Sci. Symp.*, 199:78–88.

Smith C.J. and K.-N. Papadopoulou 2008. *Nephrops growth and reproductive biology. In: Reproductive Biology of Crustaceans*. Science Publishers, Enfield, New Hampshire, USA.

Smith, C.J., Marrs, S.J., Atkinson R.J.A., Papadopoulou, K.-N. and Hills, J.M. 2003. Evaluation of the underwater television technique for fisheries-independent stock assessment of *Nephrops norvegicus* from the Aegean (Eastern Mediterranean). Marine Ecology Progress Series, 256: 161–170.

Smith, C.J., Papadopoulou, K.-N., Kallianiotis, A., Vidoris, P., Chapman, C.J. and Vafidis, D. 2001. *Growth and natural mortality of Nephrops norvegicus, with an introduction and evaluation of creeling in Mediterranean waters*. European Commission Final Report DG XIV Study Project 96/013, 195 pp.

Annex 4: Recommendations

We suggest that each Expert Group collate and list their recommendations (if any) in a separate annex to the Report. It has not always been clear to whom recommendations are addressed. Most often, we have seen that recommendations are addressed to:

- Another Expert Group under the Advisory or the Science Programme;
- The ICES Data Centre;
- Generally addressed to ICES;
- One or more members of the Expert Group itself.

RECOMMENDATION	ACTION
1. Instigate an internationally coordinated project to obtain basic biological data from the various FUs. Data to include growth, natural mortality, burrow occupancy and size of animal in relation to burrow size.	SGNepS, PGCCDBS and EU Commission
2. Fisheries management to operate at a local (i.e. FU) scale.	EU Commission
3. Further standardization of burrow counting, including further mechanaisation and development of computer-based counting to facilitate overlaying of re-counts for accuracy checking.	SGNepS members, ICES optical technologies group
4. Continue work on defining *Nephrops* grounds using VMS and sediment mapping.	SGNeps
5. Instigate an internationally coordinated project to obtain more accurate measures of discard survival. Research funding should be sought to estimate FU-specific survival from trawling.	SGNepS, PGCCDBS and EU Commission
6. Investigate alternative modelling approaches (CASAL/StockSynthesis style models).	WGMG, SGNepS .
7. Increase observer sampling rates.	National laboratories.

After submission of the Report, the ICES Secretariat will follow up on the recommendations, which will also include communication of proposed terms of reference to other ICES Expert Group Chairs. The "Action" column is optional, but in some cases, it would be helpful for ICES if you would specify to whom the recommendation is addressed.

Annex 5: SCA

Introduction

Separable Cohort Analysis (SCA) is a statistical model which estimates recruitment, selectivity and fishing mortality by fitting to catch (and discards) by length and sex. The absolute abundance index is fitted to the total population numbers at the time of the survey. This is not, strictly, an assessment model as it operates on length frequencies under the assumption of equilibrium (just as LCA does) and residuals from the model should be examined for evidence of gross departure from this assumption before any results are presented.

There are a number of similarities to LCA in terms of the equations governing the time spent in each length class and some of the key assumptions.

- Growth is continuous;
- Population is in equilibrium;
- Landings are taken throughout year;
- The change in availability with respect to length only affects females and is a function of size at first maturity.

In addition to these common assumptions, there are two other assumptions specific to this model.

- Recruitment is equal between sexes;
- Recruitment occurs at smallest size in data on 1 January;Selection functions for both the fishery and the TV survey follow a sigmoid curve and is flat topped;
- Survey represents an instantaneous snapshot in time.**Model**

It is possible to rewrite the von Bertanalaffy growth equations to give the length of time spent in any given length interval (equation 4). Assuming all recruits enter the system at the same size, it is then straightforward to project the decay of that cohort through time using the standard Baranov catch equations to give both population and catch numbers-at-length. As the population is assumed to be in equilibrium and has constant recruitment, the resulting length frequency of the catch from this cohort is equivalent to the expected length frequency of the catch in any given year.

$$N_{s,l+1} = N_{s,l} \times \exp^{-Z_{s,l}} \qquad \text{eqn 1.}$$

$$Z_{s,l} = F_{s,l} + M_{s,l} \qquad \text{eqn 2.}$$

$$C_{s,l} = N_{s,l} \times \frac{F_{s,l}}{Z_{s,l}} \times \left(1 - \exp\left(-Z_{s,l}\right)\right) \qquad \text{eqn 3.}$$

$$\Delta t_{l,s} = \frac{1}{VBK_{l,s}} \times \log\left(\frac{L.INF_{l,s}}{L.Inf_{l,s} - l_{l+1}}\right) \qquad \text{eqn 4.}$$

Fishing mortality on a particular length class therefore becomes the product of the selection ogive, the fishing mortality at full selection and the time expended in that length class.

$$F_{l,s} = \Delta t_{l,s} \times \frac{f_s}{1+\exp\left(\frac{s.50-l}{s.50-s.25}\right)} \qquad \text{eqn 5.}$$

s is sex, *l* is length, *f* is annual fishing mortality at full selection and *s.25* and *s.50* are the selection model parameters giving length at 25% selection and 50% selection respectively.

Immature female *Nephrops* were considered to have the same characteristics as male *Nephrops* and therefore utilized common parameters. For females, maturity dependent changes to parameters governing growth, natural mortality and availability to the fishery were modelled as a sigmoid function of length (equation 6). Changes to growth and natural mortality parameters have previously been knife-edge at 50% maturity resulting in sharp discontinuities in survivorship and leading to difficulties in subsequent model fitting, smoothing these changes in line with the proportion mature at length alleviates such problems (equation 7).

$$Mat = \frac{1}{1+\exp\left(\frac{L.50_{mat}-l}{L.50_{mat}-L.25_{mat}}\right)} \qquad \text{eqn 6.}$$

$$p_{l,female} = \left(P_{male} \times (1-Mat_l)\right) + \left(P_{female} \times Mat_l\right) \qquad \text{eqn 7.}$$

Where *P* is the parameter for growth, natural mortality or fishing mortality.

Discarding practice is also included in the model. The inputs to the model include landings and discards by length and sex. A discard ogive is fitted to the input data prior to the main parameter estimation section of the model. This ogive is then used to split the predicted numbers caught into landings and discard components.

In order to compare the modelled population to the estimates of abundance observed in the TV surveys a total population index was constructed. The modelled length frequency represents the continuous evolution of the population through time whereas the TV survey is a snapshot of population size at a particular point within the year subject to a survey selectivity function (same formulation as equation 8). The estimate of the population abundance at the time of the survey is therefore:

$$\hat{P} = \sum_{t=0.8,1.8,2.8....} N_{s,t}$$

As the basic unit of the model was length rather than time some form of interpolation of population numbers was required to determine the population size at the exact time of the survey and a smooth spline function was used to this effect.

The objective function used for parameter estimation was the log likelihood of the predicted length frequencies (landings and discards) plus a penalty function for deviation from the observed TV abundance (equation 8). As the penalty function comprised just a single observation there was no estimable variance term for this part of the objective function so a manual weighting term was added. The first was the difference between the observed and predicted catch-at-length while the second was the difference between the observed TV survey abundance and the estimated abundance at the time of the survey.

$$ll = \frac{1}{2}\sum_{l,s}\left[\frac{\left(L_{l,s} - \hat{L}_{l,s}\right)^2}{\sigma_L^2} + \ln\left(2\pi\sigma_L^2\right) + \frac{\left(D_{l,s} - \hat{D}_{l,s}\right)^2}{\sigma_D^2} + \ln\left(2\pi\sigma_D^L\right)\right] + \alpha\left(N_{obs} - \sum_{t,s}\hat{N}_{t,s}\right)^2$$

eqn. 8

$$\sigma_x^2 = \frac{1}{n}\sum_{l,s}\left(X_{l,s} - \hat{X}_{l,s}\right)^2$$

eqn.9

where α is a weighting factor for the fitting to TV abundance and *t* is the point in the year at which the survey takes place.

The model was fitted using the OPTIM function of R, and employed the "L-BFGS-B" fitting method to constrain the parameter estimates. Estimates of standard errors for the parameters were obtained from the inverse Hessian matrix.

The model had five parameters to estimate; initial population size at the smallest length class (equal sex distribution assumed), two selection parameters and two fishing mortalities at full selection, one for males and immature females, the other for mature females. Initial population size was estimated to be 5* the total numbers caught (TNC) and the bounds on population size were TNC to 10 000*TNC. Selection parameter L.25 was constrained to be between 10 and 40 mm while L.50 was fitted as a multiplier on L.25 ranging from 1.000001 to 10. The f multipliers for males/immature females and mature females were constrained to be between 0.01 and 2.00. For the purposes of model fitting, population numbers were scaled to bring the estimates of recruits into the same order of magnitude as the estimates of F.

Data

The model requires landing and discard numbers by length and sex, typically a 3 year average to remove strong year-class effects. Additional parameters required are the von Bertalanffy growth parameters, natural mortality and weight-length parameters by sex. Parameters for ogives governing female maturity and the selectivity of the TV survey are also required (using the same formulation as equation 6).

SCA was fitted to the latest 3-year average length frequency data for functional units 6, 7, 8, 9, 11, 12 and 13. The data for FU15 were only available for 2007. The TV indices used were the means for the same year period that the length data represented. All other parameters (growth, maturity and weight-length) were drawn from the latest working group reports.

Results

In general the fits were very encouraging with modest residuals (Figure 6.4.2.1). Parameter estimates plus their standard errors are given in Table 6.4.2.1. Estimates of F0.1 and Fmax are given in 6.4.2.2 while population abundance at the time of the survey is given in 6.4.2.3. Within each run the residuals were not random indicating some departure from the model assumptions (incorrect growth parameters, non-stationary natural mortality, etc.), but neither were the residual patterns common through all stocks suggesting that the model formulation is not systematically flawed. Having said that, there is a common pattern to the residuals of FUs 7, 9, 11, 12 and 14 for an overestimation of males at smaller sizes followed by an underestimation; the pattern changing at just below 30 mm.

The results for FU6 were strongly influenced by the high abundance of larger female in the fishery during 2006. This highly unusual pattern was such a departure from the assumption of a population in equilibrium that the model fit is relatively poor (Figure

6.4.2.2). Removal of the 2006 data (i.e. just using a mean of 2005 and 2007) significantly improved the fit.

The parameter estimates for FU9 are noticeably different from the other FUs with much lower estimates of F and much higher levels for Fmax. Recruitment estimates are the most uncertain and the difference between the TV survey estimate and the model estimate of a TV survey is the most disparate (2.44).

In order to demonstrate the influence of the survey weighting parameter (alpha) and the survey timing parameter, one FU (7) was subjected to a range of alphas and survey timings. Forcing the survey to be later in the year reduces the predicted abundance whereas the increasing alpha parameter forces the recruitment level to match the observed abundance. The overall effect of moving the survey from just after recruitment to the very end of the year had a ~20% effect on the estimate of survey abundance when there was a low weight on fitting to the observed abundance.

Discussion

This model appears to fit the majority of datasets quite well and therefore seems a reasonable approach to take in terms of estimating F0.1 and Fmax.

There is an interplay of growth rates and fishing mortality. If growth rate were underestimated individuals would be spending a longer period of time resident in each length class. In order to allow for this the model would reduce the fishing mortality. The converse is also true, that an overestimated growth rate would result in an increased fishing mortality. However, provided that a sigmoid selection pattern is reasonable, the size and shape of the residual pattern can aid detection of implausible growth rates. In FU9, the relatively large right hand tail of catches means that the model has to reduce F and increase the recruitment in order to be able to generate enough population out at this size. This appears to conflict with the numbers entering the fishery at the smaller size and results in a relatively poor fit with large residuals (~17% at the peak, compared with ~10% for the other FUs).

The common residual patterns seen for a number of the Scottish FUs is probably a function of too high an L50 in the maturity ogive. If the growth and exploitation patterns of females have diverged before the model expects them to, then a systematic pattern in the residuals would result. The length frequencies for these FUs were in 2 mm bins (as opposed to 1 mm bins in the English and Irish FUs). Given that the difference between L25 and L50 is around 2 mm it may be that a bin-size at this level too coarse for effective model fitting.

Further sensitivity analyses are required to test model robustness to uncertainty regarding estimates of natural mortality, growth rates and maturity. However, as a general approach to estimating reference points, plus the ability to directly incorporate the TV survey, SCA should be seen as a useful tool for stock assessment.

Table 6.4.2.1 Fitted values and standard errors (in italics) generated by SCA for the various Functional Units.

FU	Recruitment		L.25		L.50		F Male		F Female	
6	284 492	*5097*	22.4	*0.14*	24.7	*0.11*	0.47	*0.02*	0.10	*0.01*
7	787 734	*39 030*	24.7	*0.22*	26.6	*0.14*	0.40	*0.04*	0.29	*0.03*
8	213 863	*2922*	23.6	*0.22*	26.8	*0.17*	1.01	*0.06*	0.33	*0.02*
9	201 505	*21 720*	23.3	*0.18*	24.7	*0.10*	0.24	*0.04*	0.09	*0.01*
11	257 815	*14 690*	22.8	*0.14*	24.2	*0.09*	0.53	*0.05*	0.16	*0.02*
12	324 618	*24 543*	22.3	*0.14*	23.8	*0.07*	0.37	*0.04*	0.18	*0.02*
13	360 063	*10 751*	21.4	*0.30*	23.8	*0.11*	0.78	*0.07*	0.27	*0.02*
15	1 474 167	*29 804*	21.4	*0.22*	23.4	*0.19*	0.87	*0.06*	0.97	*0.09*

Table 6.4.2.2 Estimates of candidate reference points F0.1 and Fmax for the various Functional Units.

	F0.1			Fmax		
FU	Male	Female	Combined	Male	Female	Combined
6	0.18	0.10	0.13	0.40	1.05	0.45
7	0.20	0.15	0.17	0.55	0.60	0.55
8	0.18	0.15	0.15	0.20	0.50	0.25
9	0.20	0.18	0.17	0.90	2.10	1.10
11	0.18	0.17	0.15	0.35	1.00	0.45
12	0.18	0.17	0.16	0.50	0.95	0.60
13	0.18	0.16	0.15	0.25	0.60	0.30
15	0.20	0.13	0.17	0.25	0.15	0.20

Table 6.4.2.3 Fitted and observed abundances from the TV survey.

	TV survey abundance		
FU	Fitted	observed	Ratio
6	1 519 580	1 543 000	0.98
7	4 834 346	6 730 000	0.72
8	1 150 777	735 000	1.57
9	1 466 207	601 000	2.44
11	1 524 627	1 153 000	1.32
12	2 047 638	2 111 000	0.97
13	1 861 721	1 785 000	1.04
15	6 344 243	6 818 000	0.93

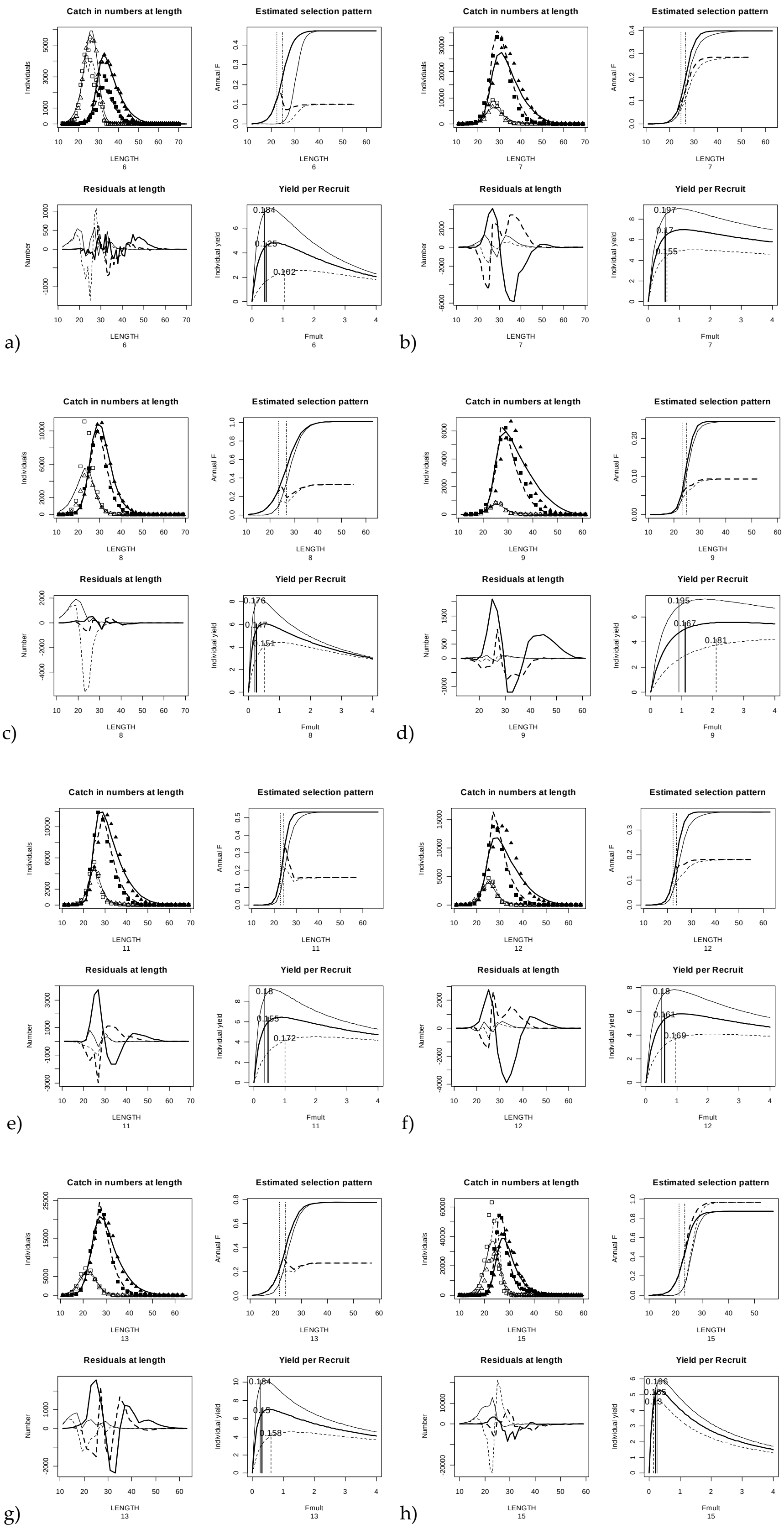


Figure 6.4.2.1. SCA output for the eight functional units. a)FU6, b)FU7, c)FU8, d)FU9, e)FU11, f)FU12, g)FU13, h)FU15.

Annex 6: Stock Annex: FU6, Farn Deeps

Stock specific documentation of standard assessment procedures used by ICES.

Stock Farn Deeps *Nephrops* (FU06

Date: 06/03/2009 (WKNEPH2009)

Revised by Ewen Bell/Jon Elson

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows, and this means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. In the Farn Deeps area the *Nephrops* stock inhabits a large continuous area of muddy sediment extending North from 54° 45′–54° 35′N and 0° 40′–1° 30′N with smaller patches to the east and west.

A.2. Fishery

In 2001 the cod recovery plan was introduced and the number of vessels recorded in this fishery and landing into England increased from around 160 in 2000 to and fluctuating around 200 between 2001 and 2003. In 2004 the number returned to around 160 vessels but stepped up to 230 vessels in 2006. Although a small increase was apparent in the number of the local fleet turning to *Nephrops* the increase in the number of visiting Scots, Northern Irish and other English vessels was greater. Visiting Scottish vessels consistently make up about 30 to 40% of the fleet during the season and account for between 20 and 30% of the landings by weight. Since 2000 there has been an increase in the effort of vessels targeting *Nephrops* using multi rig trawls. In 2004 they accounted for about 10% of the landings by weight and 20% by 2006. Over 25% of the entire fleet uses multi rigs mainly through an influx of up to 19 Northern Irish and 30 Scottish multi riggers visiting the area; coming into the fishery for the first time over the last two years. Both single and multi trawl fleets were affected by Technical Conservation Measures and Cod recovery plans. The single trawl fleet in general switched from a 70 mm to an 80 mm codend mesh in 2002. Multi rigged vessels targeting prawns use 95 mm codend mesh. The average vessel size of the visitors has remained relatively stable but average horse power has increased. With decommissioning the average size and power of the local fleet has declined slightly. Currently the average size of the local fleet is 11 m with an average engine power of around 140 kW.

The fishery is exploited throughout the year, with the highest landings made between October and March. Fishing is usually limited to a trip duration of one day with 2 hauls of 3–4 hours being carried out. The main landing ports are North Shields, Blyth, Amble and Hartlepool where, respectively, on average 45, 32, 10 and 7% of the landings from this fishery are made.

The minimum landing size for *Nephrops* in the Farn Deeps is 25 mm CL. Discarding generally takes place at sea, but can continue alongside the quay. Landings are usually made by category for whole animals, often large and medium and a single category for tails. However, landings to merchants of one category of unsorted whole and occasionally one of tails is becoming more common. Depending on the number of small, the category of tails is often roughly sorted as whole and left on deck for tailing later. This category is only landed once tailed. The local enforcement agency is discouraging the practice of tailing after tying up alongside.

Regulations

UK legislation (SI 2001/649, SSI 2000/227) requires at least a 90 mm square mesh panel in trawls from 80 to 119 mm, where the rear of the panel should be not more than 15 m from the cod-line. The length of the panel must be 3 m if the engine power of the vessel exceeds 112 kW, otherwise a 2 m panel may be used. Under UK legislation, when fishing for *Nephrops*, the codend, extension and any square mesh panel must be constructed of single twine, of a thickness not exceeding 4 mm for mesh sizes 70–99 mm, while EU legislation restricts twine thickness to a maximum of 8 mm single or 6 mm double.

Under EU legislation, a maximum of 120 meshes round the codend circumference is permissible for all mesh sizes less than 90 mm. For this mesh size range, an additional panel must also be inserted at the rear of the headline of the trawl. UK legislation also prohibits twin or multiple rig trawling with a diamond codend mesh smaller that 100 mm in the north Sea south of 57°30′N.

Legislation on catch composition for fishing N or S of 55° along with other cod recovery measures may have affected where and when effort is targeted which in turn could affect catch length distributions. This latitude bisects the Farn Deeps *Nephrops* fishery.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Three types of sampling occur on this stock, landings sampling, catch sampling and discard sampling providing information on size distribution and sex ratio. Landing and catch sampling occurs at North Shields, Blyth, Amble and Hartlepool.

Historically, estimates of discarding were made using the difference between the catch samples and the landings samples. For the period prior to 2002, catch length samples and landings length samples are considered to be representative of the fishery. An estimate of retained numbers-at-length was obtained for this period from the catch sample using a discard ogive estimated from data from the 1990s, a raising factor was then determined such that the retained numbers-at-length matched the landings numbers-at-length. This raising factor was then applied to the estimate of discard numbers-at-length.

More recently, there has been concern that the landings sampling may be missing portions of the landings landed as tails (as opposed to whole individuals) thus leading to an artificial inflation of the estimated discards. On-board discard sampling has been of sufficient frequency since 2002 to allow the estimation of discards from these data. There are two modes of operation for “tailing” in the FU6 *Nephrops* fishery, some vessels tail at sea, others tail at the quayside. Discard estimates from the latter category only sample those animals discarded at sea, the undersize individuals discarded at the quayside are not sampled, consequently the proportion of discards at sizes below MLS for this tailing practice are very low (Figure B.1.1). Discard trips, which saw discarding of less than 50% of individuals below MLS, were ignored. Annual discard ogives demonstrated no systematic change, therefore a single ogive was constructed from the pooled data from 2002–2007 (Figure B.1.2). This was then applied to the catch data to produce estimates of landings at length.

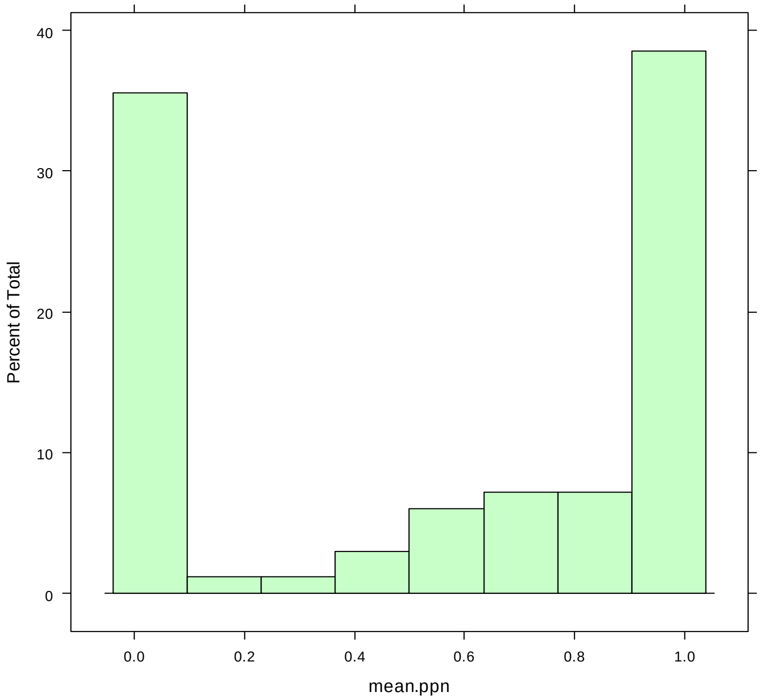


Figure B.1.1. Farn Deeps (FU 6): Histogram of proportion individuals <26 mm discarded.

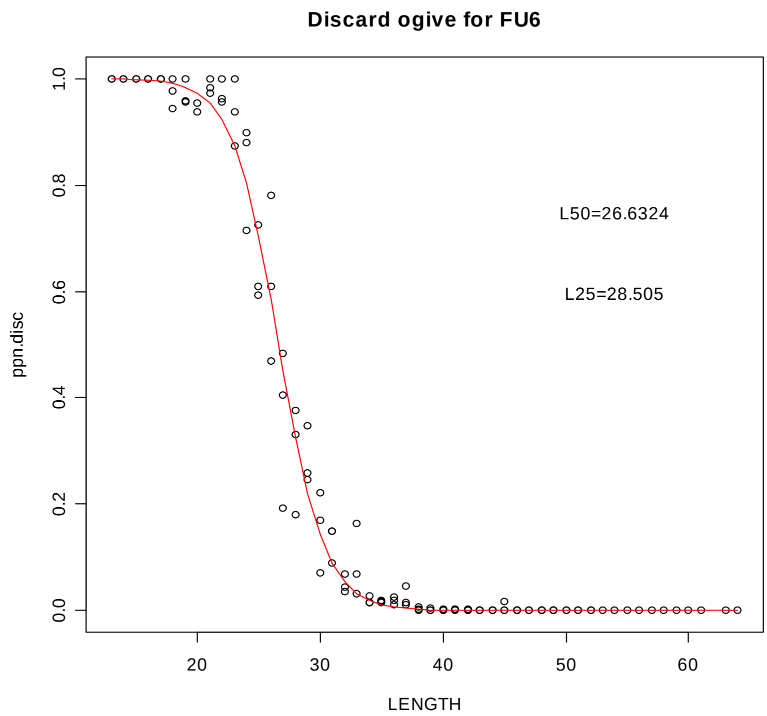


Figure B.1.2. Farn Deeps (FU 6): Discard ogive selected for FU6 *Nephrops*, trip level data pooled to year.

B.2. Biological

Mean weights-at-age for this stock are estimated from fixed weight-length relationships derived from samples collected from this fishery (Macer, unpublished data).

A natural mortality rate of 0.3 was assumed for all age classes and years for males and immature females, with a value of 0.2 for mature females based on Morizur, 1982. The lower value for mature females reflects the reduced burrow emergence while ovigerous and hence an assumed reduction in predation.

The size at maturity for females was recalculated at ICES WKNEPH 2006 to be 24.8 mm CL 24 mm CL was used in assessments prior to 2009. A sigmoid maturity function is now used: L25 = 24.5 mm, L50 = 25 mm.

Growth parameters are estimated from observations from this fishery (Macer, unpublished data) and comparison with adjacent stocks.

The time-invariant values used for proportion mature-at-age are: males age 1+: 100%; females age 1: 0%; age 2+: 100%. The source of the value for females is based on observations on 50% berried CL.

Discard survival (previously set at 25 %) was set to zero from 1991.

Summary:

Growth:

Males; L_∞ = 66 mm, k = 0.16

Immature Females; L_∞ = 66 mm, k = 0.16

Mature Females; L_∞ = 58 mm, k = 0.06,

Size-at-maturity L25=24.5 mm, L50=25 mm.

Weight-length parameters:

Males a = 0.00038, b = 3.17

Females a= 0.00091, b = 2.895

Discards

Discard survival rate: 0%.

Discard proportion: 29.5%

B.3. Surveys

Abundance indices are available from the following research-vessel surveys:

Underwater TV survey: years 1996–present. Surveys have been conducted in Spring and/or Autumn each year but only consistently in Autumn from 2001. In 2008 there was an historical revision of burrow density estimates from the TV survey. Previous estimates of burrow density had assumed that station density was independent of burrow density based analysis that demonstrated there was no evidence of differences in trends in burrow density between the different strata in the fishery (ICES WGNEPH, 2000). The assumption led to an unstratified mean density being used and multiplied by the total area to arrive at overall abundance. Analysis of burrow density by rectangle has since demonstrated that the distribution of stations is positively correlated with burrow density and therefore the unstratified mean density will overestimate burrow density. In order to compensate for the bias in sampling density, burrow abundance estimates are made for each rectangle then summed to give the new total.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates is as follows.

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 6: Farn Deeps	<=2009	1.3	0.85	1.05	1	1.2

B.4. Commercial cpue

Catch-per-unit-effort time-series are available from the following fleets:

- UK *Nephrops* trawl gears. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for English and Scottish *Nephrops* trawlers (single trawl and multiple trawl) is raised to the total landings reported by the four gear goups: *Nephrops* single trawl, multiple *Nephrops* trawl, Light trawl and multiple demersal trawl. There is no account taken of any technological creep in the fleet.

The registered buyers and sellers legislation brought in by the UK in 2006 changed the reporting procedure, which effectively breaks the continuity in the series at that point. The accuracy of the reported landings has significantly improved since then but there is currently little that can be done to determine and correct for any differences in the two series.

B.5. Other relevant data

None.

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_{l} N_L}{\sum_{l} N_L + \left(\sum_{l} N_D \times S_D \right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

		Implied fishery		
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None.

F. Long-term projections

None.

G. Biological reference points

None specified.

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F-reference point	Harvest ratio
F0.1	8.2%
Fmax	13.3%

H. Other issues

I. References

Annex 7: Stock Annex: FU7, Fladen Ground

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Fladen Ground *Nephrops* (FU 7)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. The Fladen Ground is located towards the centre of the northern part of Division IV. Its eastern boundary is adjacent to the Norwegian Deeps area, while its western boundary borders the Moray Firth functional unit (FU9). There is some evidence of overlap of habitat at the boundary of these areas. The ground represents one of the largest areas of soft muddy sediments in the North Sea and there are wide variations in sediment composition across the ground. *Nephrops* is distributed throughout the area and is associated with various benthic communities reflecting the variations in physical environment.

A.2. Fishery

The Fladen fishery (FU7), the largest Scottish *Nephrops* fishery, takes a mixed catch with haddock, whiting, cod, monkfish and flatfish such as megrim, also making an important contribution to vessel earnings. The Fladen *Nephrops* fleet comprises vessels from 12 m up to 35 m fishing mainly with 80 mm twin-rig. The fleet has a diverse range of boats, and includes some of the largest most modern purpose built boats in the Scottish fleet and vessels which have recently converted to *Nephrops* fishing.

The area supports well over 100 vessels and the majority of the fleet (80%) fish out of Fraserburgh, with the other important ports being Peterhead, Buckie, Macduff, and Aberdeen. Boats fish varying lengths of trip between 3 days (small boats) and 8–9 day trips (larger vessels). During 2006 and 2007 around 20 vessels joined the fleet and 5 ongoing new boat builds have the capability to fish at Fladen. Some whitefish vessels have converted to *Nephrops* twin-rigging.

The Fladen fishery generally follows a similar pattern every year, with different areas of the Fladen grounds producing good fishing at different times of the year (boats fish the north of the ground in winter, then move east towards the sector line in summer). During 2004–2005 this seasonal pattern was less apparent with fishing being good throughout the year on a range of grounds. There was also no lull in catch rates which traditionally happens in April–May. In 2006 however, there was a return to a more usual pattern of fishing with catches poor for most of spring and slowly getting better throughout summer. Some participating vessels explored slightly different areas to fish in 2006, particularly on the eastern edge of the ground. Bad weather at the start of 2006 and part of 2007 also contributed to the slower start to the fishery in these years. In some years, high squid abundance in the Moray Firth attracts Fladen vessels but in the last two years this was not so evident compared with 2005.

Other developments include the capability of freezing at sea and in one case, processing at sea. A recent tendency towards shorter trip lengths and improved handling practice is associated with market demand for high quality *Nephrops* which appears to have increased dramatically. The implementation of buyers and sellers legislation in 2006 has reduced the problem of underreporting and prices have risen, while weighing at sea has improved the accuracy of reported landings.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length compositions of Scottish landings and discards are obtained during monthly market sampling and quarterly on-board observer sampling respectively. Levels of sampling have increased since 2000 and are considered adequate for providing representative length structure of removals at the Fladen Ground. Although assessments based on detailed catch analysis are not currently possible, examination of length compositions can provide a preliminary indication of exploitation effects.

Lpue and cpue data were available for Scottish *Nephrops* trawls. Table B1.1 shows the data for single trawls, multiple trawls and combined. Examination of the long-term commercial lpue data (Figure B1.1) suggests a rapid increase since 2003. It is likely, however, that improved reporting of landings data in recent years particularly arising from 'buyers and sellers legislation has contributed to the increase. The high levels have been maintained since 2003. In addition, effort recording in terms of hours fished is non-mandatory and therefore it is unclear whether these trends and those that are discussed below are actually indicative of trends in lpue.

Males consistently make the largest contribution to the landings (Figure B1.2), although the sex ratio does vary. In earlier years effort was generally highest in the latter part of the year in this fishery, but the pattern varies between years, and the seasonal pattern does not appear as strong in recent years. Lpue of both sexes remained relatively constant up to 2002, and in common with the overall figure has demonstrated a marked increase since then. This suggests that exploitation (or other external factors) is not disproportionately affecting one sex or the other. Lpue is fairly similar through the year for males but for females there is no consistent pattern in these data.

Lpue data for each sex, above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the size above which the effects of discarding practices were not expected to occur and the size below which recruitment events might be observed in the length composition. The data demonstrate a rise in lpue in all categories since 2001. There is, however, no apparent lag between the increased lpues of <35 mm animals and >35 mm animals which one might expect if the reason was increasing abundance.

B.2. Biological

Dynamics for this stock are poorly understood and studies to estimate growth have not been carried out. Parameters applied in a preliminary length-based assessment and age (with length) based simulation to inform the catch forecast process were as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years.

Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

von Bertalanffy growth parameters are as follows:

Males; L_∞ = 66 mm, k = 0.16

Immature Females; L_∞ = 66 mm, k = 0.16

Mature Females; L_∞ = 56 mm, k = 0.10,

Size at maturity = 25 mm

Weight length parameters:

Males a = 0.0003, b = 3.25

Females a= 0.00074, b = 2.91

Discards

Discard survival rate: 25%.

Discard proportion: 13.8%

B.3. Surveys

TV surveys using a stratified random design are available for FU 7 since 1992 (missing survey in 1996). Underwater television surveys of *Nephrops* burrow number and distribution reduce the problems associated with traditional trawl surveys that arise from variability of burrow emergence of *Nephrops*.

On average, about 60 stations have been considered valid each year with over 70 stations in the last three years. Data are raised to a stock area of 28 153 km^2 based on the stratification. General analysis methods for underwater TV survey data are similar for each of the Scottish surveys. The ground has a range of mud types from soft silty clays to coarser sandy muds; the latter predominate (Figure B3.1). Most of the variance in the survey is associated with this variable sediment which surrounds the main centres of abundance. Abundance is generally higher in the soft and intermediate sediments located to the centre and southeast of the ground but in 2007, higher densities were also recorded in the more northerly parts of the ground. In general the confidence intervals have been fairly stable in this survey.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Fladen are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 7: Fladen	<=2009	1.45	0.9	1	1	1.35

B.4. Commercial cpue

Scottish *Nephrops* trawl gears: Landings, discards and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information See section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D \right)}$$

5) Where *R*=retention, *l*=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

6) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12 345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equivalent to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm.

F-reference point	Harvest ratio
F0.1	9.3%
Fmax	15.8%

H. Other issues

I. References

Table B1.1. ***Nephrops*****, Fladen (FU 7): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).**

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	304	8.6	35.3	304	8.6	35.3	na	na	na
1982	382	12.2	31.3	382	12.2	31.3	na	na	na
1983	548	15.4	35.6	548	15.4	35.6	na	na	na
1984	549	11.4	48.2	549	11.4	48.2	na	na	na
1985	1016	26.6	38.2	1016	26.6	38.2	na	na	na
1986	1398	37.8	37.0	1398	37.8	37.0	na	na	na
1987	1024	41.6	24.6	1024	41.6	24.6	na	na	na
1988	1306	41.7	31.3	1306	41.7	31.3	na	na	na
1989	1719	47.2	36.4	1719	47.2	36.4	na	na	na
1990	1703	43.4	39.2	1703	43.4	39.2	na	na	na
1991	3024	78.5	38.5	410	11.4	36.0	2614	67.1	39.0
1992	1794	38.8	46.2	340	9.4	36.2	1454	29.4	49.5
1993	2033	49.9	40.7	388	9.6	40.4	1645	40.3	40.8
1994	1817	48.8	37.2	301	8.4	35.8	1516	40.4	37.5
1995	3569	75.3	47.4	2457	52.3	47.0	1022	23.0	44.4
1996	2338	57.2	40.9	2089	51.4	40.6	249	5.8	42.9
1997	2713	76.5	35.5	2013	54.7	36.8	700	21.8	32.1
1998	2291	60.0	38.2	1594	39.6	40.3	697	20.5	34.0
1999	2860	76.8	37.2	1980	50.3	39.4	880	26.5	33.2
2000	2915	92.1	31.7	2002	62.9	31.8	913	29.2	31.3
2001	3539	108.2	32.7	2162	65.8	32.9	1377	42.4	32.5
2002	4513	109.6	41.2	2833	58.9	48.1	1680	50.7	33.1
2003	4175	53.7	77.7	3388	42.8	79.2	787	10.9	72.2
2004	7274	56.1	129.8	6177	47.5	130.2	1097	8.6	127.6
2005	8849	61.3	144.4	6834	43.4	157.5	2015	17.9	112.7
2006	9469	65.7	144.1	7149	50.2	142.4	2320	15.5	149.7
2007	11054	69.6	158.8	8232	52.2	157.7	2822	17.4	162.2

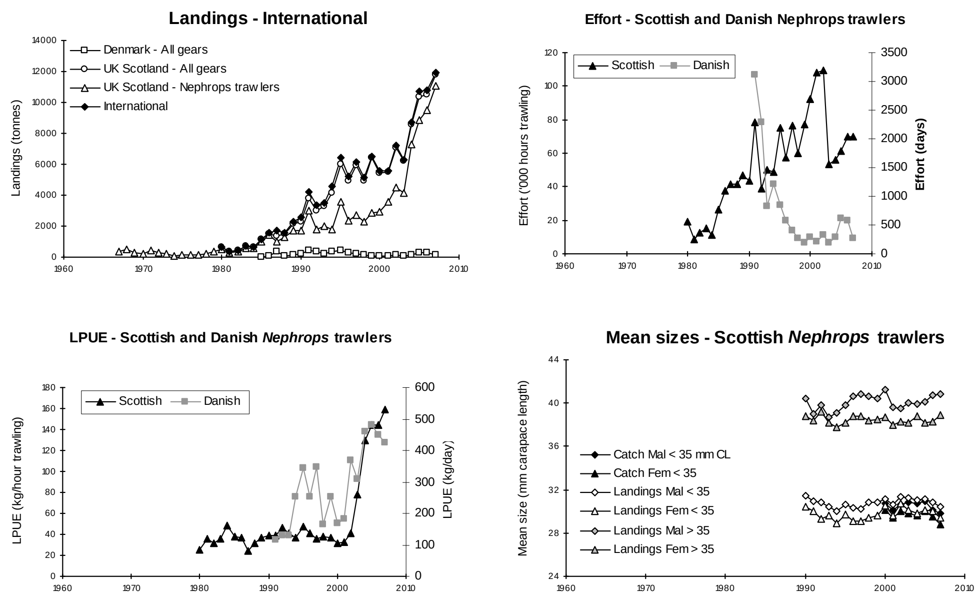


Figure B1.1. ***Nephrops*****, Fladen (FU 7), Long term landings, effort, lpue and mean sizes.**

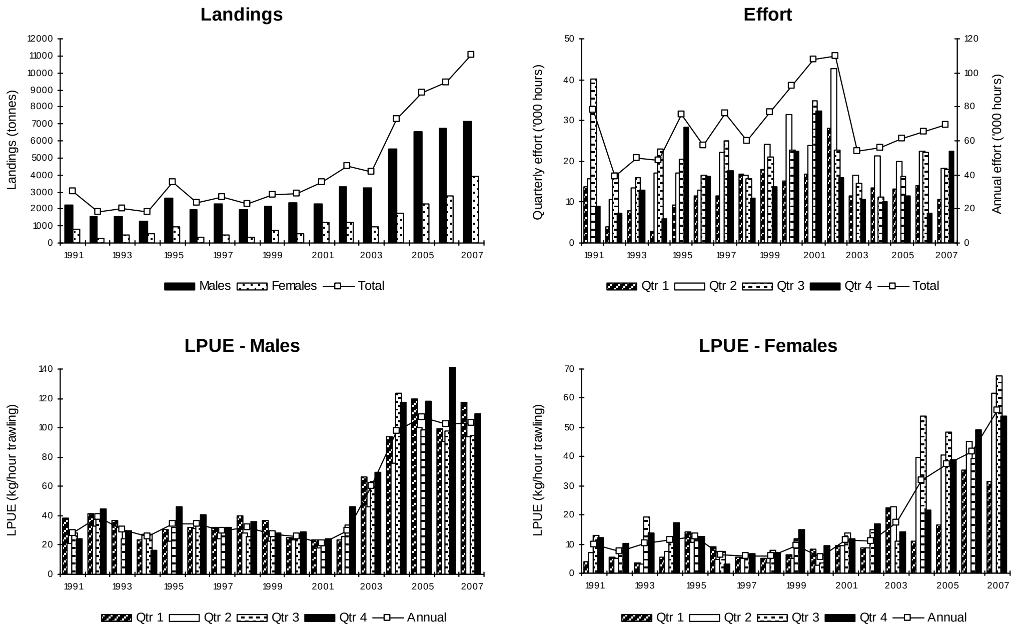


Figure B1.2. ***Nephrops*, Fladen (FU 7), Landings, effort and lpues by quarter and sex from Scottish *Nephrops* trawlers.**

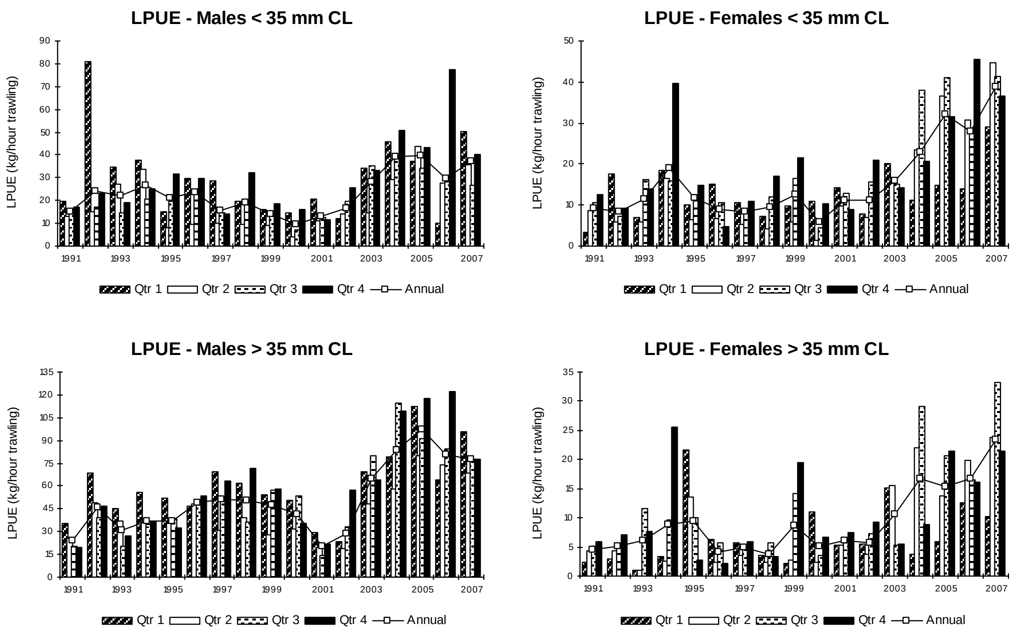


Figure B1.3. ***Nephrops*, Fladen (FU 7), cpues by sex and quarter for selected size groups, Scottish *Nephrops* trawlers.**

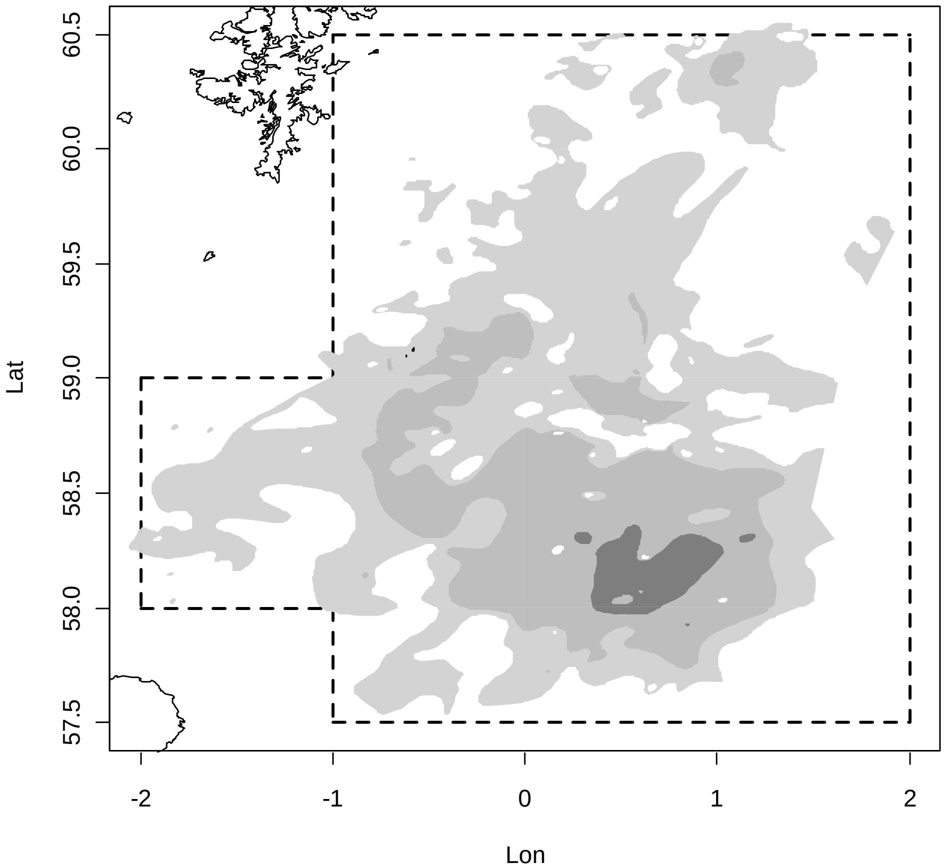


Figure B3.4. Distribution of *Nephrops* sediments in the Fladen Ground (FU 7). Thick dashed lines represent the boundary of the functional unit. Sediments are: Dark grey – Mud; Grey – Sandy Mud, Light Grey – Muddy.

Annex 8: Stock Annex: FU8, Firth of Forth

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Firth of Forth *Nephrops* (FU 8)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. The Firth of Forth is located close inshore to the Scottish coast, towards the west of the central part of Division IV. The mud substratum in the Firth of Forth area is mainly muddy sand and sandy mud, and there is only a small amount of the softest mud. The population of *Nephrops* in this area is composed of smaller animals. Earlier research suggested that residual currents moving southward from this area transport some larvae to the Farn Deeps; recent larval surveys have not been undertaken, however, and it is unclear how significant this effect is. Outside the functional unit, a *Nephrops* population is found on a smaller patch of mud beyond the northern boundary, off Arbroath.

A.2. Fishery

The *Nephrops* fishery is located throughout the Firth but is particularly focused on grounds to the east and southeast of the Isle of May. Grounds located further up the Firth occur in areas closer to industrial activity and shipping.

Most of the vessels are resident in ports around the Firth of Forth, particularly at Pittenweem, Port Seton and Dunbar. Some vessels, normally active in the Farn Deeps, occasionally come north from Eyemouth and South Shields. During 2006 and 2007 the number of vessels regularly fishing in the Firth of Forth was been around 40 (23 under 10 m and 19 over 10 m vessels). This number varies seasonally with vessels from other parts of the UK increasing the size of the fleet. Local boats sometimes move to other grounds when catch rates drop during the late spring *Nephrops* moulting period. Traditionally, Firth of Forth boats move south to fish the Farn Deeps grounds. Single trawl fishing with 80 mm mesh size is the most prevalent method. Some vessels utilize a 90 mm codend. A couple of vessels have the capability for twin rigging. Night fishing for *Nephrops* is commonest in summer. Day fishing is the norm in winter. A very small amount of creeling for *Nephrops* takes place; this is mostly by crab and lobster boats.

Nephrops is the main target species with diversification by some boats to squid, and also surf clams. Only very small amounts of whitefish are landed. The area is characterized by catches of smaller *Nephrops* and discarding is sometimes high. The latest information for 2007 suggests that large catches of small *Nephrops* were taken. In the past, small prawns generally led to high tail:whole prawn ratios in this fishery but in recent years a small whole prawn ‘paella’ market developed.

In 2006, buyers and sellers regulations led to increased traceability and improved reporting of catches. This continued and improved further in 2007 and the reporting of landings is now considered to be much more reliable.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length compositions of landings and discards are obtained during monthly market sampling and quarterly on-board observer sampling respectively. Levels of sampling are considered adequate for providing representative length structure of removals in the Firth of Forth. Although assessments based on detailed catch analysis are not currently possible, examination of length compositions can provide a preliminary indication of exploitation effects.

Lpue and cpue data were available for Scottish *Nephrops* trawls. Table B1.1 shows the data for single trawls, multiple trawls and combined. Examination of the long-term commercial lpue data (Figure B1.1) suggests that the stock is currently very abundant but the recent improvements in reporting of landings (as a consequence of 'buyers and sellers' legislation) may mean this is an artefact generated by more complete landings data. In addition, effort recording in terms of hours fished is non-mandatory which will also affect the trends in lpue.

Males consistently make the largest contribution to the landings (Figure B1.2), although the sex ratio does vary. Effort is generally highest in the 3rd quarter of the year in this fishery, but although the pattern was fairly stable in the early years, the pattern does not appear as strong in recent years and is 2007 was fairly evenly spread throughout the year. Lpue of both sexes has fluctuated through the time-series and is currently at a high level. The comments about the quality of landings data are relevant here too. Lpue is generally higher for males in the 1st and 4th quarters, and for females in the 3rd quarter; the period when they are not incubating eggs.

Cpue data for each sex, above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the size above which the affects of discarding practices were not expected to occur and the size below which recruitment events might be observed in the length composition. The data demonstrate a slight peak in cpue for smaller individuals (both sexes) in 1999, with a decline after this, followed by a steady increase in both sexes from 2002 onwards. The cpue for larger individuals demonstrated a similar pattern with higher values in the most recent years.

B.2. Biological

Dynamics for this stock are poorly understood and studies to estimate growth have not been carried out. Assumed biological parameters are as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

Growth parameters

Males; L_∞ = 66 mm, k = 0.163

Immature Females; L_∞ = 66 mm, k = 0.163

Mature Females; L_∞ = 58 mm, k = 0.065,

Size at maturity = 26 mm

Weight length parameters:

Males a = 0.00028, b = 3.24

Females a= 0.00085, b = 2.91

Discards

Discard survival rate: 25%.

Discard rate: 34.6%

B.3. Surveys

TV surveys using a stratified random design are available for FU 8 since 1993 (missing surveys in 1995 and 1997). Underwater television surveys of *Nephrops* burrow number and distribution reduce the problems associated with traditional trawl surveys that arise from variability of burrow emergence of *Nephrops*. On average, about 40 stations have been considered valid each year with more stations sampled in the last three years. The survey in 2006 was conducted in December so that densities may not be strictly compatible with the remainder of the series. Abundance data are raised to a stock area of 915 km^2. General analysis methods for underwater TV survey data are similar for each of the Scottish surveys. The ground is predominantly of coarser muddy sand (Figure B3.1). Depending on the year, high variance in the survey is associated with different strata and there is no clear distributional or sedimentary pattern in this area. Abundance is generally higher towards the central part of the ground and around the Isle of May. In recent years higher densities have been recorded over quite wide areas. Confidence intervals have been fairly stable in this survey.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Firth of Forth are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 8: Firth of Forth	<=2009	1.23	0.9	1.05	1	1.18

B.4. Commercial cpue

Scottish *Nephrops* trawl gears: Landings, discards and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in

1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information see Section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight-in-landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight, use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_{l} N_L}{\sum_{l} N_L + \left(\sum_{l} N_D \times S_D \right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equivalent to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm.

F-reference point	Harvest ratio
F0.1	8.0%
Fmax	13.7%

H. Other issues

I. References

Table B1.1. ***Nephrops*****, Firth of Forth (FU 8): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).**

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	945	42.6	22.2	945	42.6	22.2	na	na	na
1982	1138	51.7	22.0	1138	51.7	22.0	na	na	na
1983	1681	60.7	27.7	1681	60.7	27.7	na	na	na
1984	2078	84.7	24.5	2078	84.7	24.5	na	na	na
1985	1908	73.9	25.8	1908	73.9	25.8	na	na	na
1986	2204	74.7	29.5	2204	74.7	29.5	na	na	na
1987	1582	62.1	25.5	1582	62.1	25.5	na	na	na
1988	2455	94.8	25.9	2455	94.8	25.9	na	na	na
1989	1833	78.7	23.3	1833	78.7	23.3	na	na	na
1990	1901	81.8	23.2	1901	81.8	23.2	na	na	na
1991	1359	69.4	19.6	1231	63.9	19.3	128	5.5	23.3
1992	1714	73.1	23.4	1480	63.3	23.4	198	8.5	23.3
1993	2349	100.3	23.4	2340	100.1	23.4	9	0.2	45.0
1994	1827	87.6	20.9	1827	87.6	20.9	0	0.0	0.0
1995	1708	78.9	21.6	1708	78.9	21.6	0	0.0	0.0
1996	1621	69.7	23.3	1621	69.7	23.3	0	0.0	0.0
1997	2137	71.6	29.8	2137	71.6	29.8	0	0.0	0.0
1998	2105	70.7	29.8	2105	70.7	29.8	0	0.0	0.0
1999	2192	67.7	32.4	2192	67.7	32.4	0	0.0	0.0
2000	1775	75.3	23.6	1761	75.0	23.5	14	0.3	46.7
2001	1484	68.8	21.6	1464	68.3	21.4	20	0.5	40.0
2002	1302	63.6	20.5	1286	63.3	20.3	16	0.3	53.3
2003	1115	53.0	21.0	1082	52.4	20.6	33	0.6	55.0
2004	1651	63.2	26.1	1633	62.9	26.0	18	0.4	49.7
2005	1973	66.6	29.6	1970	66.5	29.6	3	0.1	58.8
2006	2437	61.4	39.7	2432	61.0	39.9	5	0.4	14.2
2007	2622	57.6	45.5	2601	57.1	45.6	21	0.5	43.2

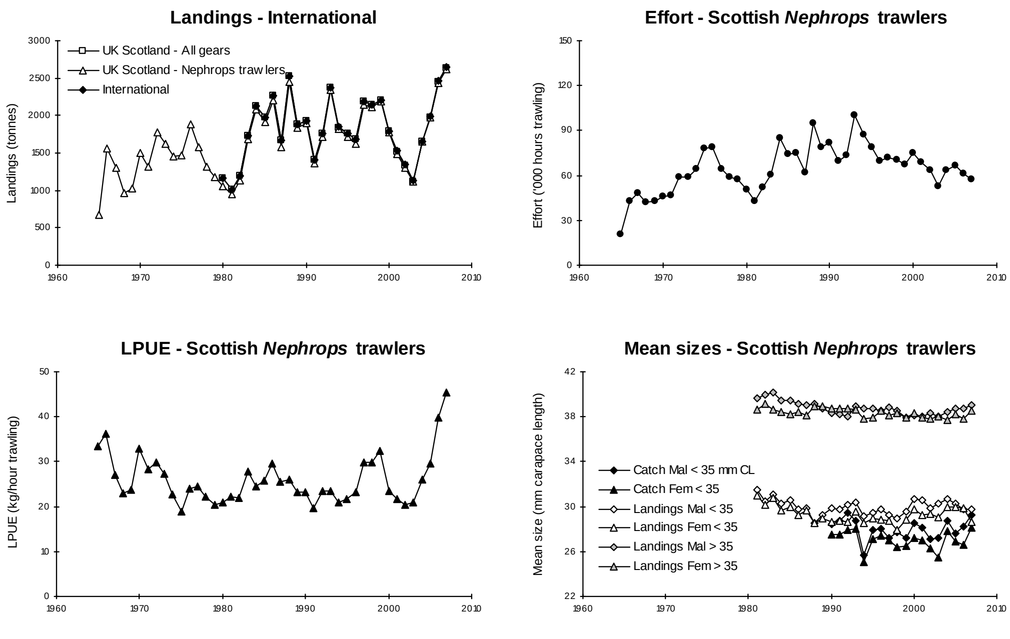


Figure B1.1. ***Nephrops*****, Firth of Forth (FU 8), Long term landings, effort, lpue and mean sizes.**

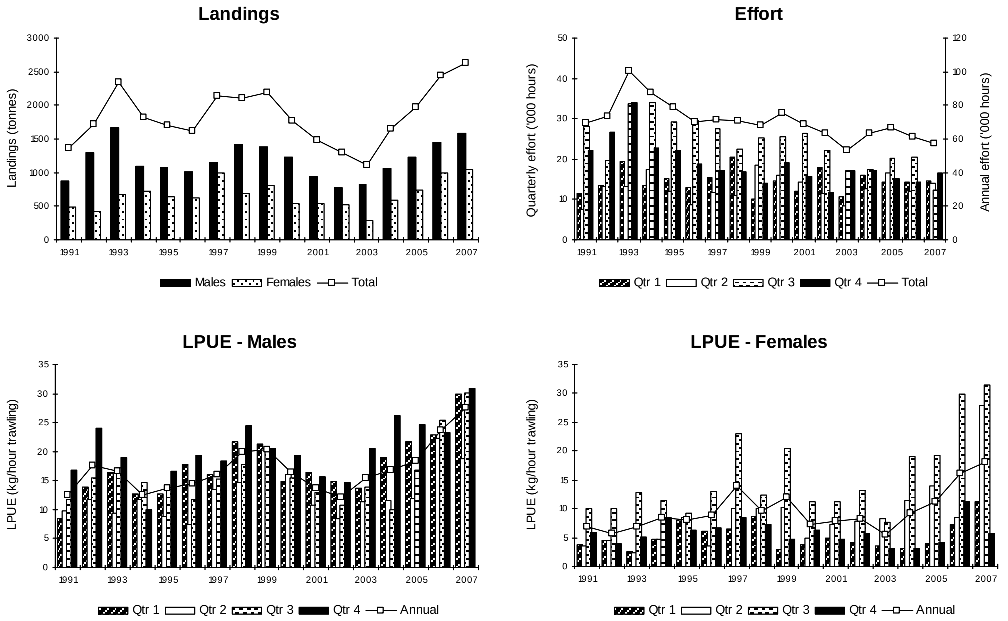


Figure B1.2. ***Nephrops*****, Firth of Forth (FU 8), Landings, effort and lpues by quarter and sex from Scottish *Nephrops* trawlers.**

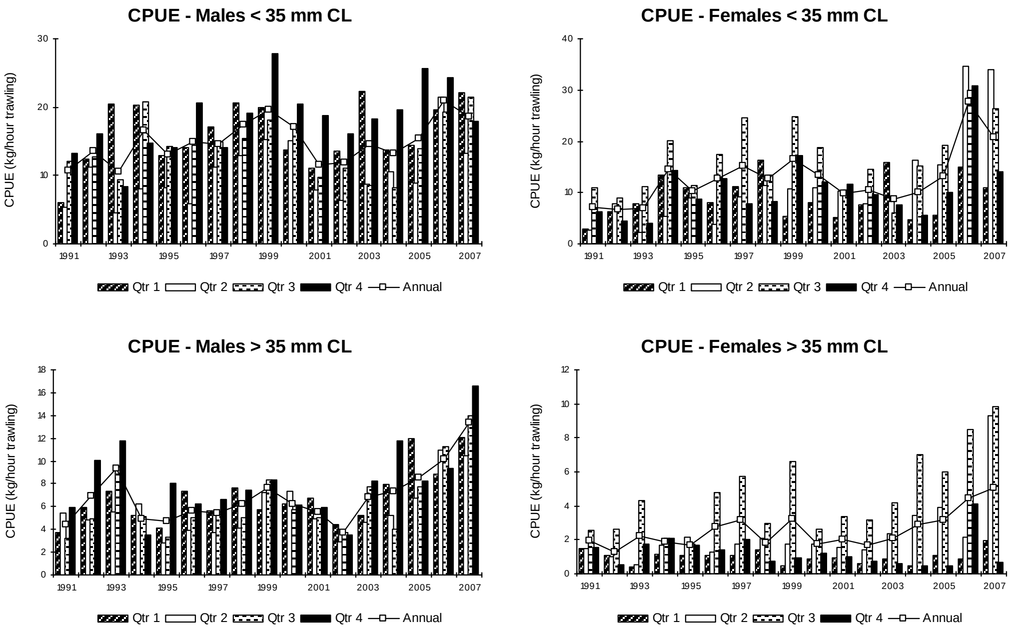


Figure B1.3. ***Nephrops*****, Firth of Forth (FU 8), cpues by sex and quarter for selected size groups, Scottish *Nephrops* trawlers.**

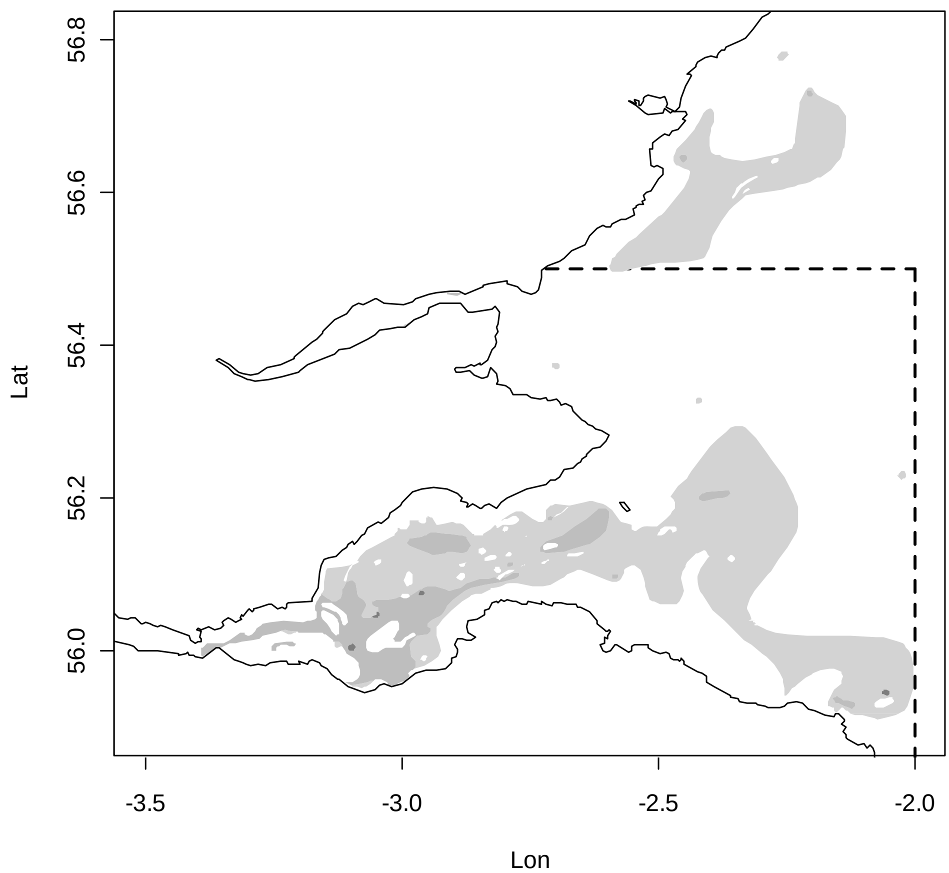


Figure B3.1. Distribution of *Nephrops* sediments in the Firth of Forth (FU 8). Thick dashed lines represent the boundary of the functional unit. Sediments are: Dark grey – Mud; Grey – Sandy Mud, Light Grey – Muddy.

Annex 9: Stock Annex: FU9, Moray Firth

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Moray Firth *Nephrops* (FU 9)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. The Moray Firth is located to the northwest of Division IV. In common with other *Nephrops* fisheries the bounds of the Functional Unit are defined by the limits of muddy substratum. The major *Nephrops* fisheries within this management area fall within 30 miles of the UK coast. The Moray Firth (FU9) is a relatively sheltered inshore area that supports populations of juvenile pelagic fish and relatively high densities of squid at certain times. The Moray Firth borders the Fladen functional unit (FU7) and there is some evidence of *Nephrops* populations lying across this boundary.

A.2. Fishery

The Moray Firth area is fished by a number of the smaller class of *Nephrops* boat (12–16 m) regularly fishing short trips from Buckie, Helmsdale, Macduff and Burghead. Most boats still fish out of Burghead, and are about 15 ; leaving and returning to port within 24 hours (day boats). Many of the smaller boats are now only manned by one or two people. Several of the larger *Nephrops* trawlers fish the outer Moray Firth grounds on their way to or from the Fladen grounds (especially when they are fishing the Skate Hole area). Also in times of bad weather many of the larger *Nephrops* trawlers which would normally be fishing the Fladen grounds fish the Moray Firth grounds. In recent years a squid fishery has been seasonally important in the Moray Firth. Squid appear to the east of the Firth and gradually move west during summer, increasing in size as they shift. During autumn the movement is reversed. A large fishery took place in 2004 that attracted a number of *Nephrops* vessels and in 2005, additional vessels joined in the seasonal fishery, but catches were noticeably down in 2006. In 2007 however the fishery for squid improved again and a number of boats switched effort until around October, with some boats fishing squid until December.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length compositions of landings and discards are obtained during monthly market sampling and quarterly on-board observer sampling respectively. Levels of sampling are considered adequate for providing representative length structure of removals in the Moray Firth. Although assessments based on detailed catch analysis are not currently possible, examination of length compositions can provide a preliminary indication of exploitation effects.

Lpue data were available for Scottish *Nephrops* trawls. Table B1.1 shows the data for single trawls, multiple trawls and combined. Examination of the long-term commercial lpue data (Figure B1.1) suggests that the stock increased in the early 1980s then declined to a stable level over the next 12 years or so and has recently increased to its highest level in 2007. It is thought that gear efficiency changes have occurred over time, particularly in relation to multiple trawl gears but this has not been quantified. Additionally, improved reporting of landings data in recent years, arising from 'buyers and sellers' legislation, is likely also to have contributed to the increase in lpue. Furthermore, effort recording is non-mandatory in terms of hours fishing and therefore it is unclear whether these trends and those that are discussed below are actually indicative of trends in lpue.

Males generally make the largest contribution to the landings (Figure B1.2), although the sex ratio does vary, and female landings exceeded males in 1994. Effort is generally highest in the 3rd quarter of the year in this fishery, but the pattern varies between years, and the seasonal pattern does not appear as strong in recent years. Lpue of both sexes remained relatively constant up to 2002, but has demonstrated an increase since then. Lpue is generally higher for males in the 1st and 4th quarters, and for females in the 3rd quarter; the period when they are not incubating eggs.

Cpue data for each sex, above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the general size limit for discarded animals. The data demonstrate a slight peak in cpue for smaller individuals (both sexes) in 1995, with a slight decline after this and relatively stable values from 2001 onwards. There is a peak in catches of small males in 2006 quarter 4 but taken annually the pattern is relatively stable. The cpue for larger males demonstrates relatively stable levels during the late 1990s and slightly higher levels in the most recent years, particularly from 2003 onwards. Cpue for large females declined in 2005 but have risen again over the past two years, and demonstrated a significant large value in 2007 quarter 3.

B.2. Biological

Dynamics for this stock are poorly understood and studies to estimate growth have not been carried out. Assumed biological parameters are as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

Growth parameters:

Males; L_∞ = 62 mm, k = 0.165

Immature Females; L_∞ = 62 mm, k = 0.165

Mature Females; L_∞ = 56 mm, k = 0.06,

Size at maturity = 25 mm

Weight length parameters:

Males a = 0.00028, b = 3.24

Females a= 0.00074, b = 2.91

Discards

Discard survival rate: 25%

Discard rate: 7.4%

B.3. Surveys

TV surveys are available for FU 9 since 1993 (missing survey in 1995). Underwater television surveys of *Nephrops* burrow number and distribution reduce the problems associated with traditional trawl surveys that arise from variability of burrow emergence of *Nephrops*.

On average, about 36 stations have been considered valid each year, and are raised to a stock area of 2195 km^2. General analysis methods for underwater TV survey data are similar for each of the Scottish surveys. The ground is predominantly of coarser muddy sand (Figure B3.1) and most of the variance in the survey is associated with a patchy area of this sediment to the west of the ground. Abundance has generally been higher towards the west of the ground but in recent years higher densities have been recorded throughout, and are quite evenly distributed at the east and west ends in 2006 and 2007. With the exception of 2003, the confidence intervals have been fairly stable in this survey.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Moray Firth are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 9: Moray Firth	<=2009	1.31	0.9	1	1	1.21

B.4. Commercial cpue

Scottish *Nephrops* trawl gears: Landings-at-age and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information see Section B.1

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.
2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.
3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.
2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.
3) Multiply the survey index by the harvest ratios to give the number of total removals.
4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D\right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.
5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F-reference point	Harvest ratio
F0.1	8.9%
Fmax	16.6%

H. Other issues

I. References

Table B1.1. *Nephrops*, Moray Firth (FU 9): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	1298	36.7	35.4	1298	36.7	35.4	na	na	na
1982	1034	28.2	36.7	1034	28.2	36.7	na	na	na
1983	850	21.4	39.7	850	21.4	39.7	na	na	na
1984	960	23.2	41.4	960	23.2	41.4	na	na	na
1985	1908	49.2	38.8	1908	49.2	38.8	na	na	na
1986	1933	51.6	37.5	1933	51.6	37.5	na	na	na
1987	1723	70.6	24.4	1723	70.6	24.4	na	na	na
1988	1638	60.9	26.9	1638	60.9	26.9	na	na	na
1989	2102	69.6	30.2	2102	69.6	30.2	na	na	na
1990	1700	58.4	29.1	1700	58.4	29.1	na	na	na
1991	1284	47.1	27.3	571	25.1	22.7	713	22.0	32.4
1992	1282	40.9	31.3	624	24.8	25.2	658	16.1	40.9
1993	1505	48.6	31.0	783	28.1	27.9	722	20.6	35.0
1994	1178	47.5	24.8	1023	42.0	24.4	155	5.5	28.2
1995	967	30.6	31.6	857	27.0	31.7	110	3.6	30.6
1996	1084	38.2	28.4	1057	37.4	28.3	27	0.8	33.8
1997	1102	47.7	23.1	960	42.5	22.6	142	5.1	27.8
1998	739	34.4	21.5	576	28.1	20.5	163	6.3	25.9
1999	813	35.5	22.9	699	31.5	22.2	114	4.0	28.5
2000	1343	49.5	27.1	1068	39.8	26.8	275	9.7	28.4
2001	1188	47.6	25.0	913	37.0	24.7	275	10.6	25.9
2002	1526	35.5	43.0	649	27.2	23.9	234	7.9	29.6
2003	1718	41.1	41.8	737	25.3	29.1	135	3.6	37.5
2004	1818	36.9	49.3	1100	29.2	37.7	123	2.5	49.2
2005	1526	37.6	40.6	1309	34.0	38.5	217	3.6	60.3
2006	1718	41.1	41.8	1477	37.4	39.5	241	3.7	65.1
2007	1818	36.9	49.3	1503	32.4	46.4	315	4.5	70.0

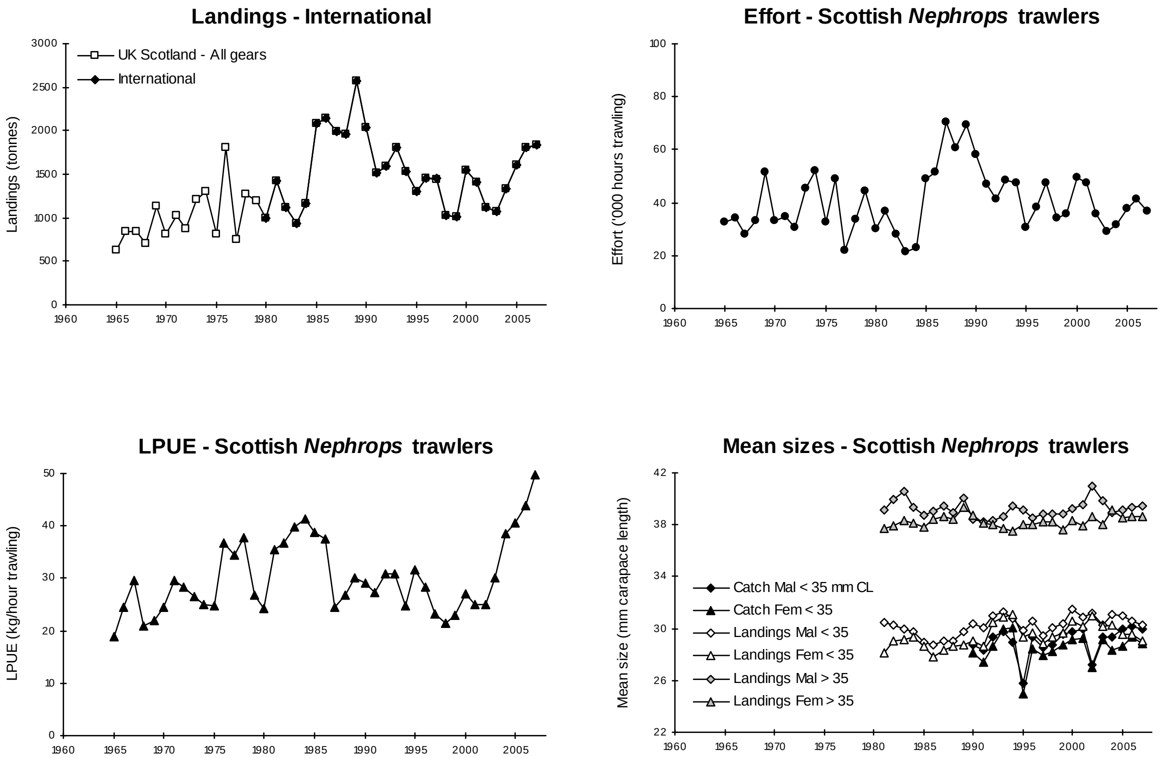


Figure B1.1. ***Nephrops*, Moray Firth (FU 9), Long term landings, effort, lpue and mean sizes.**

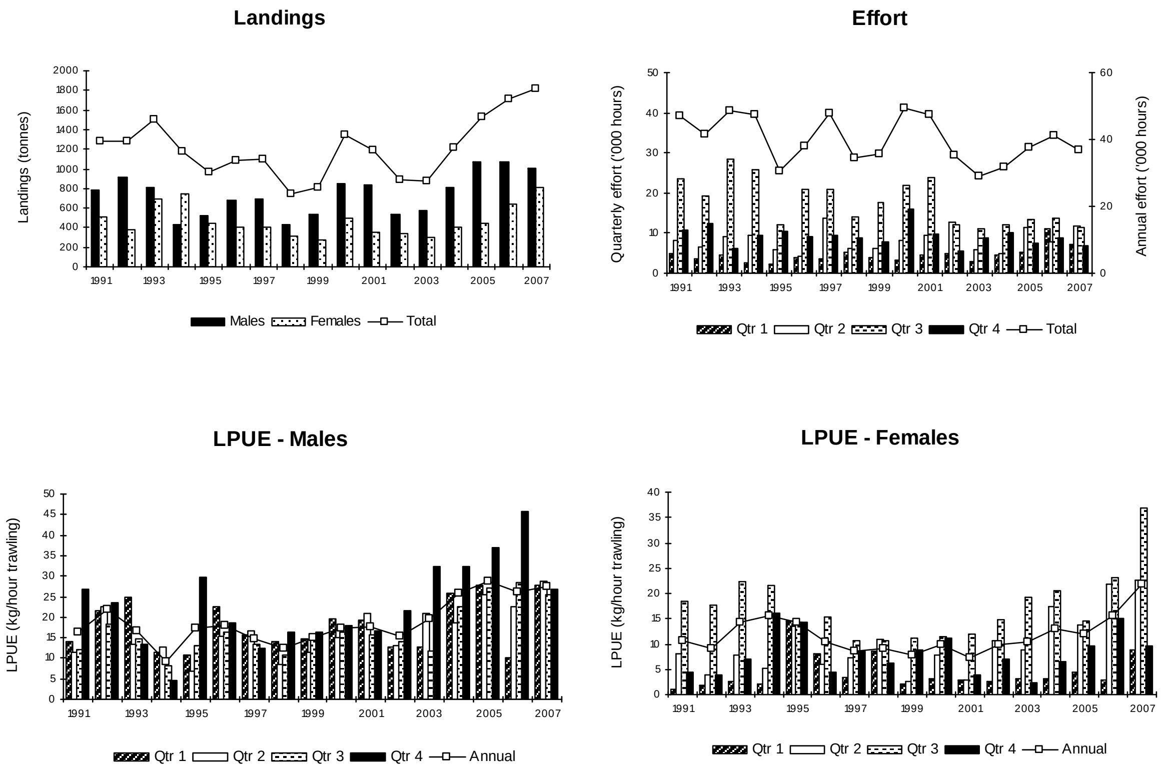


Figure B1.2. ***Nephrops*****, Moray Firth (FU 9), Landings, effort and unstandardized lpues by quarter and sex from Scottish *Nephrops* trawlers.**

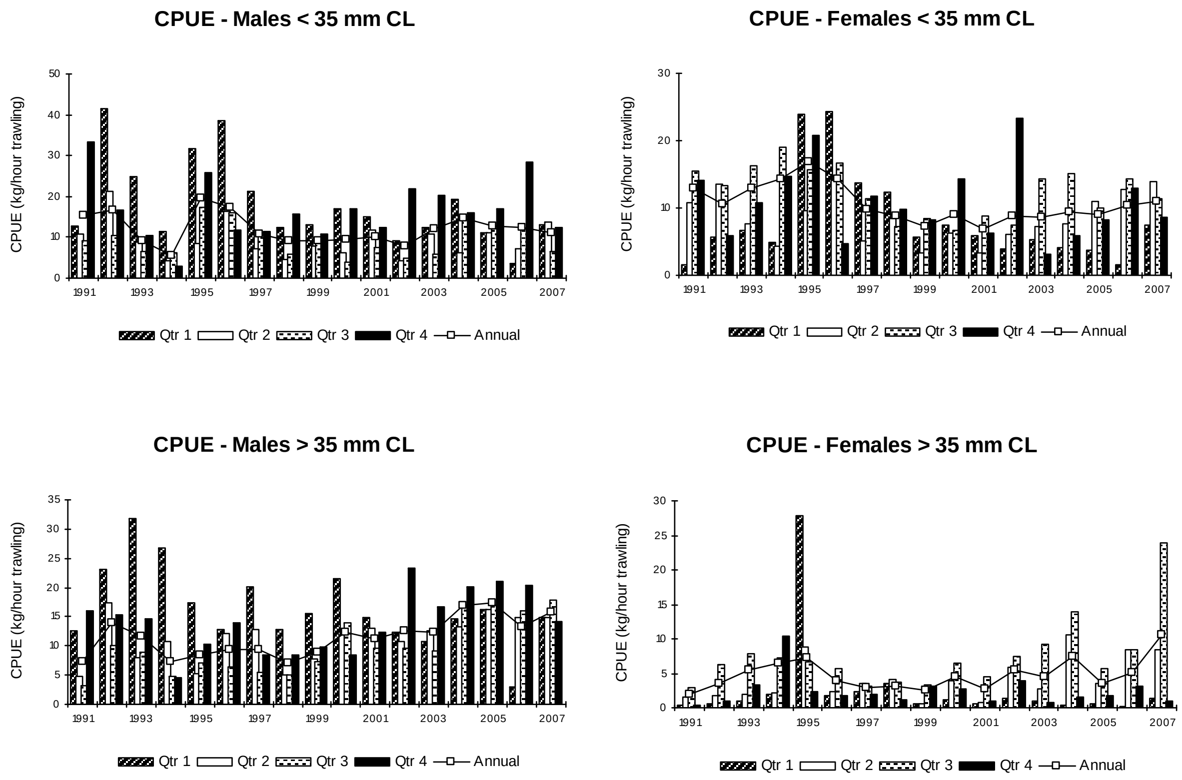


Figure B1.3. ***Nephrops*, Moray Firth (FU 9), cpues by sex and quarter for selected size groups, Scottish *Nephrops* trawlers.**

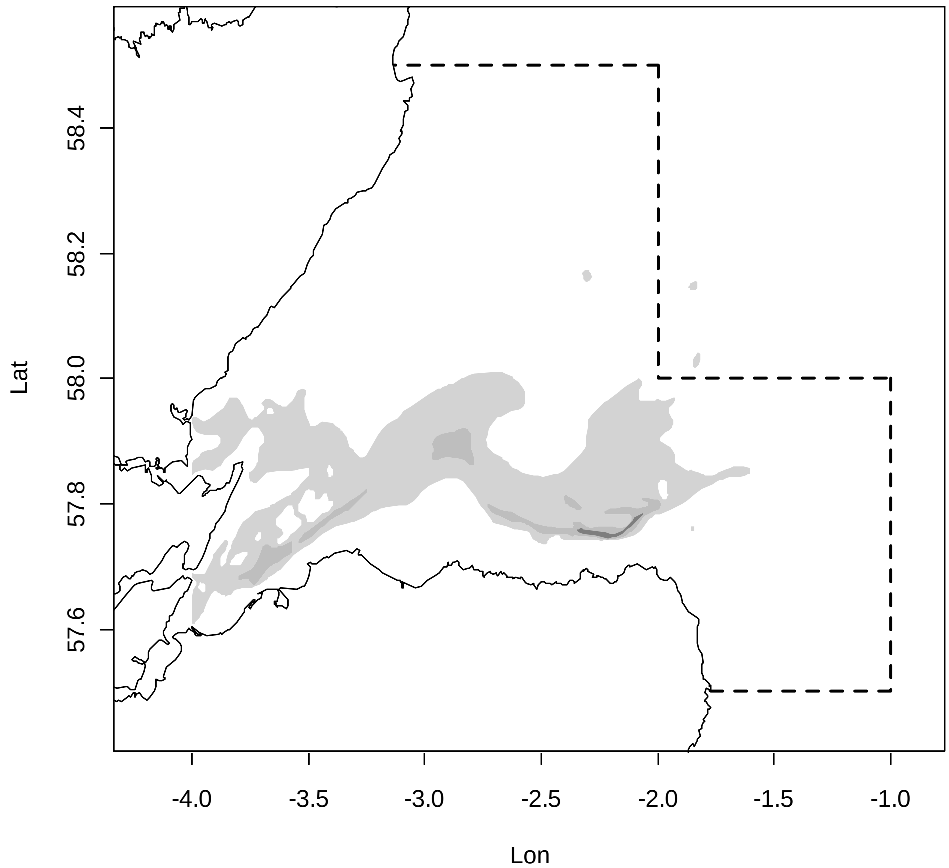


Figure B3.1. Distribution of *Nephrops* sediments in the Moray Firth (FU 9). Thick dashed lines represent the boundary of the functional unit. Sediments are: Dark grey – Mud; Grey – Sandy Mud, Light Grey – Muddy.

Annex 10: Stock Annex: FU10, Noup

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Noup *Nephrops* (FU 10)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. The Noup is located to the far northwest of Division IV adjacent to ICES VIa and closer to the influence of the west of Scotland waters. In common with other *Nephrops* fisheries the bounds of the Functional Unit are defined by the limits of muddy substratum. This small stock is one of the most isolated Functional Units. Particle tracking models suggest that plankton is transported from the west coast and passes across this area.

A.2. Fishery

The Noup grounds are regularly fished by 3–4 boats (16–24m) from Scrabster. They mainly target a mixed fish (mainly flat fish and monkfish) and *Nephrops* fishery using 100 mm (twin-rig) to stay within the catch composition regulations. Boats land an average of around 1.5 tonnes of *Nephrops* from a 6–7 day trip. Occasionally some of the Fraserburgh *Nephrops* fleets fish the Noup grounds although this did not happen in 2005–2007, as many of the boats who used to make the journey have been decommissioned. The Noup ground has previously produced a period of good fishing every year but the area has not been important in the last couple, of years.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Given that the levels of market sampling are low and discard sampling is not available, the length structure of removals in the fishery is not considered to be well represented by the available data.

Table B1.1 shows the landings, effort and lpue data for single trawls, multiple trawls and combined while Figure B1.1 illustrates the long-term commercial lpue data. The low levels of sampling for this fishery mean, it is not realistic to draw conclusions from changes in size composition or sex ratio. Figures B1.2 and B1.3 show landings and effort and lpue data, respectively. As a consequence of the very low levels of effort, small changes are likely to have very large effects and for this reason some data points in Figure B1.3 have been removed.

B.2. Biological

No data available.

B.3. Surveys

Underwater TV surveys are available for this stock in 1994 and 1999 and were also carried out in 2006 and 2007, where 7 and 9 stations were successfully surveyed in each year respectively and raised to a stock area of 339 km^2 (Figure B3.1). These two most recent surveys give consistent estimates of population size which are slightly lower than the 1999 value. All of these are lower than the very high value observed in 1994.

B.4. Commercial cpue

Scottish *Nephrops* trawl gears: Landings-at-age and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information see Section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don’t attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_{l} N_L}{\sum_{l} N_L + \left(\sum_{l} N_D \times S_D \right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

The time-series of available length frequencies were insufficient to generate reliable estimates of F0.1 and Fmax.

H. Other issues

I. References

Table B1.1. ***Nephrops*****, Noup (FU 10): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish** ***Nephrops*** **trawlers, 1981–2007 (data for all** ***Nephrops*** **gears combined, and for single and multirigs separately).**

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	13	0.4	34.3	13	0.4	34.3	na	na	na
1982	12	0.5	24.7	12	0.5	24.7	na	na	na
1983	9	0.3	30.7	9	0.3	30.7	na	na	na
1984	75	2.0	36.9	75	2.0	36.9	na	na	na
1985	2	0.1	25.0	2	0.1	25.0	na	na	na
1986	46	0.7	62.6	46	0.7	62.6	na	na	na
1987	12	0.7	18.1	12	0.7	18.1	na	na	na
1988	23	1.0	34.3	23	1.0	34.3	na	na	na
1989	24	0.9	25.8	24	0.9	25.8	na	na	na
1990	101	2.9	34.6	101	2.9	34.6	na	na	na
1991	110	4.8	22.9	23	0.9	25.6	87	3.9	22.3
1992	56	1.8	31.1	33	1.4	23.6	23	0.4	57.5
1993	200	4.8	41.7	152	3.6	42.0	48	1.2	39.0
1994	308	8.4	36.7	273	7.6	36.0	35	0.8	42.1
1995	162	3.9	41.5	139	3.5	39.9	23	0.4	63.2
1996	180	4.4	40.9	174	4.2	41.4	6	0.2	30.0
1997	185	5.3	34.9	172	4.9	35.1	13	0.4	32.5
1998	183	3.2	57.2	171	3.0	57.0	12	0.2	60.0
1999	211	4.1	51.8	196	3.8	53.0	15	0.3	54.9
2000	196	2.0	98.0	161	1.8	89.4	35	0.2	175.0
2001	89	1.7	52.4	82	1.4	58.6	7	0.3	23.3
2002	81	0.6	133.9	185	2.1	88.1	59	1.2	49.2
2003	258	0.5	551.3	217	2.3	94.3	41	0.4	102.5
2004	175	2.2	79.5	144	2.2	65.2	31	0.0	-
2005	81	0.6	135.0	58	0.6	98.3	23	0.0	-
2006	44	0.3	146.7	42	0.4	94.6	2	0.0	-
2007	47	0.6	78.3	43	0.6	71.3	4	0.0	-

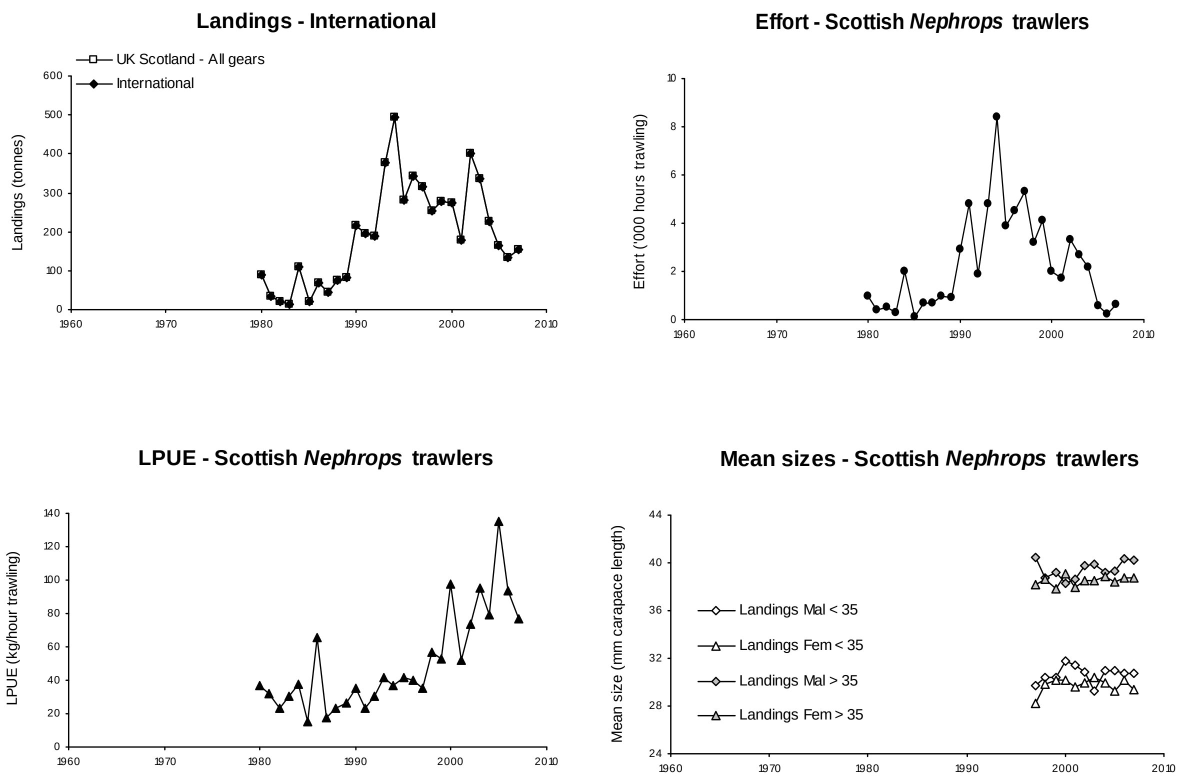


Figure 3.4.1.11. ***Nephrops*, Noup (FU 10), Long term landings, effort, lpue and mean sizes.**

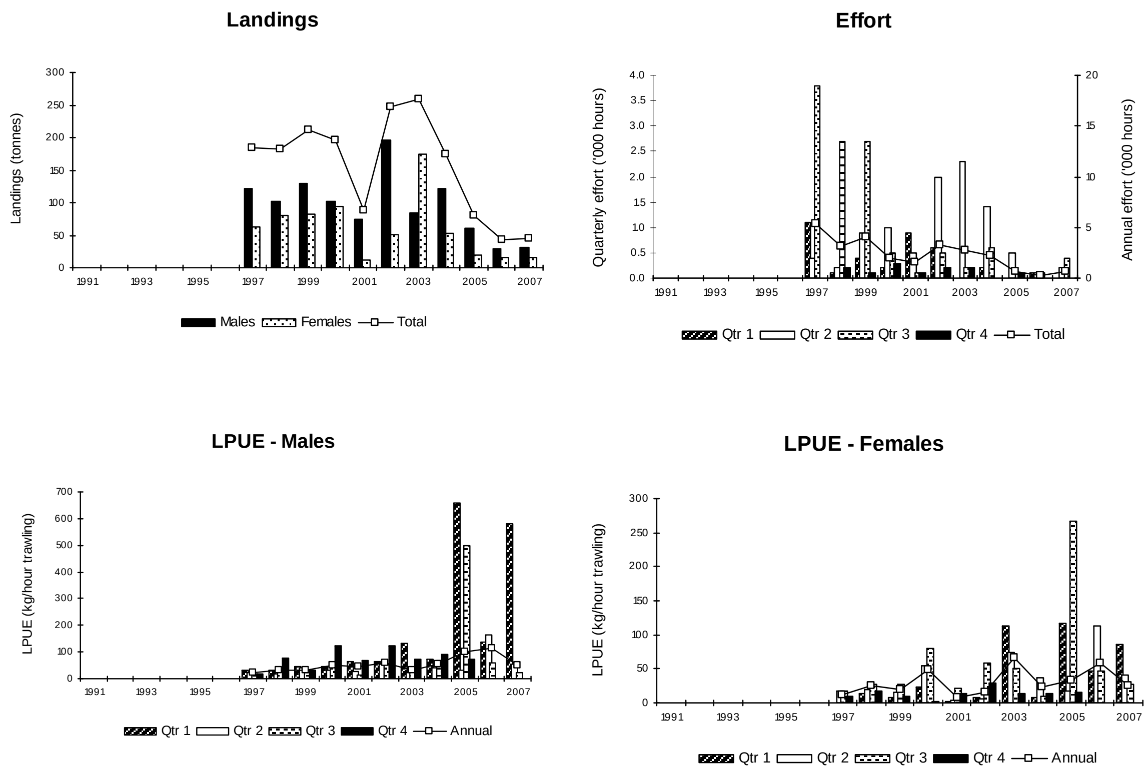


Figure 3.4.1.12. ***Nephrops*, Noup (FU 10), Landings, effort and lpues by quarter and sex from Scottish *Nephrops* trawlers.**

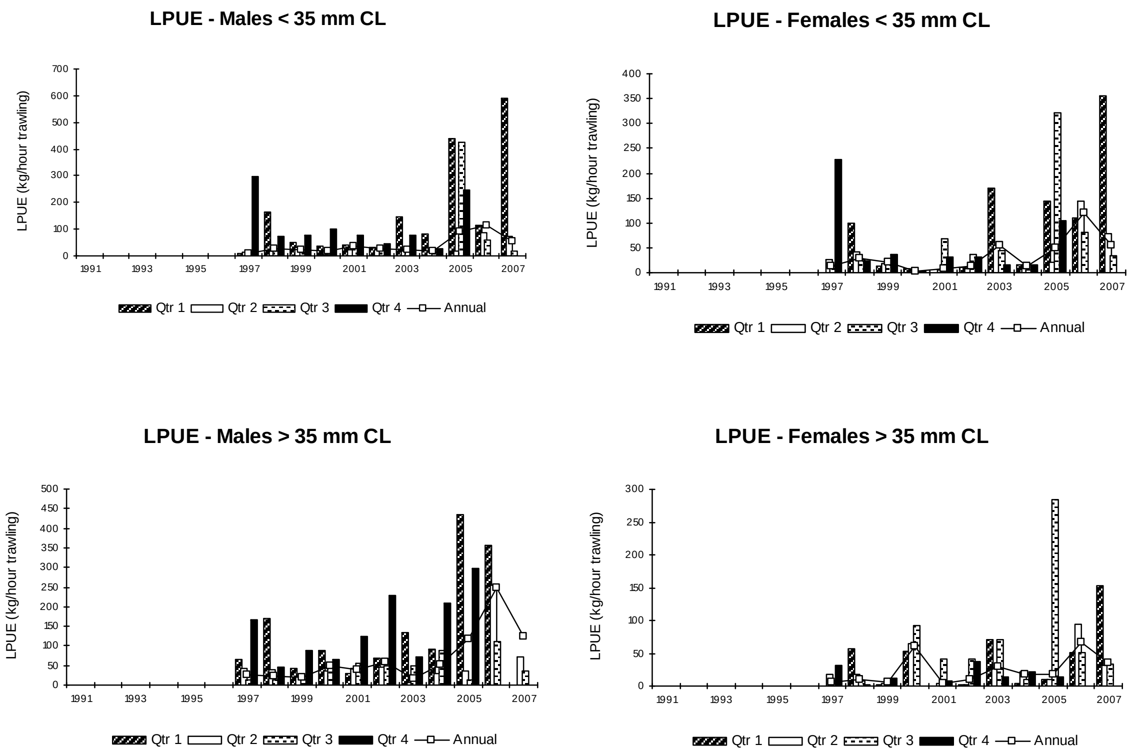


Figure 3.4.1.13. ***Nephrops*, Noup (FU 10), lpues by sex and quarter for selected size groups, Scottish *Nephrops* trawlers.**

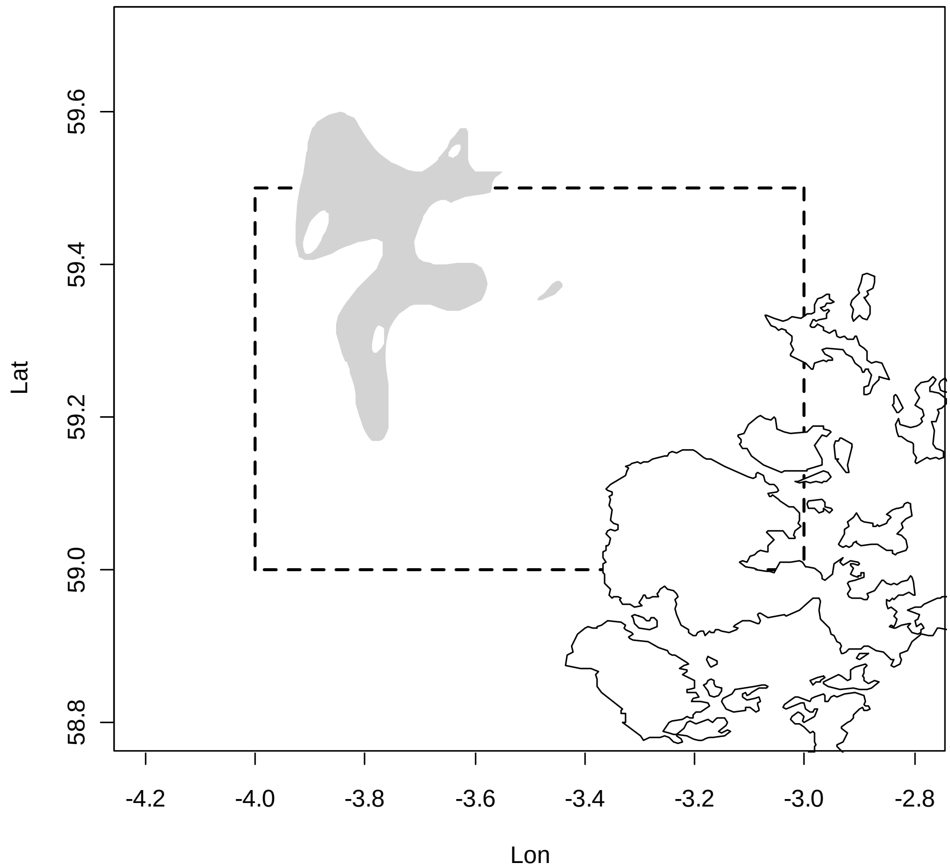


Figure B3.1. Distribution of *Nephrops* sediments in Noup (FU 10). Thick dashed lines represent the boundary of the functional unit. Sediments are: Dark grey – Mud; Grey – Sandy Mud, Light Grey – Muddy.

Annex 11: Stock Annex: FU11, North Minch

Stock specific documentation of standard assessment procedures used by ICES.

Stock	North Minch *Nephrops* (FU 11)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows. This means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. The North Minch Functional Unit (FU 11) is located off the northwest coast of Scotland. The northern boundary of the FU is the 59°N line, although there are no areas of suitable sediment north of 58°30′N. The boundary with the South Minch FU is at 57°30′N. The North Minch includes areas of sediment in the Inner Sound, between Skye and the mainland, with other small, isolated areas of sediment.

A.2. Fishery

The North Minch *Nephrops* fishery is predominantly exploited by *Nephrops* trawlers using single rig gear with a 70 mm mesh, although about 15% of landings are currently made by creel vessels. About 15% of the trawl landings are made with a 100 mm mesh, and only 1% of landings appear to be made by twin-rig vessels.

All the creel vessels are local, and roughly three quarters of the trawl landings are made by vessels based between Mallaig and Kinlochbervie on the mainland, and Stornoway on the Isle of Lewis. The major landing ports are Ullapool, Gairloch and Stornoway. In all, about 135 trawlers contribute to the landings, 75% of which are local. Mean engine power is 206 kW, and mean vessel length 15.5 m. Most vessels were built between the 1960s and 1980s.

The minimum landing size for *Nephrops* in the North Minch is 20 mm CL, and less than 0.5% of the animals are landed under size. Discarding takes place at sea, and landings are made by category for whole animals (small, medium and large) and as tails. The main bycatch species is haddock, although whiting and Norway pout also feature significantly in discards.

The fishery is exploited throughout the year, with the highest landings usually made in spring and summer. Vessels usually have a trip duration of one day in winter, but up to six days in summer.

The current legislation governing *Nephrops* trawl fisheries on the West coast of Scotland was laid down by the North Sea and West of Scotland cod recovery plan (EC 2056/2001), which established measures additional to EC 850/98. This regulation was amended in 2003 by Annex XVII of EC 2341/2002, which establishes fishing effort and additional conditions for monitoring, inspection and surveillance for the recovery of certain cod stocks. This regulation effectively limits vessels targeting *Nephrops* with 70–99 mm mesh size to 25 days at sea per month. The use of square mesh and headline panels are compulsory in this fishery.

Additional Scottish legislation (SSI No 2000/226) applies to twin trawlers operating North of 560N, A mesh size of 100 mm or above must be used without a lifting bag and with not more than 100 meshes round the circumference but with up to 5 mm double twine. By comparison, vessels using a single trawl may use 70–89 mm mesh with a lifting bag and 120 meshes round the codend but with 4 mm single twine.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length and sex compositions of *Nephrops* landed from the North Minch are estimated from port sampling in Scotland. Length data from Scottish sampling are applied to all catches and raised to total international landings. Rates of discarding by length class are estimated for Scottish fleets by on-board sampling, and extrapolated to all other fleets. The proportion of discarded to landed *Nephrops* changes with year, often determined by strong year classes. Discard sampling started in 1990, and for years prior to this estimates have been made based on later data. Landings and discards at length are combined (assuming a discard survival rate of 25%) to removals. Removals are raised separately for each sex.

Scottish *Nephrops* trawler lpue remains at a high level in 2007, demonstrating a marked increase for females; although lpue on males demonstrates a reduction in 2007 (Table B1.1 and Figure B1.1). However, it is difficult to conclude whether these data are representative of actual lpue as improved reporting of landings in recent years (as a consequence of 'buyers and sellers') will have contributed to this increase and the trends also likely to be affected by non-mandatory effort recording (hours fished). These comments also apply to the paragraphs below.

In general, males make the largest contribution to the landings (Figure B1.2). Effort has traditionally been higher in the 2nd and 3rd quarters of the year in this fishery, but has declined in the 3rd quarter in the most recent years and it is now the 2nd quarter that exhibits the highest fishing effort. Male lpue declined between 1996 and 1998, but has increased since then, and has been particularly high in the 1st and 4th quarters of recent years. The lpue for females is highest in summer between the hatching and spawning periods.

Cpue data for each sex, for *Nephrops* above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the general size limit above which the effects of discarding practices and the addition of recruits were likely to be small. The data demonstrate a peak in cpue for smaller individuals in 1994 (and for females in 1995), with values declining to the longer term average until 2001. Since then, values have been increasing and reached a peak in 2006. The drop in 2007 may be associated with reduced recruitment and corresponds to the reduced UWTV densities (see report). The cpue for larger males demonstrate a similar pattern, although the cpue has increased further in 2007. Cpue for the larger females appears to be very stable, with small increases in the past two years.

Trawl and creel fisheries are sampled separately.

B.2. Biological

Mean weights-at-age for this stock are estimated from fixed Scottish weight-length relationships (Howard *et al.*, 1988, citation required). Relevant biological parameters are as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

Growth parameters:

Males; L_∞ = 70 mm, k = 0.16

Immature Females; L_∞ = 70 mm, k = 0.16

Mature Females; L_∞ = 60 mm, k = 0.06,

Size at maturity = 27 mm

Weight length parameters:

Males a = 0.00028, b = 3.24

Females a= 0.00074, b = 2.91

Discards

Discard survival rate: 25%

Discard rate: 19.9%

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning-stock biomass at January 1.

B.3. Surveys

Abundance indices are available from the following research-vessel surveys:

Underwater TV survey: years 1995–present. The survey usually occurs in June. The burrowing nature of *Nephrops*, and variable emergence rates mean that trawl catch rates may bear little resemblance to population abundance. An underwater TV survey has been developed, estimating *Nephrops* population abundance from burrow density raised to stock area. The survey provides a total abundance estimate, and is not age or length structured.

Because of this uncertainty in sediment distribution and suitability, the North Minch is divided into four arbitrary rectangles, roughly corresponding to discrete patches of mud in (or on the border of) the functional unit, for survey purposes (Figure B3.1). Samples are distributed randomly over the area of suitable sediment within each rectangle. In the assessment, burrow densities in the four rectangles are raised to the area of suitable sediment in each region.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the North Minch are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 11: North Minch	<=2009	1.38	0.85	1.1	1	1.33

B.4. Commercial cpue

Catch-per-unit-effort time-series are available from the following fleets:

Scottish *Nephrops* trawl gears: Landings-at-age and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information see Section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight-in-landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_{l} N_L}{\sum_{l} N_L + \left(\sum_{l} N_D \times S_D \right)}$$

Where *R*=retention, *l*=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F-reference point	Harvest ratio
F0.1	8.8%
Fmax	15.4%

H. Other issues

I. References

Table B1.1. *Nephrops*, North Minch (FU 11): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	2320	78.5	29.6	2320	78.5	29.6	na	na	na
1982	2323	82.4	28.2	2323	82.4	28.2	na	na	na
1983	2784	64.9	42.9	2784	64.9	42.9	na	na	na
1984	3449	79.3	43.5	3449	79.3	43.5	na	na	na
1985	3236	96.8	33.4	3236	96.8	33.4	na	na	na
1986	2642	93.2	28.4	2642	93.2	28.4	na	na	na
1987	3458	121.2	28.5	3458	121.2	28.5	na	na	na
1988	3449	115.0	30.0	3449	115.0	30.0	na	na	na
1989	2603	87.9	29.6	2603	87.9	29.6	na	na	na
1990	1941	79.8	24.3	1941	79.8	24.3	na	na	na
1991	2228	93.4	23.9	2123	90.5	23.5	105	2.9	36.7
1992	2978	99.4	30.0	2810	95.7	29.4	168	3.7	45.4
1993	2699	105.4	25.6	2657	104.4	25.4	42	1.0	43.4
1994	2916	100.8	28.9	2916	100.8	28.9	0	0.0	0.0
1995	2940	94.2	31.2	2937	94.1	31.2	3	0.1	60.0
1996	2355	78.0	30.2	2354	78.0	30.2	1	0.0	0.0
1997	2553	90.0	28.4	2510	88.8	28.3	43	1.2	35.8
1998	2023	84.9	23.8	1973	83.4	23.7	50	1.5	33.3
1999	2791	96.7	28.9	2750	95.5	28.8	41	1.2	34.2
2000	2695	92.6	29.1	2675	92.2	29.0	21	0.4	52.5
2001	2651	82.1	32.3	2599	80.9	32.1	51	1.2	43.3
2002	2775	79.3	35.0	2684	76.5	35.1	91	2.8	32.5
2003	2607	74.1	35.2	2589	73.9	35.0	17	0.2	85.0
2004	2400	69.7	34.4	2377	69.0	34.4	23	0.2	99.6
2005	2267	58.0	39.1	2241	57.7	38.8	26	0.2	114.5
2006	3446	62.4	55.2	3383	61.8	54.7	63	0.6	105.0
2007	3362	65.7	51.2	3304	65.4	50.5	58	0.3	193.3

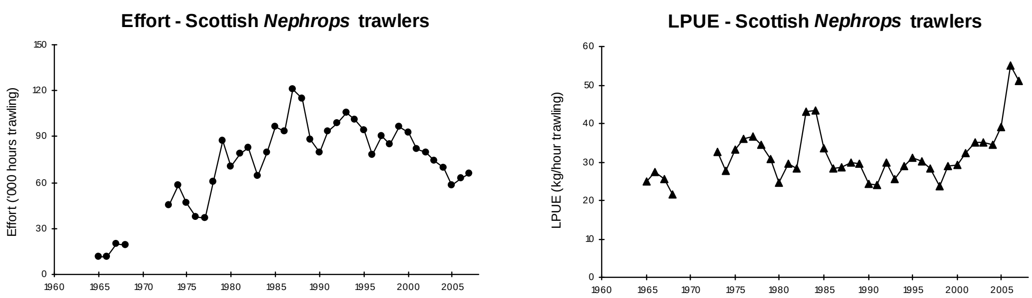


Figure B1.1. *Nephrops*. North Minch (FU11). Effort and lpue from Scottish *Nephrops* trawlers.

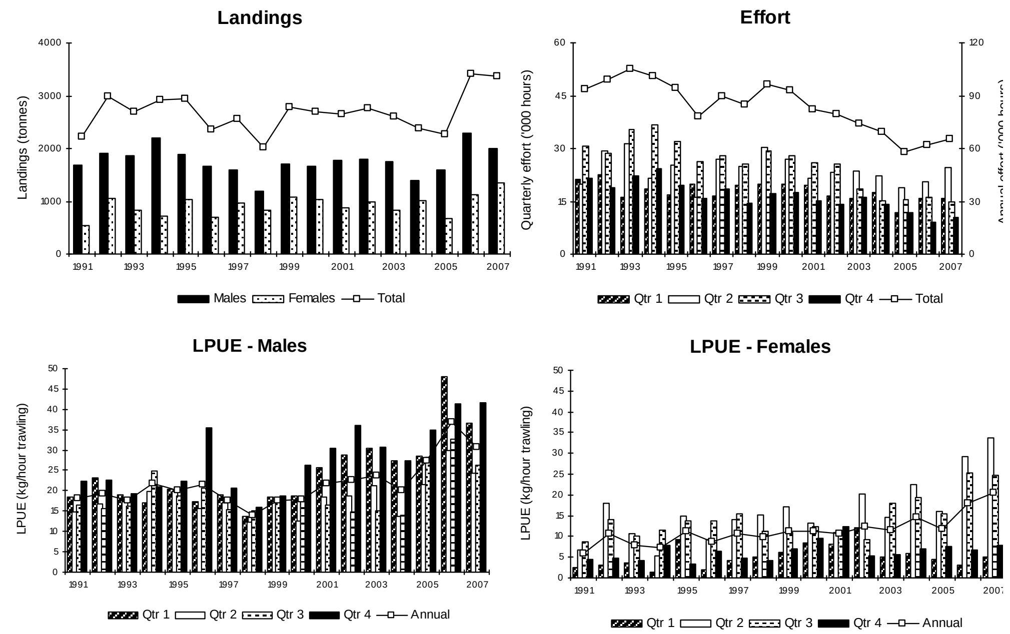


Figure B1.2. ***Nephrops*****. North Minch (FU11), Landings, effort and lpues by quarter and sex from Scottish *Nephrops* trawlers.**

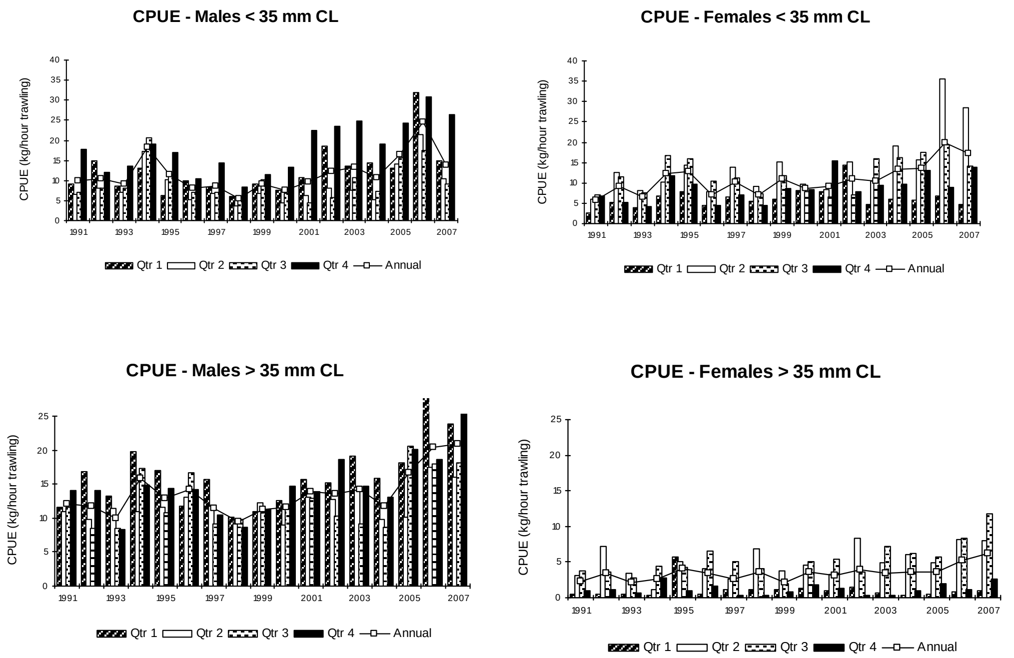


Figure B1.3. ***Nephrops*****, North Minch (FU11), cpues by sex and quarter for selected size groups, Scottish *Nephrops* trawlers.**

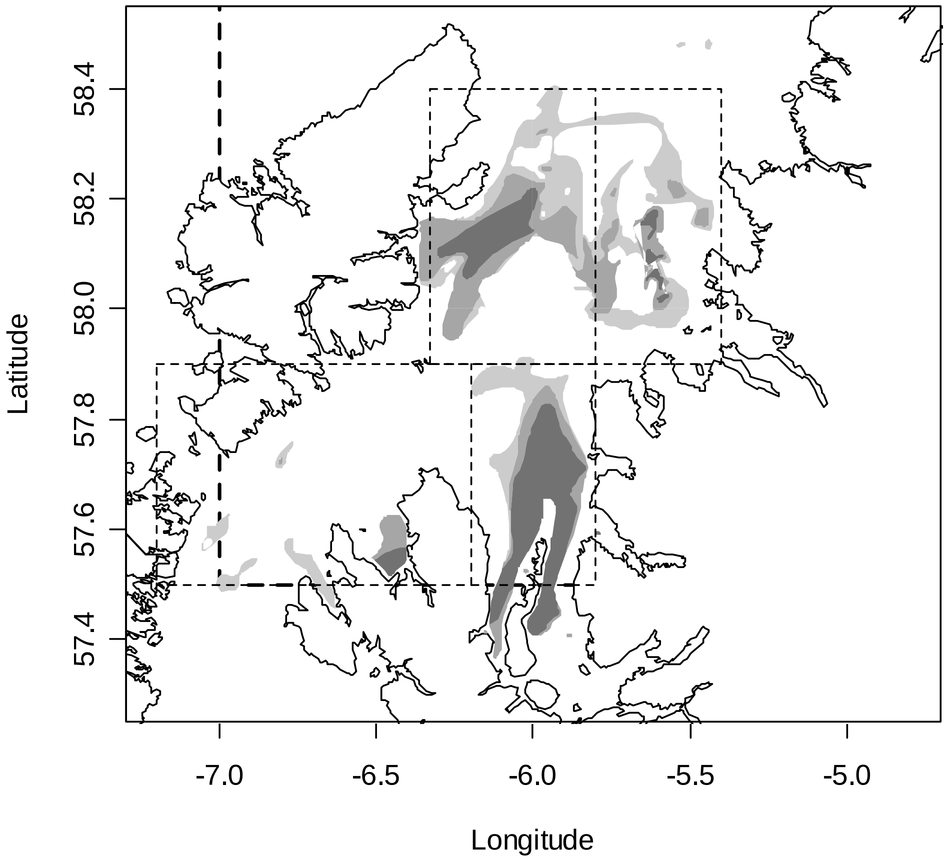


Figure B3.1. Distribution of *Nephrops* sediments in the North Minch. Thick dashed lines represent the boundary of the functional unit. Thin dashed lines represent the arbitrary rectangles used as survey strata. Sediments are: Dark grey – Mud; Grey – Sandy Mud, Light Grey – Muddy.

Annex 12: Stock Annex: FU12, South Minch

Stock specific documentation of standard assessment procedures used by ICES.

Stock	South Minch *Nephrops* (FU 12)
Date:	09 March 2009 (WKNEPH2009)
Revised by	Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows, and this means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. In the South Minch area the *Nephrops* stock inhabits a generally continuous area of muddy sediment extending from the south of Skye to the Stanton Bank, to the south of the Outer Hebrides. The South Minch functional unit (FU12) is located off the west coast of Scotland, and is bounded to the north and south by the 56°00′ and 57°30′ circles of latitude, and to the west by the 8°W meridian. Out with the functional unit, a mixed fishery for gadoids and *Nephrops* takes place on Stanton Bank, to the southwest of the Outer Hebrides.

A.2. Fishery

The South Minch *Nephrops* fishery is predominantly exploited by *Nephrops* trawlers, although about 15% of landings are made by creel vessels, which has increased in recent years. About 90% of trawler landings are made by vessels targeting *Nephrops*, and only 1% of landings are made by twin-rig vessels. Of the *Nephrops* trawlers, about 80% of landings are made with a 70 mm mesh.

All the creel vessels are local, and roughly half of the trawl landings are made by vessels based between Mallaig and Campbeltown. Visiting vessels originate in the North Minch (8% of landings) and the Scottish East coast. The East coast vessels tend to be larger than the local ones, and carry out longer trips. Mean engine power of the local vessels is 200 kW, and their mean length 15.0 m. Most vessels were built between the 1960s and the 1980s. The major landing ports are Oban and Mallaig. The smaller vessels usually have a trip duration of 1–3 days, while larger boats may stay out for 5–6 days.

The minimum landing size for *Nephrops* in the South Minch is 20 mm CL and less than 0.5% of animals are landed under size. Discarding takes place at sea and landings are made by category for whole animals (small and large) and as tails. The main bycatch species are whiting and haddock, with whiting in particular featuring heavily in discards. Of the non-commercial species caught, poor cod, Norway pout and long rough dab contribute significantly to the discards.

The fishery is exploited throughout the year, with the highest landings usually being made in spring and summer. A seasonal sprat fishery often develops in November and December, which is targeted by vessels of all sizes (including those that usually target *Nephrops*). Some vessels also turn to scallop dredging when *Nephrops* catches or prices drop, although the scope for this has been limited in recent years with ASP and PSP closures of the scallop fishery in some areas.

The current legislation governing *Nephrops* trawl fisheries on the West coast of Scotland was laid down by the North Sea and West of Scotland cod recovery plan (EC 2056/2001), which established measures additional to EC 850/98. This regulation was amended in 2003 by Annex XVII of EC 2341/2002, which establishes fishing effort and additional conditions for monitoring, inspection and surveillance for the recovery of certain cod stocks. This regulation effectively limits vessels targeting *Nephrops* with 70–99 mm mesh size to 25 days at sea per month. The use of square mesh and headline panels are compulsory in this fishery.

Additional Scottish legislation (SSI No 2000/226) applies to twin trawlers operating North of 56^0N, A mesh size of 100 mm or above must be used without a lifting bag and with not more than 100 meshes round the circumference but with up to 5 mm double twine. By comparison, vessels using a single trawl may use 70–89 mm mesh with a lifting bag and 120 meshes round the codend but with 4 mm single twine.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length and sex compositions of *Nephrops* landed from the South Minch are estimated from port sampling in Scotland. Length data from Scottish sampling are applied to all catches and raised to total international landings. Rates of discarding by length class are estimated for Scottish fleets by on-board sampling, and extrapolated to all other fleets. The proportion of discarded to landed *Nephrops* changes with year, often determined by strong year classes. Discard sampling started in 1990, and for years prior to this estimates have been made based on later data. Landings and discards at length are combined (assuming a discard survival rate of 25%) to removals. The differences in catchability between sexes have lead to the two sexes being assessed separately. And hence removals are raised separately for each sex.

Reported *Nephrops* trawl effort in 2007 was similar to the 4 previous years, while total landings demonstrate a marked increase since 2006 (Figure B1.1), possibly as a result of more accurate reporting since the introduction of the "buyers and sellers" regulations in the UK in this year.

Reported effort by Scottish *Nephrops* trawlers demonstrated a steady decline since 1990 to 2002 but has since stabilized (Figure B1.2 and Table B1.1). The reliability of these data (and the resulting lpue trends) is questionable because the logsheet recording of 'hours fished' is known to have been erratic in the past as it is a non-mandatory field on the logsheet. Scottish *Nephrops* trawler lpue remained stable between 1998 and 2001, but has demonstrated an increase more recently; particularly over the last two years (2006 and 2007).

Males contribute more to the landings than females (Figure B1.2), as in all other functional units. Effort is normally highest in the 2nd quarter in this fishery, and generally lowest in the 4th quarter. Male lpue has remained relatively stable over the time-series prior to 2006, but demonstrates a marked increase in 2006 and 2007, possibly as a result of the aforementioned introduction of the "buyers and sellers" regulations.

Discarding of undersize and unwanted *Nephrops* occurs in this fishery, and quarterly discard sampling has been conducted on the Scottish *Nephrops* trawler fleet since 1990. Discarding rates averaged over the period 2005 to 2007 for this stock were 21% by number or 12% by weight. This represents a decrease on the 2003 to 2005 period.

Cpue data for each sex, for *Nephrops* above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the general size limit above which the effects of discarding practices and the addition of recruits were likely to be small. The data demonstrate a peak in cpue for smaller individuals in 1995, with values declining to the longer term average after this, and a second rise in 2001 which has continued upwards to 2007. The higher values are particularly evident for males in the 1st and 4th quarters. The cpue for females over 35 mm has fluctuated without trend over the period, and demonstrate consistently higher values in the 2nd and 3rd quarters of the year.

Trawl and creel fisheries are sampled separately.

B.2. Biological

Mean weights-at-age for this stock are estimated from fixed Scottish weight-length relationships (Howard *et al.*, 1988, citation required). Relevant biological parameters are as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

Growth parameters:

Males; L_∞ = 66 mm, k = 0.16

Immature Females; L_∞ = 66 mm, k = 0.16

Mature Females; L_∞ = 59 mm, k = 0.06,

Size at maturity = 25 mm

Weight length parameters:

Males a = 0.00028, b = 3.24

Females a= 0.00074, b = 2.91

Discards

Discard survival rate: 25%

Discard rate: 16.7%

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning-stock biomass at January 1.

B.3. Surveys

Abundance indices are available from the following research-vessel surveys:

Underwater TV survey: years 1995–present. The survey usually occurs in June. The burrowing nature of *Nephrops*, and variable emergence rates mean that trawl catch rates may bear little resemblance to population abundance. An underwater TV survey has been developed, estimating *Nephrops* population abundance form burrow density raised to stock area. A random stratified sampling design is used, on the basis of British Geological Survey sediment strata. The survey provides a total abundance estimate, and is not age or length structured (Figure B3.1).

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the South Minch are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 12: South Minch	<=2009	1.37	0.85	1.1	1	1.32

B.4. Commercial cpue

Landings-per-unit-effort time-series are available from: *Nephrops* single trawl, multiple *Nephrops* trawl, light trawl and multiple demersal trawl.

Scottish *Nephrops* trawl gears: Landings-at-age and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

For more information see Section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.
2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.
3) Generate mean weight-in-landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.
2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D\right)}$$

Where *R*=retention, *l*=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

			Implied fishery	
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12 345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F-REFERENCE POINT	HARVEST RATIO
F0.1	9.6%
Fmax	16.0%

Table B1.1. *Nephrops*. South Minch (FU 12).): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	2965	81.6	36.4	2965	81.6	36.4	na	na	na
1982	2925	93.1	31.4	2925	93.1	31.4	na	na	na
1983	2595	77.9	33.3	2595	77.9	33.3	na	na	na
1984	3228	93.4	34.6	3228	93.4	34.6	na	na	na
1985	3096	130.3	23.8	3096	130.3	23.8	na	na	na
1986	2694	105.8	25.5	2694	105.8	25.5	na	na	na
1987	2927	126.3	23.2	2927	126.3	23.2	na	na	na
1988	3544	120.9	29.3	3544	120.9	29.3	na	na	na
1989	3846	138.3	27.8	3846	138.3	27.8	na	na	na
1990	3732	153.5	24.3	3732	153.5	24.3	na	na	na
1991	3597	150.5	23.9	3109	134.6	23.1	488	15.8	30.8
1992	3479	127.3	27.3	3092	115.0	26.9	387	12.3	31.5
1993	3608	126.5	28.5	3441	122.5	28.1	167	4.0	41.5
1994	3743	144.4	25.9	3650	141.4	25.8	93	3.0	31.3
1995	3442	100.4	34.3	3407	99.6	34.2	35	0.9	39.8
1996	3108	106.4	29.2	3036	104.1	29.2	71	2.4	30.1
1997	3519	117.5	29.9	3345	112.1	29.8	174	5.4	32.0
1998	2851	101.4	28.1	2792	99.5	28.1	59	1.9	30.4
1999	3165	111.5	28.4	3111	109.3	28.5	54	2.2	24.6
2000	2939	106.2	27.7	2819	102.1	27.6	121	4.1	29.7
2001	2823	101.7	27.8	2764	99.8	27.7	59	1.9	30.8
2002	2234	75.7	29.5	2210	75.1	29.4	25	0.6	38.9
2003	2812	94.3	29.8	2716	93.5	29.0	96	0.8	113.9
2004	2865	89.8	31.9	2598	84.7	30.7	267	5.1	52.0
2005	2810	82.5	31.9	2566	79.3	32.4	244	3.2	76.8
2006	3569	93.3	38.3	3271	89.5	36.5	298	3.8	78.4
2007	4436	90.8	39.3	3820	83.1	46.0	616	7.7	80.0

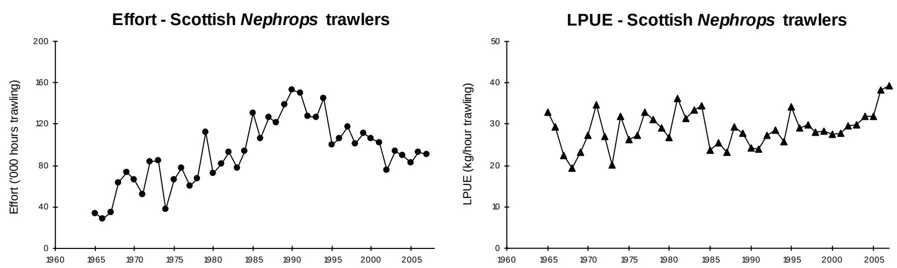


Figure B1.1. *Nephrops*, South Minch (FU12). Effort and lpue by Scottish *Nephrops* trawlers.

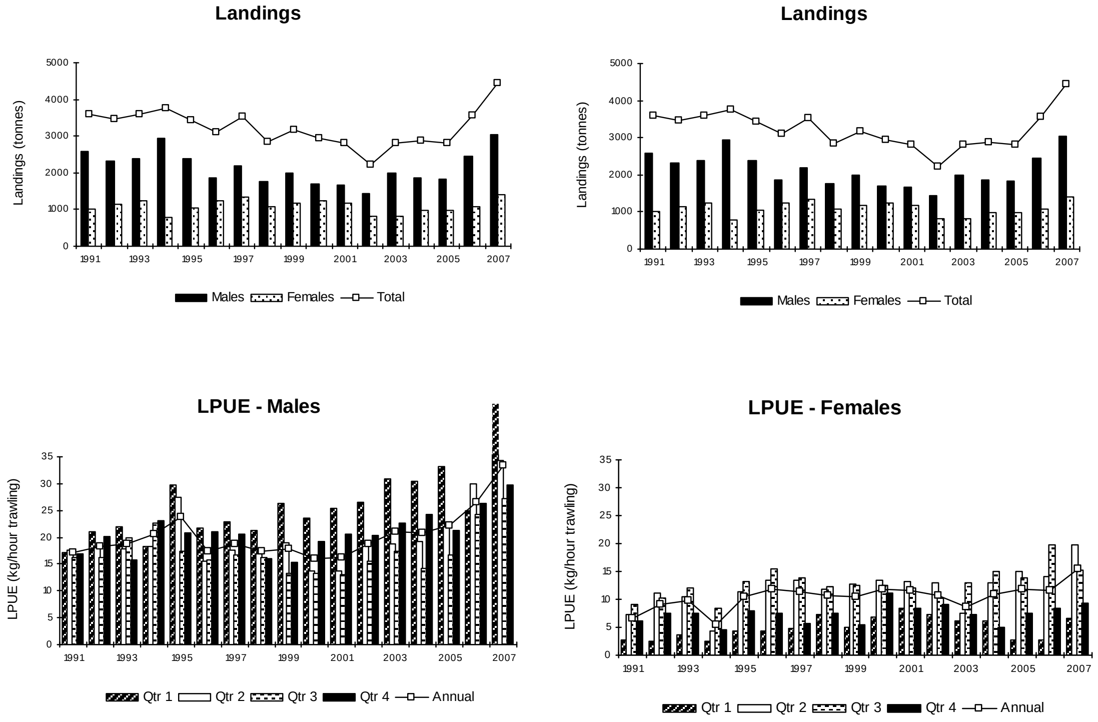


Figure B1.2. ***Nephrops*****, South Minch (FU12), Landings, effort and lpues by quarter and sex from Scottish** ***Nephrops*** **trawlers.**

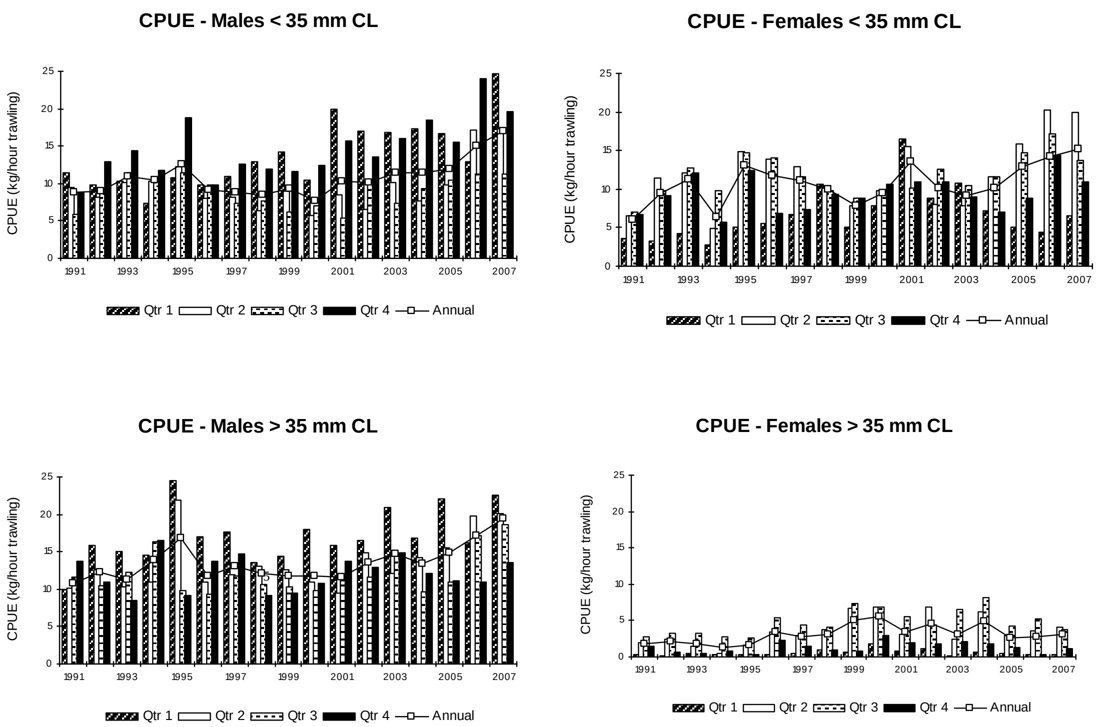


Figure B1.3.***Nephrops*****, South Minch (FU12), cpues by sex and quarter for selected size groups, Scottish** ***Nephrops*** **trawlers.**

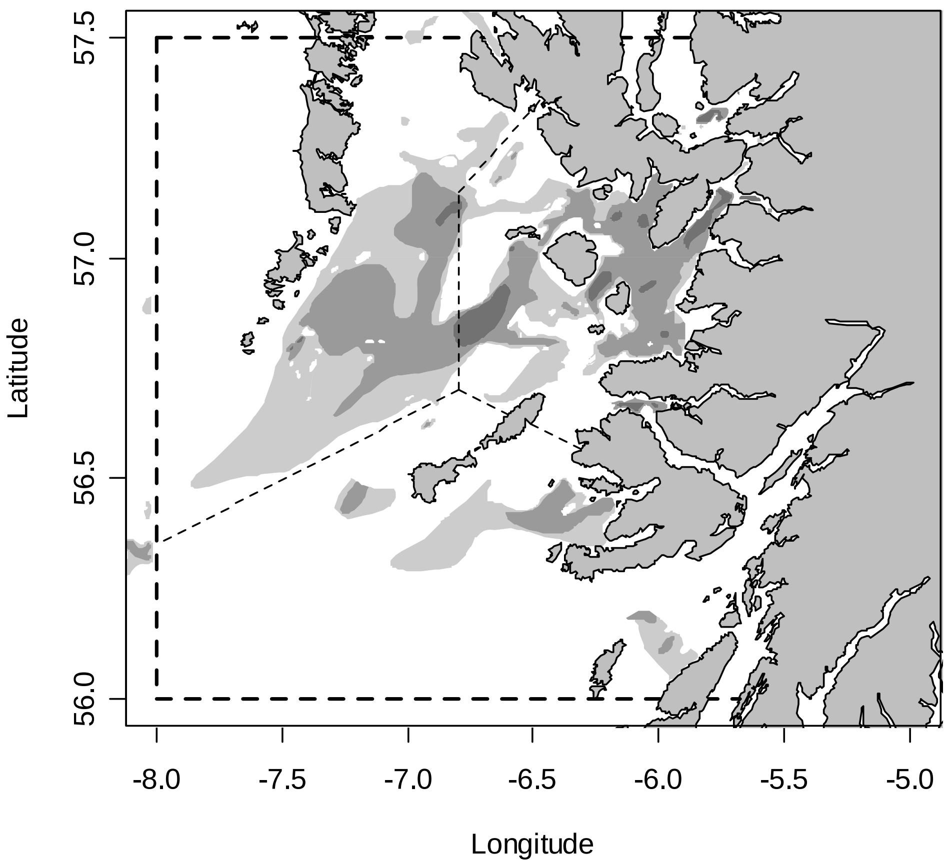


Figure B3.1. Sediment strata in the South Minch. Light Grey – Muddy sand, Grey – Sandy mud, Dark Grey – Mud. Light dashed lines represent spatial strata imposed on the sampling regime to ensure adequate spatial coverage.

Annex 13: Stock Annex: FU13, Clyde

Stock specific documentation of standard assessment procedures used by ICES.

Stock Clyde *Nephrops* (FU 13)

Date: 09 March 2009

Revised by Sarah Clarke/Carlos Mesquita

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows, and this means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. In the Clyde area the *Nephrops* stock inhabits an area of muddy sediment extending throughout the Firth of Clyde, and another smaller area in the Sound of Jura, as shown in Figure B3.1. The two areas are separated by a large area of sandy gravely sediment around the Mull of Kintyre, and are treated as separate populations because they have differing population characteristics.

A.2. Fishery

Firth of Clyde

The Firth of Clyde *Nephrops* fishery is predominantly exploited by a dedicated *Nephrops* trawler fleet of approximately 120 vessels, with less than 2–3% of the landings made by creel vessels. The 90 resident Clyde trawlers make about 90% of the *Nephrops* landings. Under the Scottish 'Inshore Fishing Order' of 1989 (Prohibition of Fishing and Fishing Methods), fishing with mobile gear is prohibited within the Firth of Clyde over weekends, and with vessels >70 feet (about 21 m) in length.

The trawler fleet that fishes the Firth of Clyde mostly consists of vessels between 10 and 20 m in length (mean overall length 14 m), with a mean engine power of 185 kW. Almost half the fleet was built during the 1960s, with less than 20% built after 1979. Most vessels use single otter trawls with a 70 mm mesh codend, but just under a third of *Nephrops* landings are taken by vessels using twin-rig trawls with an 80 mm mesh codend. Vessels employing twin-rig gear are generally slightly more powerful than the single rig vessels (mean power 214 kW compared with 176 kW).

The regular fleet is composed of Scottish vessels, but some catches are taken by Northern Ireland and Republic of Ireland vessels. The major landing ports are Troon, Campbeltown, Girvan and Tarbert, but smaller landings are also made at Carradale, Largs and Rothsay.

The minimum landing size for *Nephrops* in the Clyde is 20 mm CL. Compliance with the minimum landing size is good, with samples suggesting only a very small undersized component in the landings (<0.5%).

Nephrops growth varies within the area, with low density animals growing to large sizes in the North, and with higher density animals reaching smaller sizes in the South. Far more *Nephrops* material (undersized individuals and 'heads' from tailed animals) is discarded in the South. Discarding usually takes place at sea and landings are made by category for whole animals (small, medium and large) and as tails. In poor weather or for the last haul of the day, discarding may take place within the harbour, thus increasing discard mortality.

Only a small fish bycatch is made in the Firth of Clyde, with whiting and cod being the most important species. The composition of the bycatch and discards varies within the Firth of Clyde, with more flatfish (common and long rough dab), echinoderms and crustaceans (other than *Nephrops*) caught in the North, while more roundfish (particularly whiting) are caught in the South. These differences reflect the different habitats and fish communities in the area.

The fishery is exploited throughout the year, with highest landings usually made between July and September. Vessels usually have a trip duration of one day, sailing to shoot before dawn, and carrying out 3–4 hauls of 4 hours per day.

Sound of Jura

The fishery for *Nephrops* in the Sound of Jura constitutes part of the Clyde FU, but is examined separately from the fishery within the Firth of Clyde, because of differences in the biological parameters of the *Nephrops* populations.

The fleet exploiting the Sound of Jura is also different from the Firth of Clyde, with vessels tending to be slightly smaller but more powerful. Most landings are taken by Scottish vessels (which are virtually all local to the area), although a very small proportion is taken by boats from the rest of the UK. The local trawler fleet consists of vessels between 9 and 16 m in length, and with a mean engine power of 185 kW.

Just over half the landings are made by twin-rig *Nephrops* trawlers using 80 mm meshes, with most of the remainder landed by single rig vessels using 70 mm meshes. Vessels employing twin-rig gear are generally larger and more powerful than those using single rig trawls (15 m and 220 kW compared with 13 m and 160 kW). The main landing ports are Port Askaig, West Loch Tarbert and Crinan.

The minimum landing size for *Nephrops* in the Sound of Jura is 20 mm CL. *Nephrops* are found in high densities in this stock, but only grow to relatively small sizes. Discarding takes place at sea (this can be a large proportion of the catch by number, because of the small mean size of the animals caught), and landings are made by category for whole animals (small, medium and large) and as tails.

Catches of fish in the Sound of Jura area are generally poor, and *Nephrops* are clearly the target species, with only small bycatches of whitefish and flatfish.

The fishery is exploited throughout the year, with highest landings usually made between April and June. Vessels usually have a trip duration of one day, with 3–4 hauls per day.

For both areas the current legislation governing *Nephrops* trawl fisheries on the West coast of Scotland was laid down by the North Sea and West of Scotland cod recovery plan (EC 2056/2001), which established measures additional to EC 850/98. This regulation was amended in 2003 by Annex XVII of EC 2341/2002, which establishes fishing effort and additional conditions for monitoring, inspection and surveillance for the recovery of certain cod stocks. This regulation effectively limits vessels targeting *Nephrops* with 70–99 mm mesh size to 25 days at sea per month. The use of square mesh and headline panels are compulsory in this fishery. Additional UK legislation has also been applied in the southern areas of the Firth of Clyde in recent years, aimed at protecting the aggregating cod in the south of the Clyde during February, March and April.

A.3. Ecosystem aspects

No information on the ecosystem aspects of this stock has been collated by the Working Group.

B. Data

B.1. Commercial catch

Length and sex compositions of *Nephrops* landed from the Firth of Clyde are estimated from port sampling in Scotland. Length data from Scottish sampling are applied to all catches and raised to total international landings. Rates of discarding by length class are estimated for Scottish fleets by on-board sampling, and extrapolated to all other fleets. The proportion of discarded to landed *Nephrops* changes with year, often determined by strong year classes. Discard sampling started in 1990, and for years prior to this estimates have been made based on later data. Landings and discards at length are combined (assuming a discard survival rate of 25%) to removals. As a consequence of differences in catchability between sexes removals are raised separately for each sex.

Reported effort has declined from high levels in the mid 1990s until 2004, but has demonstrated an increase since then (Figure B1.1). Landings also declined, to a lesser extent, over this period and demonstrate a sharp increase over the past two years. Scottish *Nephrops* trawler lpue has increased markedly since 2001(Figure B1.1 and Table B1.1). However this may be more of an artefact as a consequence of improved reporting of landings data because of the introduction of the buyers and sellers regulations in the UK in 2006. In addition, logsheet recording of 'hours fished' is known to be erratic as it is a non-mandatory field on the logsheet It is therefore not clear whether the observed interannual trends described below are actually indicative of real trends in lpue.

Males contribute more to the landings than females. Effort has previously been highest in the 3rd quarter in this fishery, but has become far more even through the year as the overall level of effort has declined (Figure B1.2). Male lpue demonstrated an increase in 1995, to a relatively stable level, then a further increase between 2001 and 2005. It has increased again in 2006 and remains high in 2007 particularly in the first and fourth quarters. Female lpue is lower than that for males, but demonstrates similar increases after 1995 and 2001; the highest rates are obtained in the second and third quarters.

Cpue data for each sex, for *Nephrops* above and below 35 mm CL, are shown in Figure B1.3. This size was chosen for all the Scottish stocks examined as the general size limit above which the effects of discarding practices and the addition of recruits were likely to be small. For both sexes the data show a series of increases in cpue for smaller individuals in 1995, 2003 and 2007 The cpue for larger males remained relatively stable prior to 2003, fell to a slightly lower level in 2005, then increased markedly in 2006; remaining high but falling in 2007. Cpue for the larger females has fluctuated around a stable level for the entire time-series, demonstrating significantly higher values in the second quarter. These trends, are however, effected by the recent improvements in the reliability of catch data and erratic effort recording and are therefore difficult to interpret reliably.

B.2. Biological

Mean weights-at-age for this stock are estimated from fixed Scottish weight-length relationships (Howard *et al.*, 1988, citation required). Relevant biological parameters are as follows: natural mortality was assumed to be 0.3 for males of all ages and in all years. Natural mortality was assumed to be 0.3 for immature females, and 0.2 for mature females.

Summary

Growth parameters:

Males; L_∞ = 73 mm, k = 0.16

Immature Females; L_∞ = 73 mm, k = 0.16

Mature Females; L_∞ = 60 mm, k = 0.06,

Size at maturity = 25 mm

Weight length parameters:

Males a = 0.00028, b = 3.24

Females a= 0.00074, b = 2.91

Discards

Discard survival rate: 25%

Discard rate: 18.6%

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning-stock biomass at January 1.

B.3. Surveys

The burrowing nature of *Nephrops*, and variable emergence rates mean that trawl catch rates may bear little resemblance to population abundance. An underwater TV survey has been developed, estimating *Nephrops* population abundance from burrow density raised to stock area. A random stratified sampling design is used; on the basis of British Geological Survey sediment strata and latitude (Tuck *et al.*, 1999; see Figure B3.1). The survey provides a total abundance estimate, and is not age or length structured. A series of annual underwater TV surveys are available since 1995 for the Firth of Clyde and Sound of Jura. While the survey in the Clyde has been continuous, the TV survey for the Sound of Jura was not conducted from 1997 to 2000, and again in 2004. Such large gaps in the series make interpretation of any trends from the data difficult. The number of valid stations in the survey has remained relatively stable throughout the period. An average of 36 stations have been sampled in each year, then raised to a stock area of 2062.2 km^2 for the Firth of Clyde, and an average of 10 stations have been considered valid each year for the Sound of Jura. Confidence intervals around the abundance estimates have remained relatively stable through the period.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Fladen are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 13: Clyde	<=2009	1.19	0.75	1.25	1	1.19

B.4. Commercial cpue

Landings-per-unit-effort time-series are available from the following fleets: *Nephrops* single trawl, multiple *Nephrops* trawl, light trawl and multiple demersal trawl.

Scottish *Nephrops* trawl gears: Landings-at-age and effort data for Scottish *Nephrops* trawl gears are used to generate a cpue index. Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* single trawl and multiple *Nephrops* trawl is raised to landings reported by the four gears listed above. Discard sampling commenced in 1990 for this fishery, and for years prior to this, an average of the 1990 and 1991 values is applied. There is no account taken of any technological creep in the fleet.

More information is contained in Section B.1.

B.5. Other relevant data

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D\right)}$$

Where *R*=retention, *l*=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F-reference point	Harvest ratio
F0.1	8.7%
Fmax	15.1%

H. Other issues

I. References

Year	All *Nephrops* gears combined			Single rig			Multirig		
	Landings	Effort	LPUE	Landings	Effort	LPUE	Landings	Effort	LPUE
1981	1861	108.8	17.1	1861	70.5	26.4	na	na	na
1982	1798	93.1	19.3	1798	148.0	12.1	na	na	na
1983	3258	131.9	24.7	3258	108.8	29.9	na	na	na
1984	2433	122.5	19.9	2433	93.1	26.1	na	na	na
1985	3154	131.6	24.0	3154	131.9	23.9	na	na	na
1986	2745	141.5	19.4	2745	122.5	22.4	na	na	na
1987	2126	126.8	16.8	2126	131.6	16.2	na	na	na
1988	3190	141.6	22.5	3190	141.5	22.5	na	na	na
1989	2393	144.3	16.6	2393	126.8	18.9	na	na	na
1990	2435	142.8	17.0	2435	141.6	17.2	na	na	na
1991	2489	152.9	16.3	1594	144.3	11.0	895	39.5	22.7
1992	2091	144.6	14.5	1316	142.8	9.2	775	42.4	18.3
1993	2650	156.8	16.9	1771	113.5	15.6	879	43.1	20.4
1994	1996	118.0	16.9	1484	102.2	14.5	512	27.6	18.6
1995	3501	133.8	26.2	2583	113.7	22.7	918	31.5	29.1
1996	3530	150.1	23.5	2474	90.4	27.4	1048	38.1	27.5
1997	3020	131.9	22.9	2158	98.0	22.0	861	33.9	25.4
1998	4107	150.8	27.2	2964	110.2	26.9	1142	40.5	28.2
1999	3175	117.2	27.1	2322	86.3	26.9	853	30.9	27.6
2000	2980	124.4	24.0	2100	90.9	23.1	880	33.5	26.3
2001	2711	111.6	24.3	2445	100.2	24.4	266	11.4	23.3
2002	3043	99.6	30.6	2896	94.0	30.8	147	5.6	26.3
2003	2937	84.2	34.9	2839	81.2	35.0	97	3.0	32.3
2004	2611	72.3	36.1	2531	69.6	36.4	80	2.7	29.6
2005	3133	79.8	39.3	3108	78.7	39.5	25	1.1	23.8
2006	4356	87.1	50.0	4348	85.4	50.9	8	1.7	4.7
2007	6069	113	53.7	6055	99	61.2	14	1.6	8.8
* provisional na = not available, landings not recorded to Multirig trawl before 1991.									

Table B1.1. *Nephrops*, Firth of Clyde (FU 13): Landings (tonnes), effort ('000 hours trawling) and lpue (kg/hour trawling) of Scottish *Nephrops* trawlers, 1981–2007 (data for all *Nephrops* gears combined, and for single and multirigs separately).

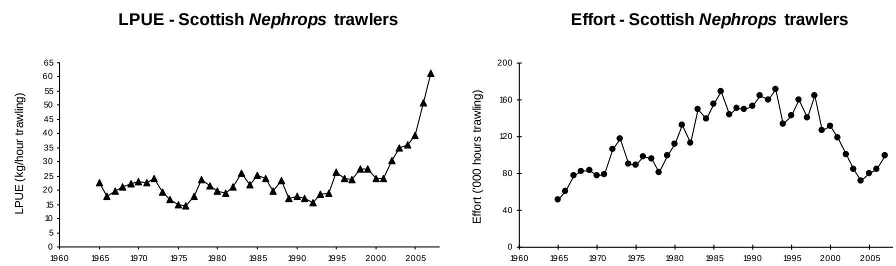


Figure B1.1. *Nephrops*, Firth of Clyde (FU13), Effort and lpue for Scottish *Nephrops* trawlers.

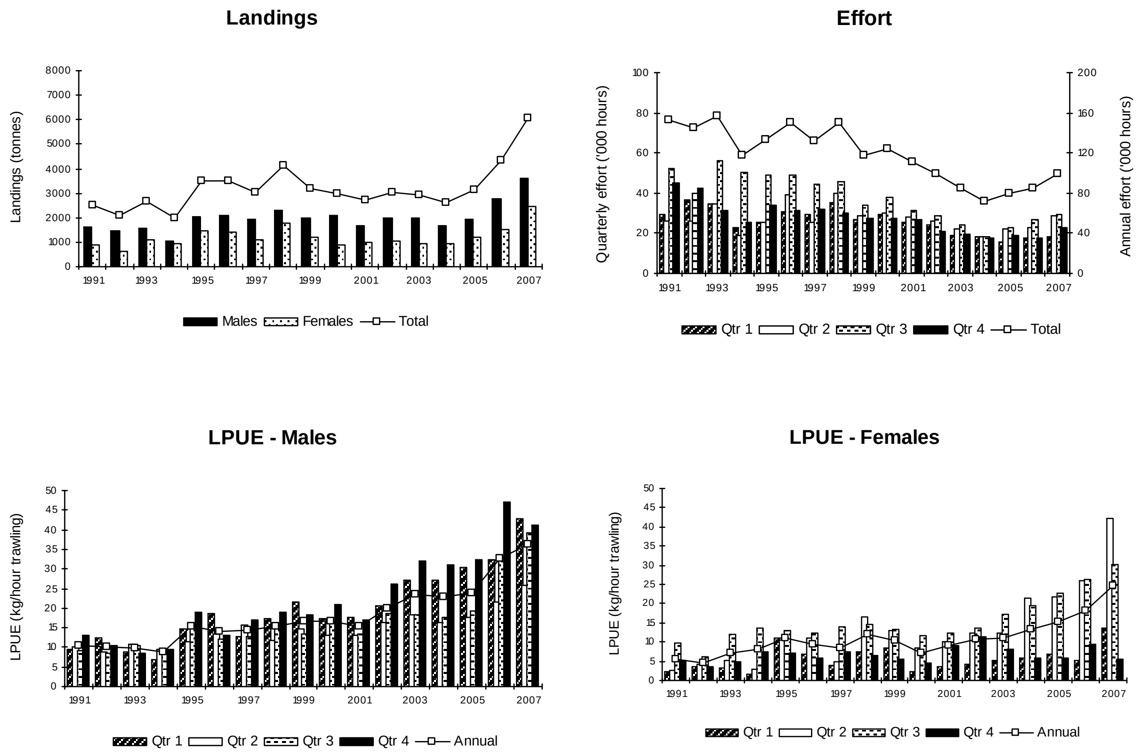


Figure B1.2. ***Nephrops*****, Firth of Clyde (FU13), Landings, effort and lpues by quarter and sex from Scottish** ***Nephrops*** **trawlers.**

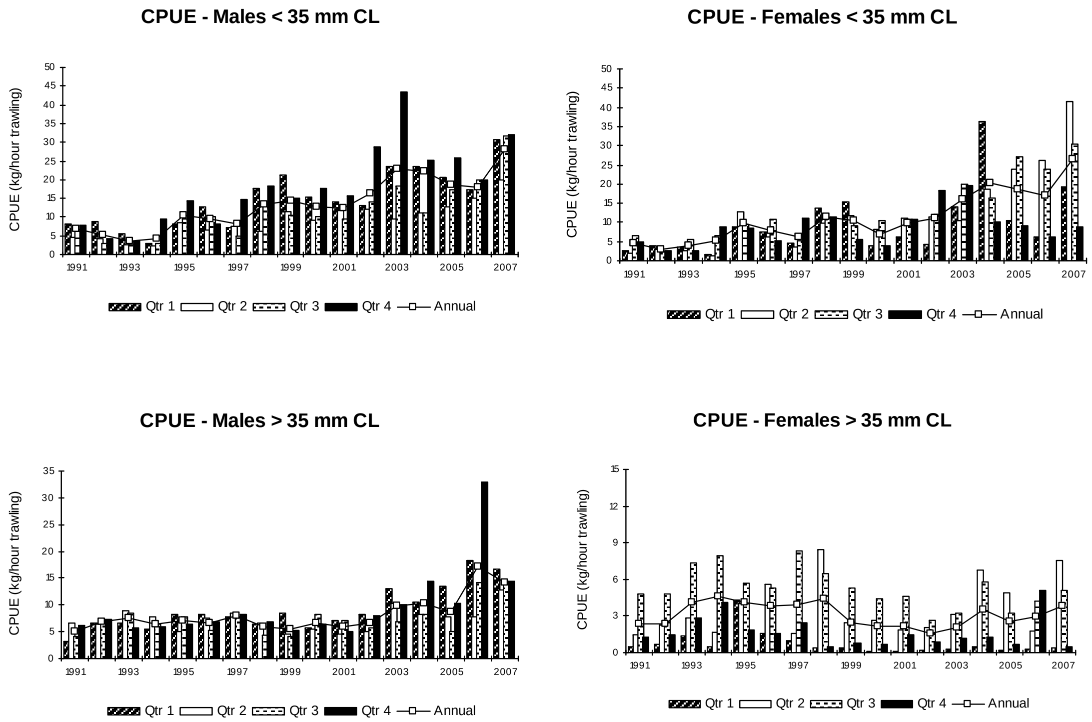


Figure B1.3. ***Nephrops*****, Firth of Clyde (FU13), cpues by sex and quarter for selected size groups, Scottish** ***Nephrops*** **trawlers.**

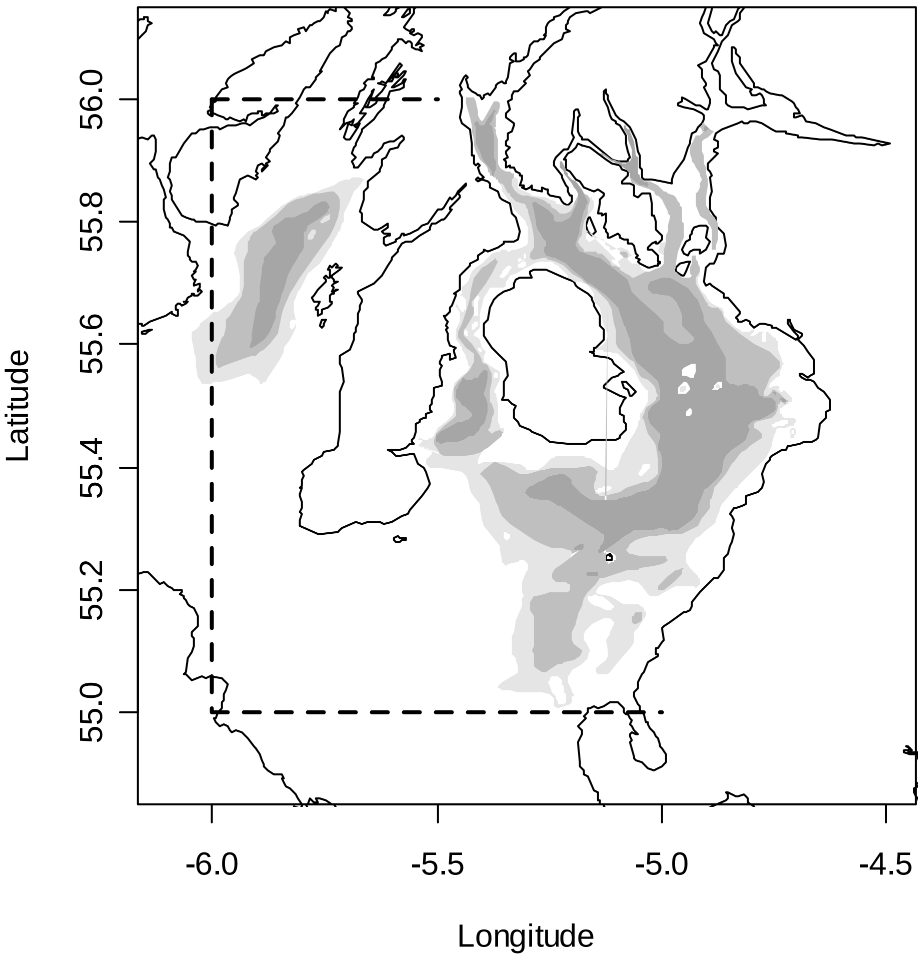


Figure B3.4. Distribution of suitable sediments in Clyde. Light grey - muddy sand; medium grey - sandy mud; dark grey - mud.

Annex 14: Stock Annex: Irish Sea West *Nephrops* (FU15)

Stock specific documentation of standard assessment procedures used by ICES.

Stock: Irish Sea West *Nephrops* (FU15)

Working Group: WKNEPH09 (WKNEPH2009)

Date: 6 March 2009

A. General

A.1. Stock definition

Throughout its distribution, *Nephrops* is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows, and this means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. In the western Irish Sea the *Nephrops* stock inhabits an extensive area of muddy sediment between the Isle of Man and Northern Ireland and its fishery contributes to more than 90% of overall Irish Sea landings. There is little evidence of mixing between the east and west Irish Sea stocks as a consequence of the nature of water current movements, which is characterized in the west by a gyre, which has a retention affect on both sediment and larvae. The eastern and western *Nephrops* stocks are treated as separate populations as they have different population characteristics.

A.3. Ecosystem aspects

A number of studies have examined *Nephrops* larvae distribution in order to examine how recruitment may impinge upon the distribution of a "catchable" (adult) *Nephrops* population and the maintenance of the population. Hillis, 1968 found that although generally the larvae occupied the same areas as the adults, there was some evidence of advective losses to the southeastern part of their range, most probably as a consequence of tidal currents (White *et al.*, 1988). More recent studies in the western Irish Sea have uncovered the existence of a seasonal cyclonic gyre which appears to facilitate retention of larvae over the mud patch (Dickey-Collas *et al.*, 1996; Hill *et al.*, 1996; Horsburgh *et al.*, 2000)

B. Data

B.1. Commercial catch

Length and sex compositions of *Nephrops* landed from the Irish Sea West are estimated from port sampling by Ireland and Northern Ireland and Ireland. A lack of cooperation by the Northern Ireland industry prevented sampling commercial catches over the period 2003–2007. The Irish LFDs are therefore raised to the international catch for these years. Northern Ireland sampling resumed in 2008 and these data are combined with those from Ireland for that year. Sample data are used to compute international removals (Landings + dead discards).

Landings-per-unit-effort time-series are available from the following fleets:

Northern Ireland *Nephrops* trawl gears. Landings-at-age and effort data from this fishery from 1986 are used to generate a cpue index. There is also a cpue series from 1995 for a subset of Republic of Ireland *Nephrops* vessels. Catch-at-age are estimated by raising length sampling of discards and landings to officially recorded landings and slicing into ages (knife edge slicing using growth parameters). Cpue is estimated using officially recorded effort (hours fished) although the recording of effort is not mandatory. Combined effort for *Nephrops* trawlers is raised to landings. Discard sampling commenced in the mid 1980s by Northern Ireland and the Republic of Ireland. There is no account taken of any technological creep in the fleet.

B.2. Biological

Mean weights-at-length for this stock are estimated from studies by Pope and Thomas, 1955.

A natural mortality rate of 0.3 was assumed for males and immature females, with a value of 0.2 for mature females. The lower value for mature females reflects the reduced burrow emergence while ovigerous and hence an assumed reduction in predation.

Maturity for females is taken as 22.1 mm carapace length (McQuaid *et al.*, 2006).

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning-stock biomass at January 1. In the absence of independent estimates, the mean weights-at-age in the total catch were assumed to represent the mean weights in the stock.

B.3. Surveys

Ireland and Northern Ireland jointly carried out underwater television (UWTV) surveys on the main *Nephrops* grounds in the western Irish Sea (Figure 1) in 2003–2008. These surveys are based on a randomized fixed grid design. The methods used during the survey are similar to those employed for UWTV surveys of *Nephrops* stocks elsewhere and are detailed in WKNEPHTV, 2007 and WKNEPHBID, 2008.

Northern Ireland have carried out a spring (April) and summer (August) *Nephrops* trawl surveys since 1994. These surveys provide data on catch rates and LFDs from of stations throughout in the western Irish Sea. These surveys generate data on *Nephrops* size composition, mean size, maturity and sex ratio.

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Irish Sea West are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 15: Irish Sea West	<=2009	1.24	0.75	1.15	1	1.14

B.4. Commercial cpue

B.5. Other relevant data

Table 1 is a summary of available data along with an assessment of its reliability.

Table 2 is a summary of assessment parameters.

C. Historical stock development

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D \right)}$$

Where R=retention, l=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

	Implied fishery			
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

Harvest ratios equating to fishing at F0.1 and Fmax were calculated in WKNeph, 2009. These calculations assume that the TV survey has a knife-edge selectivity at 17 mm and that the supplied length frequencies represented the population in equilibrium.

F0.1 = 10.2%

Fmax= 16.9%

I. References

Dickey-Collas, M., Gowen, R.J. and Fox, C.J. 1996. Distribution of larval and juvenile fish in the western Irish Sea: Relationship to phytoplankton, zooplankton biomass and recurrent physical features. *Marine and Freshwater Research* 47: 169–181.

Horsburgh, K.J., Hill, A.E., Brown, J., Fernand, L., Garvine, R.W., Angelico, M.M.P. 2000. Seasonal evolution of the cold pool gyre in the western Irish Sea. *Progress in Oceanography* 46: 1–58.

Hill, A.E., Brown, J. and Fernand, L. 1996. The western Irish Sea gyre: a retention mechanism for the Norway Lobster (*Nephrops norvegicus) Oceanologica Acta* 19: 357–369.

Hillis, J.P. 1968. Larval distribution of *Nephrops norvegicus* (L.) in the Irish Sea and North Channel. *ICRES C.M*. 1968. Doc. No. K6. (Mimeo).

McQuaid, N., Briggs, R.P. and Roberts, D, 2006. Estimation of the size of onset of sexual maturity in *Nephrops norvegicus* (L.). *Fisheries Research.*

White, R.G., Hill, A.E. and Jones, D.A. 1988. Distribution of *Nephrops norvegicus* (L.) larvae in the western Irish Sea: an example of advective control on recruitment. *Journal of Plankton Research* 10(4): 735–747.

Table 1. Summary table of Available data.

FU15 Irish Sea West: Data Available															
Data															
Commercial Data	pre-1995	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Landings															
Effort															
cpue/lpue															
Mean size															
Sex ratio															
LFDs															
catch															
landings															
discards															
Survey Data															
Trawl surveys															
Catch rate															
mean size															
LFDs															
Sex ratio															
Camera Surveys															
Density estimate															
Data Quality															
Poor															
Acceptable															
Reliable															

Table 2: Biological Input Parameters.

PARAMETER	VALUE	SOURCE
Discard Survival	0.10	ICES (1991a)
Discard rate	40.2%	2007 discard sampling.
MALES		
Growth - K	0.160	Hillis (1979) ; ICES (1991a)
Growth - L(inf)	60	"
Natural mortality - M	0.3	Brander and Bennett (1986, 1989)
Length/weight - a	0.00032	After Pope and Thomas (1955; data for Scottish stocks)
Length/weight - b	3.210	"
FEMALES		
Immature Growth		
Growth - K	0.160	Hillis (1979) ; ICES (1991a)
Growth - L(inf)	60	"
Natural mortality - M	0.3	Brander and Bennett (1986, 1989)
Size at maturity	22.1	McQuaid et al., 2006
Mature Growth		
Growth - K	0.100	Hillis (1979) ; ICES (1991a)
Growth - L(inf)	56	"
Natural mortality - M	0.2	Brander and Bennett (1986, 1989)
Length/weight - a	0.00068	After Pope and Thomas (1955; data for Scottish stocks)
Length/weight - b	2.960	"

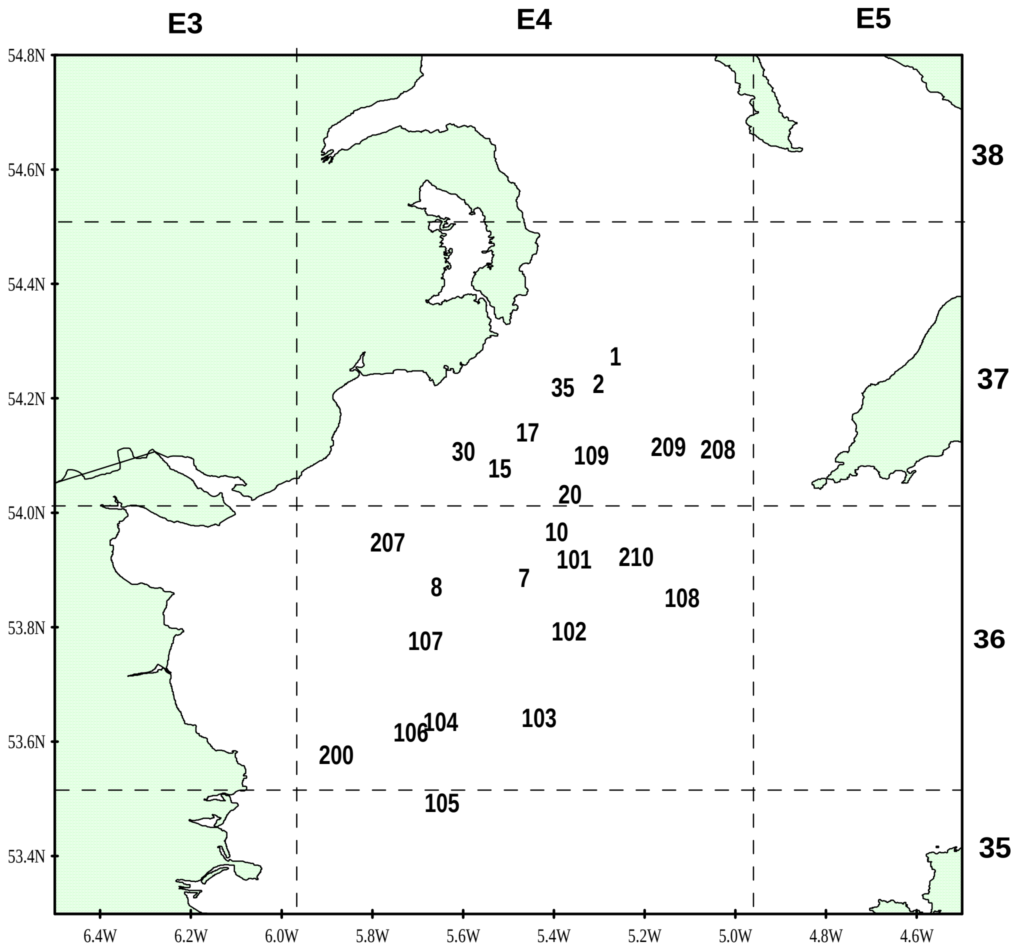


Figure 1: Western Irish Sea Nephrops stations

Annex 15: Stock Annex: FU17, Aran Grounds

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Aran Grounds *Nephrops* (FU17)
Date:	06 March 2009 (WKNEPH2009)
Revised by	Colm Lordan and Jennifer Doyle (WKNEPH, 2009)

A. General

A.1. Stock definition

Nephrops is limited to muddy habitat, and requires sediment with a silt and clay content of between 10–100% to excavate its burrows, and this means that the distribution of suitable sediment defines the species distribution. Adult *Nephrops* probably only undertake very small-scale movements (a few 100 m) but larval transfer may occur between separate mud patches in some areas. In FU 17, the main *Nephrops* stock inhabits an extensive area of muddy sediment known as the Aran Grounds which lie to the west and southwest of the Aran Islands; there are also smaller discrete mud patches in Galway Bay and Slyne Head.

A.2. Fishery

In recent years the *Nephrops* stock in FU 17 are almost exclusively exploited by Irish vessels. Figure A.2.1 shows the spatial distribution of landings and lpue for Irish otter trawl vessels in 2005 using logbook and VMS data linked together to give finer spatial resolution. The Aran ground fishery is clearly highlighted.

The *Nephrops* fishery 'at the back of the Aran Islands' can be considered the mainstay of the Ros a Mhíl fleet. Without this *Nephrops* fishery the majority of vessels in the fleet would cease being economically viable (Meredith, 1999). The Irish fishery consists entirely of otter trawl vessels. The majority of vessels use twin-rigs and 80 mm. Smaller vessels do use 70 mm with a SMP. Some vessels have using 90 mm. Vessels from Ros a Mhíl, Dingle, Union Hall, Dunmore East, Clogherhead and Kinsale mainly exploit the fishery.

The number of Irish vessels reporting *Nephrops* landings from FU 17 has fluctuated around 50/yr (Figure A.2.2). Around 18 vessels report landings in excess of 10 t. These are the main vessels in the fishery accounting for around 85% of the total landings. The majority of these vessels are between 20–22 m overall length (Figure A.2.3). There has been a slight shift to lager vessels over time. The majority of the vessels are in the power range of 200–400 KW (Figure A.2.4). There has also been a shift to more powerful vessels over time with the introduction of twin-rigs to the fishery in the early 2000s. Most of the larger boats move freely between the *Nephrops* fisheries in FUs 15, 16, 20-22 and other areas depending on the tides and weather.

The fishery demonstrates a distinctive seasonal pattern with highest landings, catches, lpue and cpue in April–June and October–November. The monthly landings time-series with the average pattern is shown in Figure A.2.5. The first period of elevated landings is associated with the emergence of females from their burrows post-hatching of their eggs. The sex ratio during this period is biased towards females (Figure A.2.6). Females mature quickly during the early summer and spawning occurs in July and August. This is coincident with a decline in landings and cpue in the fishery. The Ros a Mhíl fleet traditionally tie up in August each year for maintenance and refurbishment.

The following TCMs are in place for *Nephrops* in VII (excluding VIIa) after EC 850/98: Minimum Landing Sizes (MLS); total length >85 mm, carapace length >25 mm, tail length >46 mm. Mesh Size Restrictions; Vessels targeting *Nephrops* using towed gears having at least 35% by weight of this species on board will require 70 mm diamond mesh plus an 80 mm square mesh panel as a minimum or having at least 30% by weight of *Nephrops* on board will require 80–99 mm diamond mesh.

A.3. Ecosystem aspects

Physical oceanography

The Aran ground is coincident with a pool of oceanic water, which is rich in nutrients and low in dissolved oxygen. The currents throughout the water column over the ground are generally weak although there is a well-documented bottom density front on the eastern flank of the ground (Nolan and Lyons, 2006). This is a seasonal feature, which establishes in May and persists until autumn. The front causes a persistent jet like flow from south to north close to the seabed through the *Nephrops* ground. The mean position of jet varies from year to year by up to 30 km. Timing and position of the jet may influence recruitment and settlement success of post-larval *Nephrops* because it could potentially advect larval from the area. Salinity differences, because of over winter freshwater input, are thought to heavily influence the density structure and location of this front. Until a time-series of recruitment and jet dynamics is established it is not possible to draw any firm conclusions about the impact of this ecosystem feature on the stock and fishery. Potential sinks for advected larvae include Slyne head and possibly Galway Bay.

Temperature and salinity time-series

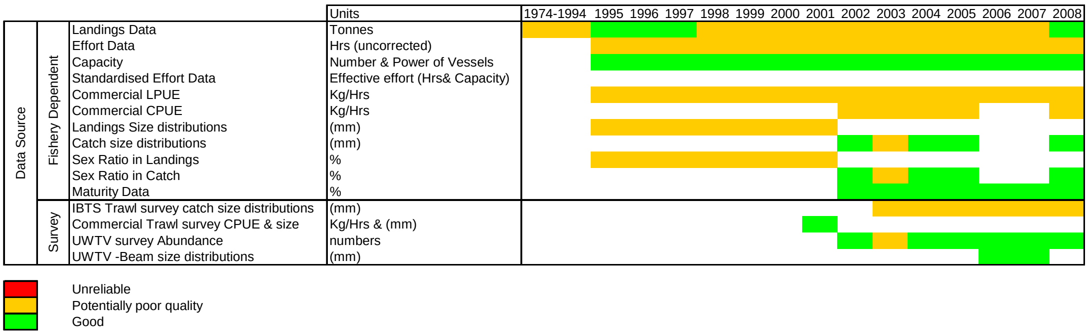
An emerging time-series of temperature and salinity data are available for a transect through the Aran Grounds (Nolan and Lyons, 2006). In all years since 1999 (except 2001) the 53°N section has exhibited positive anomalies in temperature of between 0.2°C and 2°C (Figure A.3.1). In 2001, the temperature anomaly from the long-term climatology was zero. Years with lower temperature anomalies seem to coincide with years of strongly negative salinity anomalies (e.g. 2001 and 2005, 2006) perhaps reflecting the limited influence of ENAW on the section in those years as the section is dominated by coastal discharges from the Loire and Shannon. Salinity anomalies along 53°N range from –0.3 to +0.1 psu over the period. The freshest years were 2001, 2005 and 2006. In 2000, 2003 and 2004 ENAW has a stronger influence on the salinity structure and positive anomalies in salinity from the long-term climatology are the result. The higher UWTV abundance in 2003 and 2004 is coincident with the warmest anomaly but the time-series remains too short to draw definitive conclusions.

Sediment distribution

There is a growing body of information on the spatial extent of the sediment suitable for *Nephrops* from UWTV surveys, seabed mapping programmes and the fishing industry. Figure A.3.1 depicts contour and post plots of the a) mean size (phi) and classification based on the Friedman and Sanders, 1978 scales and b) sorting (σ_g) of the sediments on the Aran Grounds based on PSA results from samples collected from 2002–2006 UWTV surveys. The majority of the ground has similar mean particle size at around 4–5 µm. There are some patches of softer silt towards the middle of the ground. Figure A.3.2**.** is bathymetry of the Aran grounds obtained from seabed mapping programmes. The eastern flank of the ground shallows up quickly but the majority of the ground is gradually deepening from around 100 m–110 m with the deepest parts to the southwest.

B. Data

The table below summarizes the available data for this stock and attempts to quantify the quality subjectively.



B.1. Commercial catch

Prior to 1988 landings data for this fishery are only available to the WG for France. Since 1988 reported landings data for the Irish fleet were obtained from EU logbooks. The quality of landings data is not well known. In earlier, years there are no landings from Ireland although there was probably some catch. The Irish landings have been close to quota for this TAC area since around 1997 (Figure B.1.1). In more recent years (2003–2005 and 2008) there are a few observations of both under- and over-reporting but it is not possible to correct landings using these as it is not known how representative they might be.

Landings length and sex compositions were estimated from port sampling by Ireland (between 1995 and 2001). There was a perception during this period that that discarding was not significant. In 2002 a new catch self-sampling programme was put in place. This involves unsorted catch and discard samples being provided by vessels or collected by observers at sea on discard trips. The catch sample is partitioned into landings and discards using an on-board discard selection ogive derived for the discard samples (Table B.1.1). Sampling effort is stratified monthly but quarterly aggregations are used to derive length distributions and selection ogives. The length-weight regression parameters given in Table B.2.1 are used to calculate sampled weights and appropriate quarterly raising factors. The sampling intensity and coverage has varied over the time-series (Table B.1.1). The quality of the sampling has not yet been qualitatively assessed in terms of precision and accuracy.

Nephrops landings and discards from the Aran Grounds have not been sampled for the majority of 2006 and all 2007 as a consequence of a lack of cooperation by the industry. However, sampling resumed in 2008 and the intensity and coverage is considered the best to date.

Fish and other bycatches in the fishery have been collected by on-board observers since 1994. The number of trips is variable over time with a gap in the series in 2006 and 2007.

B.2. Biological

Biological parameters for this stock are outlined in Table B.2.1.

Length-weight

Mean weights-at-age for this stock are estimated from studies on Scottish stocks by Pope and Thomas, 1955. This relationship was examined in 2003 and it seemed appropriate. Given the variability of length-weight parameters found in Allan *et al.*, 2009, it would be worth monitoring these more closely in future.

Natural mortality

A natural mortality rate of 0.3 was assumed for all age classes and years for males and immature females, with a value of 0.2 for mature females. The lower value for mature females reflects the reduced burrow emergence while ovigerous and hence an assumed reduction in predation. The accuracy of these assumptions is unknown. Cod are not common on the Aran Grounds but other potential predators include dogfish, monkfish megrim and gurnards. Stomach contents data on the Irish GFS could be used to examine this in future.

Maturity

The L_{50} of females using a macroscopic visual maturity scale is known to vary depending sampling month (Lordan and Gerritsen, 2006). The L_{50} in July was chosen as the most appropriate estimate given the maturity schedules observed (Figure B.2.1). It is worth mentioning that commercial vessel surveys in November 2001 and in June 2002 demonstrated considerable differences between the maturity schedules of female *Nephrops* sampled in shallower waters of Galway Bay compared with the Aran Grounds.

Proportion of F and M prior to spawning was specified as zero to give estimates of spawning-stock biomass at January 1. In the absence of independent estimates, the mean weights-at-age in the total catch were assumed to represent the mean weights in the stock.

Discard Survival

Given the trip durations (~5 days average) and behaviour of the fleet the majority of discards on the Aran Grounds are returned to the sea over suitable sediment. The proportion scavenged by birds is probably quite low. Tow durations, volume of catches, prolonged sorting on deck and relatively high density of *Nephrops* on the seabed probably results in relatively low discard survival. This is estimated to be around 10%.

B.3. Surveys

Since 2002 Ireland has conducted underwater television survey (UWTV) annually on the main *Nephrops* grounds-Aran grounds. Indicator camera stations are also carried out on the adjacent grounds of Galway Bay and Slyne Head weather and time permitting. The surveys were based on a randomized fixed grid design. The methods used during the survey were similar to those employed for UWTV surveys of *Nephrops* stocks around Scotland and elsewhere and are documented by WKNEPHTV (ICES, 2007).

A number of factors are suspected to contribute bias to the surveys. In order to use the survey abundance estimate as an absolute it is necessary to correct for these potential biases. The history of bias estimates are given in the following table and are based on simulation models, preliminary experimentation and expert opinion, the biases associated with the estimates of *Nephrops* abundance in the Aran Grounds are:

	Time period	Edge effect	Detection rate	Species identification	Occupancy	Cumulative bias
FU 17: Aran	<=2009	1.35	0.9	1.05	1	1.3

B.4. Commercial cpue

Prior to 1988 landings data for this fishery are only available to the WG for France. Since 1988 reported landings data for the Irish fleet were obtained from EU logbooks (Table B.4.1.).

Effort data for FU17 is available from 1995 for the Irish otter trawl *Nephrops* directed fleet (Table B.4.2.). A threshold of 30% of *Nephrops* in reported landings by trip is used to identify the catches and effort of this fleet. This threshold was based on an analysis of the trip-by-trip catch compositions. In 2007 this fleet accounted for ~90% of the landings and compared with an average of 70% over the period. These data have not been standardized to take into account vessel or efficiency changes during the period. Landings per unit effort (lpues) have been fluctuating around an average of 39 kg/hr with an increasing trend since 2004, to the highest observed (59 kg/hr) in the time-series in 2007 (Figure B.4.1.).

B.5. Other relevant data

C. Historical stock development

Age structured XSA assessment for this stock was carried *Nephrops* WG in 2003 (ICES, 2003). The results were considered unreliable for several reasons most importantly; inadequate historical sampling of catch, growth and natural mortality assumptions and concern about accuracy of tuning data. Since then the focus has been on developing a time-series of UWTV survey data as the basis of assessment and advice for this stock.

The 2009 Benchmark decided on the following procedure:

1) Survey indices are worked up annually resulting in the TV index.

2) Adjust index for bias (see Section B3). The combined effect of these biases is to be applied to the new survey index.

3) Generate mean weight in landings. Check the time-series of mean landing weights for evidence of a trend in the most recent period. If there is no firm evidence of a recent trend in mean weight use the average of the three most recent years. If, however, there is strong evidence of a recent trend then apply most recent value (don't attempt to extrapolate the trend further in future).

D. Short-term projection

1) The catch option table will include the harvest ratios associated with fishing at $F_{0.1}$ and Fmax. These values have been estimated by the Benchmark Workshop (see Section 9.2) and are to be revisited by subsequent benchmark groups. The values are FU specific and have been put in the Stock Annexes.

2) Create catch option table on the basis of a range of harvest ratios ranging from 0 to the maximum observed ratio or the ratio equating to F_{max}, whichever is the larger. Insert the harvest ratios from step 4 and also the current harvest ratio.

3) Multiply the survey index by the harvest ratios to give the number of total removals.

4) Convert removals to landings by applying a retention factor. The formula is as follows:

$$R = \frac{\sum_l N_L}{\sum_l N_L + \left(\sum_l N_D \times S_D\right)}$$

Where *R*=retention, *l*=length, N_L= number of individuals retained, N_D=number of individuals discarded and S_D =survivorship of discards. Create a landings number by applying a discard factor. This retention factor has been estimated by the Workshop as a 3 year average (2005–2007) and is to be revisited at subsequent benchmark groups, although some in-year revision may be required where changes to data quality or discarding practice occurs. The value is FU specific and has been put in the Stock Annex.

5) Produce landings biomass by applying mean weight.

The suggested catch option table format is as follows.

			Implied fishery	
	Harvest rate	Survey Index	Retained number	Landings (tonnes)
	0%	12 345	0	0.00
	2%	"	247	123.45
	4%	"	494	246.90
	6%	"	741	370.35
	8%	"	988	493.80
F0.1	8.60%	"	1062	530.84
	10%	"	1235	617.25
	12%	"	1481	740.70
Fmax	13.50%	"	1667	833.29
	14%	"	1728	864.15
	16%	"	1975	987.60
	18%	"	2222	1111.05
	20%	"	2469	1234.50
	22%	"	2716	1357.95
Fcurrent	21.5%	"	2654	1327.09

E. Medium-term projections

None presented.

F. Long-term projections

None presented.

G. Biological reference points

The time-series of available length frequencies were insufficient to generate reliable estimates of F0.1 and Fmax.

H. Other issues

I. References

ICES 2007. Report of the Workshop on the use of UWTV surveys for determining abundance in *Nephrops* stocks throughout European waters (WKNEPHTV). ICES CM: 2007/ACFM: 14 Ref: LRC, PGCCDBS.

ICES 2008. Report of the Workshop and training course on *Nephrops* Burrow Identification (WKNEPHBID). ICES CM: 2008/LRC: 03 Ref: ACOM.

ICES 2008. Report of the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM). ICES CM: 2008/ ACOM:07.

ICES 2005. Using UWTV surveys to develop a conceptual ecosystem model of Aran Grounds *Nephrops* population distribution. ICES CM 2005/L:30 Annual Science Conference.

Nolan. G.D. and Lyons. 2006.Ocean climate variability on the western Irish Shelf, an emerging time-series., K., *Proceedings of the ICES Annual Science Conference*, Theme Session C, C:28.

Fernand, L., Nolan, G.D., Raine, R., Chambers, C.E., Dye, S.R., White, M. and Brown, J. 2006. The Irish coastal current: A seasonal jet-like circulation. *Continental Shelf Research*, Vol. 26, Issue 15, 1775–1793.

ICES 2006. Report of the Workshop on *Nephrops* Stocks. Annex 6: Working Document by Lordan and Gerritsen. ICES CM 2006/ACFM:12.

Colm Lordan and Hans Gerritsen. 2006. The accuracy and precision of maturity parameters from sampling of female *Nephrops* from stocks around Ireland. WD6 in the Report of the Workshop on *Nephrops* stocks. ICES CM 2006/ACFM:12.

Table B.1.1. *Nephrops* in FU 17 (Aran Grounds) Landings and discard numbers by year and sex.

	Female Numbers '000s		Male Numbers '000s		Both sexes
Year	Landings	Discards	Landings	Discards	% Discard
2001	18,665	12,161	29,949	13,250	34%
2002	23,105	9,374	31,256	8,326	25%
2003	14,530	9,577	29,538	8,744	29%
2004	16,109	7,068	12,930	4,282	28%
2005	20,280	11,383	21,828	8,967	33%
2006	No Sampling				
2007					

Table B.2.2. Numbers of samples and numbers measured for the FU 17 *Nephrops* Stock by year.

Number of Samples				Total numbers of Nephrops measured			
Year	Graded Landings	Catch	Discards	Year	Graded Landings	Catch	Discards
1990	24			1990	10 451		
1991	20			1991	8260		
1992	0			1992	0		
1993	0			1993	0		
1994	0			1994	0		
1995	13			1995	6370		
1996	3			1996	1440		
1997	11			1997	5203		
1998	12			1998	5388		
1999	16			1999	6944		
2000	5			2000	2255		
2001	32	5	5	2001	13 231	3194	3891
2002		13		2002		9399	
2003	1	9	9	2003		6284	4829
2004		14	14	2004	578	12 934	13 167
2005		13	9	2005		8729	7559
2006		2	0	2006		767	436
2007		0	0	2007			
2008		19	18	2008		4944	8701

Table B.2.1. Biological Input Parameters for FU 17 *Nephrops* Stock.

Parameter	Value	Source
Discard Survival	10%	WKNEPH 2009
Discard rate	40.2%	WGCSE 2009
MALES		
Growth - K	0.150	based on FUs 15 and 16
Growth - L(inf)	60	based on FU 15
Natural mortality - M	0.3	assumed, in line with other stocks
Length/weight - a	0.000322	based on Scottish data (Pope and Thomas, 1955)
Length/weight - b	3.207	"
FEMALES		
Immature Growth		
Growth - K	0.150	based on FUs 15 and 16
Growth - L(inf)	60	based on FU 15
Natural mortality - M	0.3	assumed, in line with other stocks
Size at maturity (L50)	22	ICES 2006 (Lordan and Gerritsen)
Mature Growth		
Growth - K	0.100	based on FUs 15 and 16
Growth - L(inf)	50	based on FU 15
Natural mortality - M	0.2	assumed, in line with other stocks
Length/weight - a	0.000684	based on Scottish data (Pope and Thomas, 1955)
Length/weight - b	2.963	"

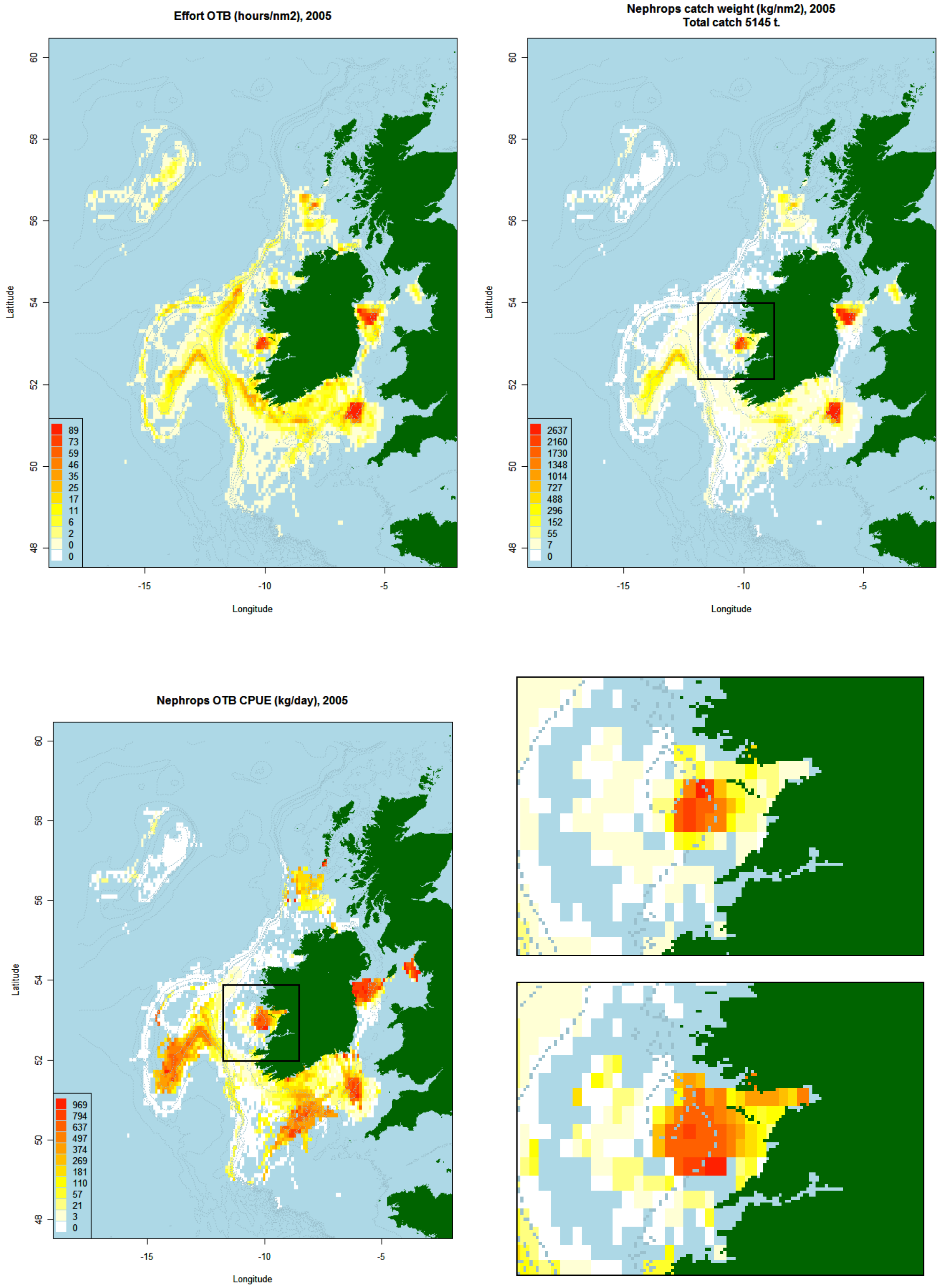


Figure A.2.1. Effort, catch and catch per unit of effort for *Nephrops*, Irish otter trawlers in 2005. The boxed and zoomed in plots show a zoomed in view of landings and lpue from the fishery on the Aran ground.

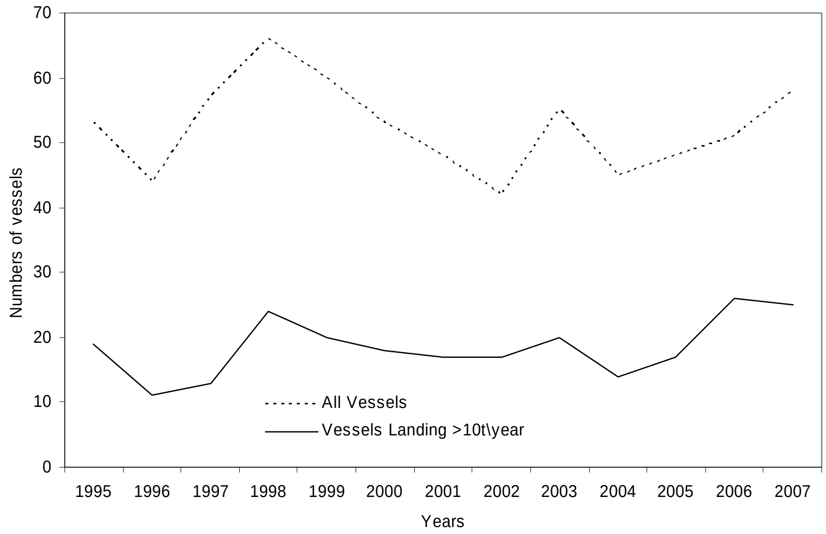


Figure A.2.2. Time-series of the number of Irish vessels reporting landings of *Nephrops* from FU17. The vessels with annual landings >10 t/yr can be considered the main participants in the fishery these general account for ~85% of the total landings.

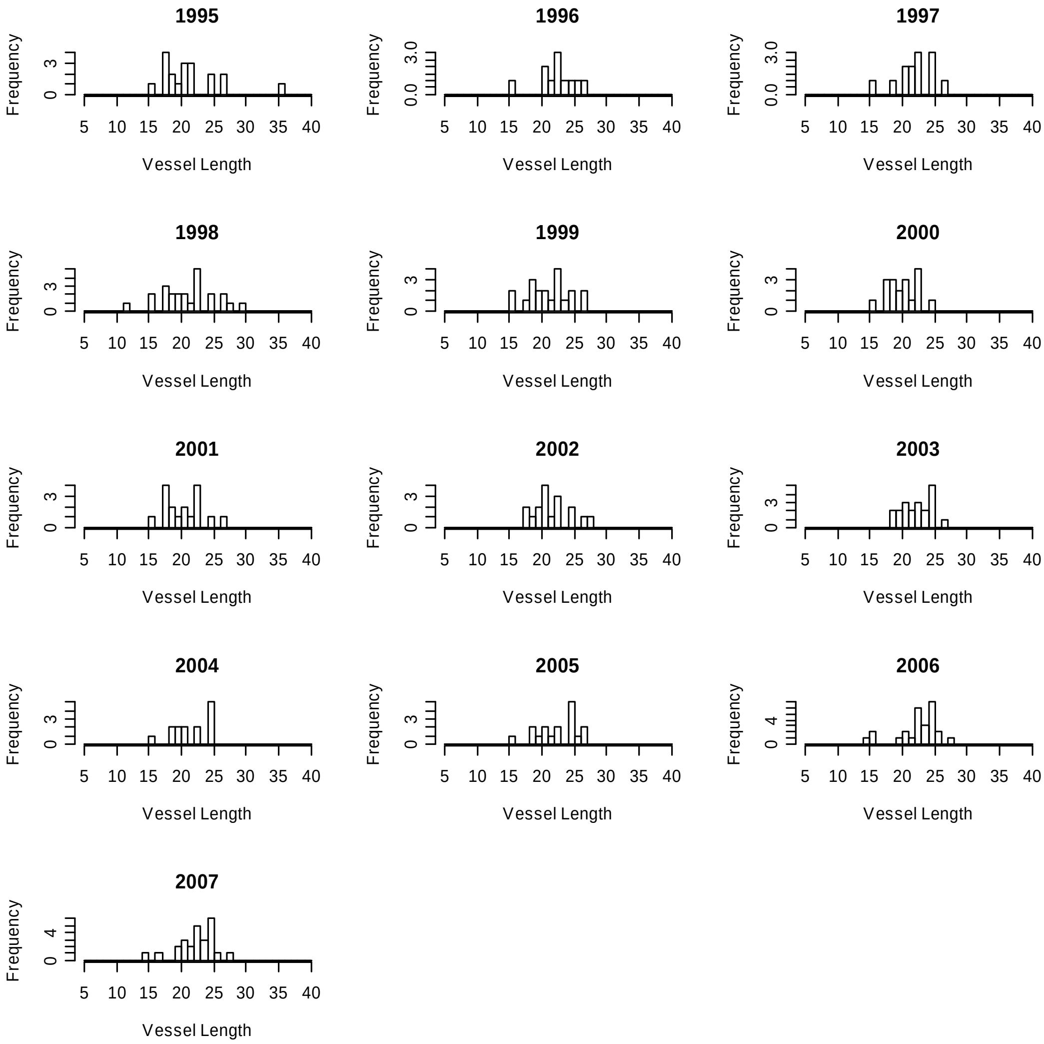


Figure A.2.3. The time-series of length distributions of Irish vessels landing >10 t of *Nephrops* from FU17.

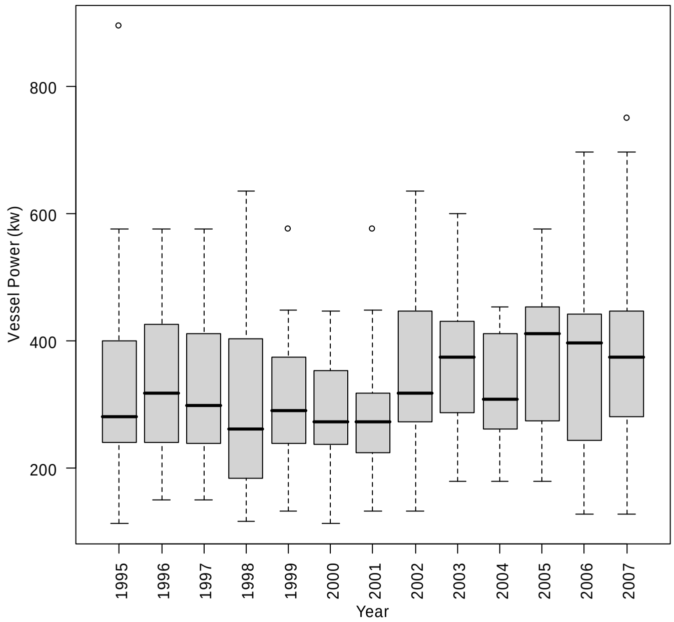


Figure A.2.4. Box plot of the time-series of vessel power in KW of Irish vessels landing >10 t of *Nephrops* from FU17.

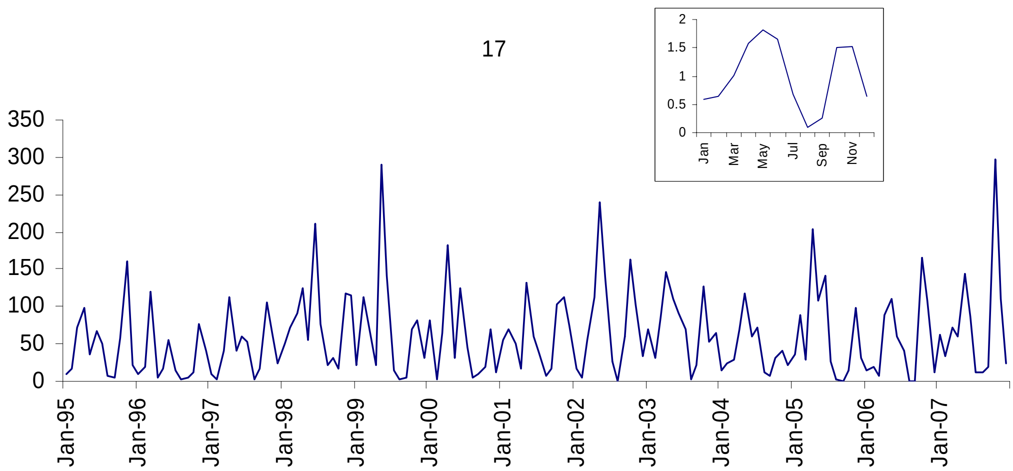


Figure A.2.5. Monthly landings of *Nephrops* from FU17 from 1995–2007. The inset shows the average pattern for all years.

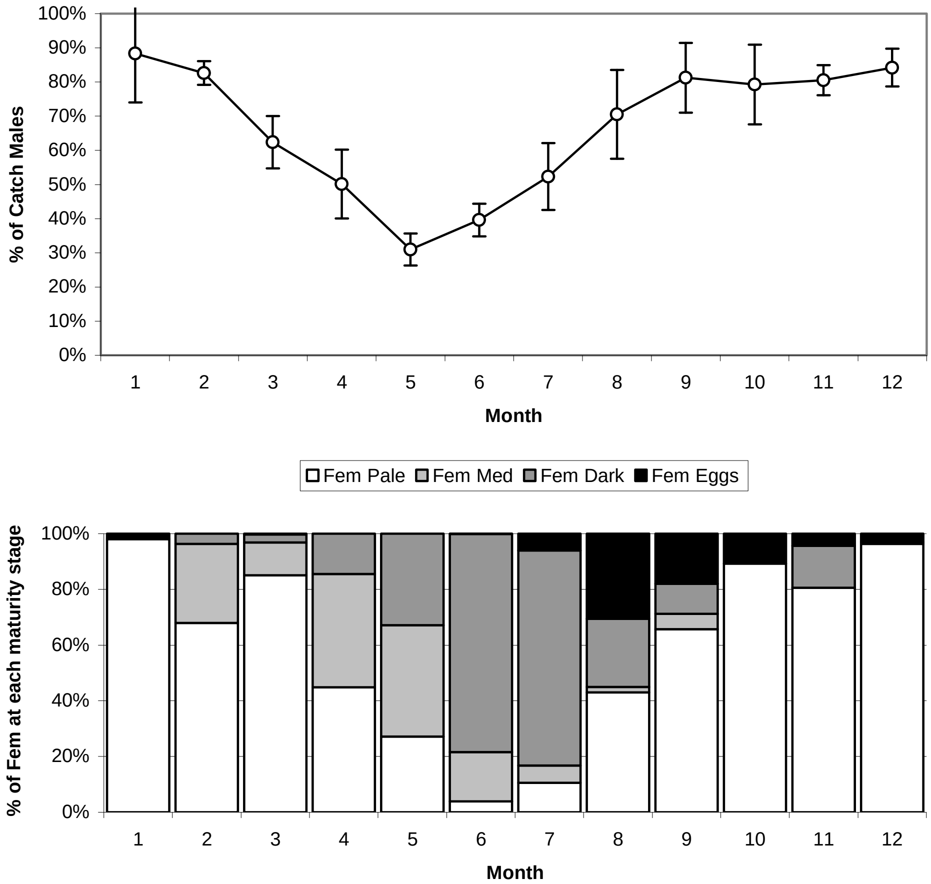


Figure A.2.6. The upper panel shows the sex ratio in sampled catches 2003–2008 (error bars = 95% confidence intervals). The low panel shows the female maturity schedule i.e. percentage at each maturity stage by month.

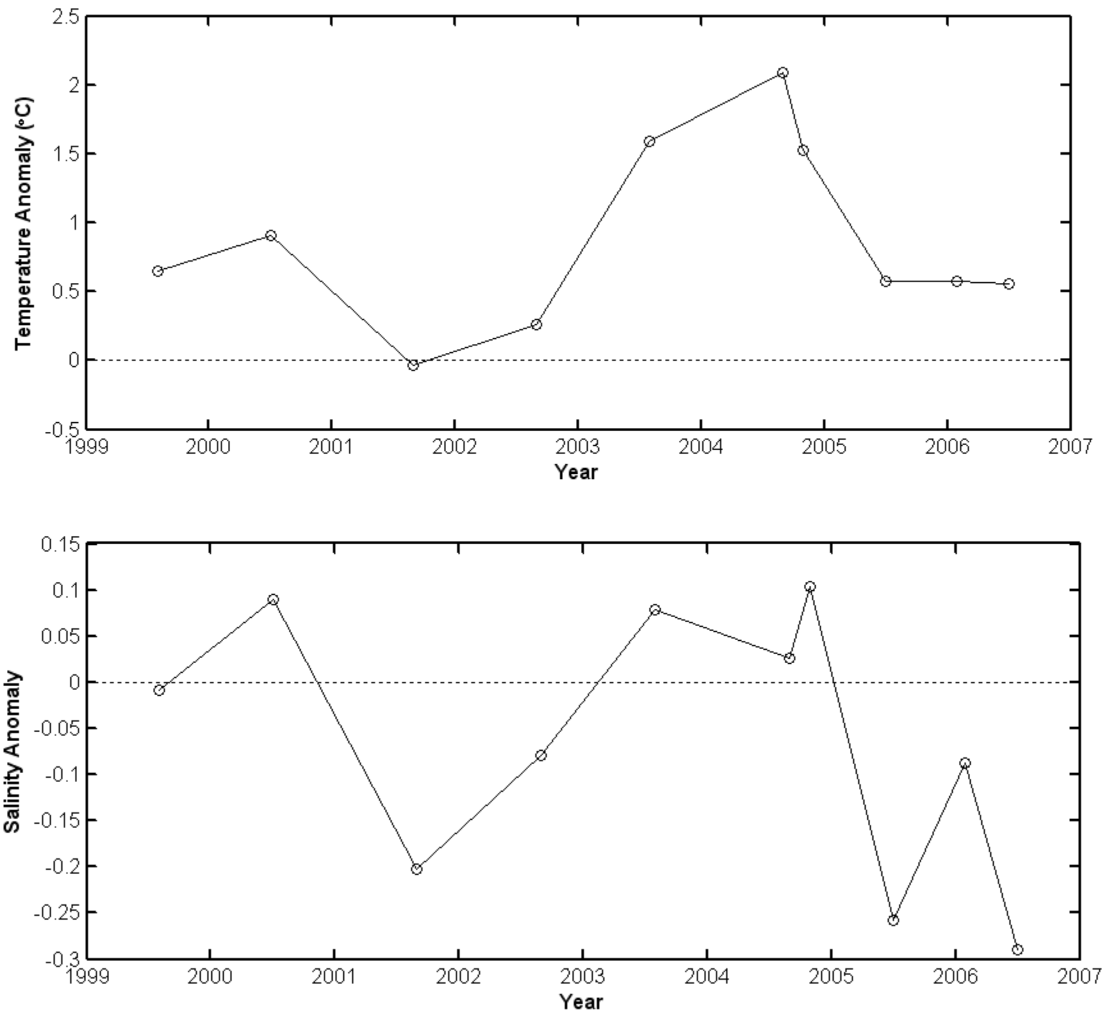
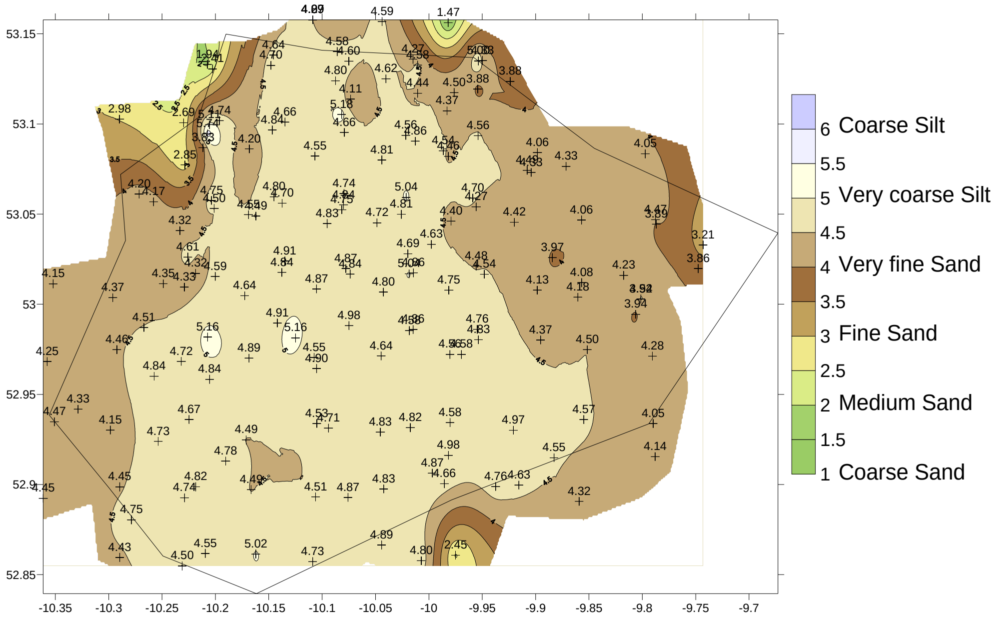


Figure A.3.1. Anomalies in temperature (upper panel) and salinity (lower panel) for the 53°N section running through the Aran Grounds (1999–2006).

a)



b)

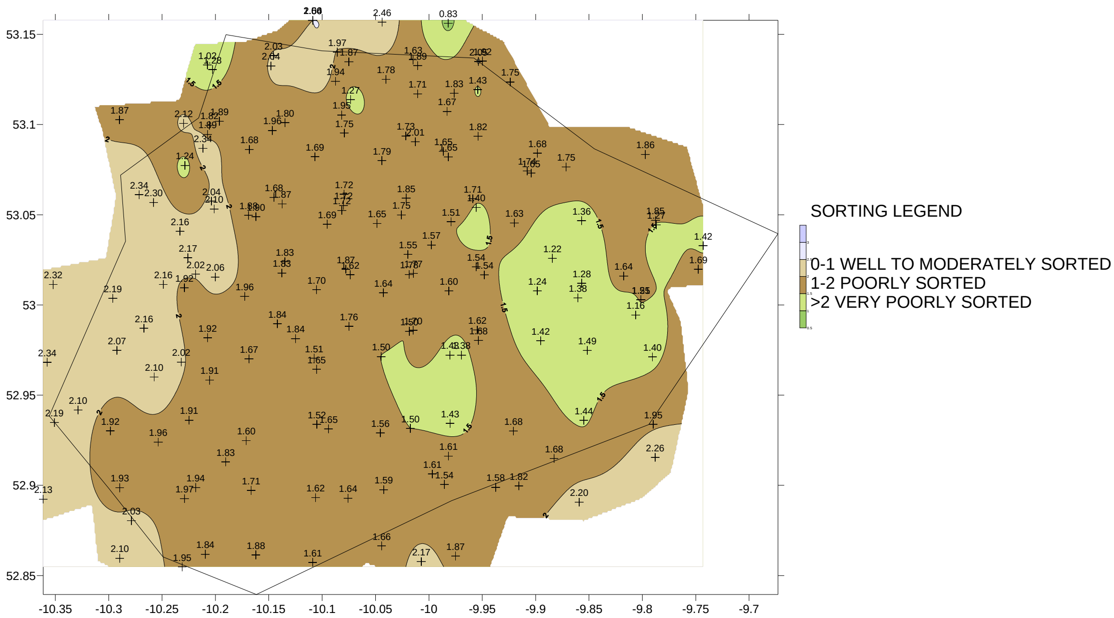


Figure A.3.1. Contour and post plots of the a) mean size (phi) and classification based on the Friedman and Sanders, 1978 scales and b) sorting (σ_g) of the sediments on the Aran Grounds based on PSA results from samples collected from 2002–2006.

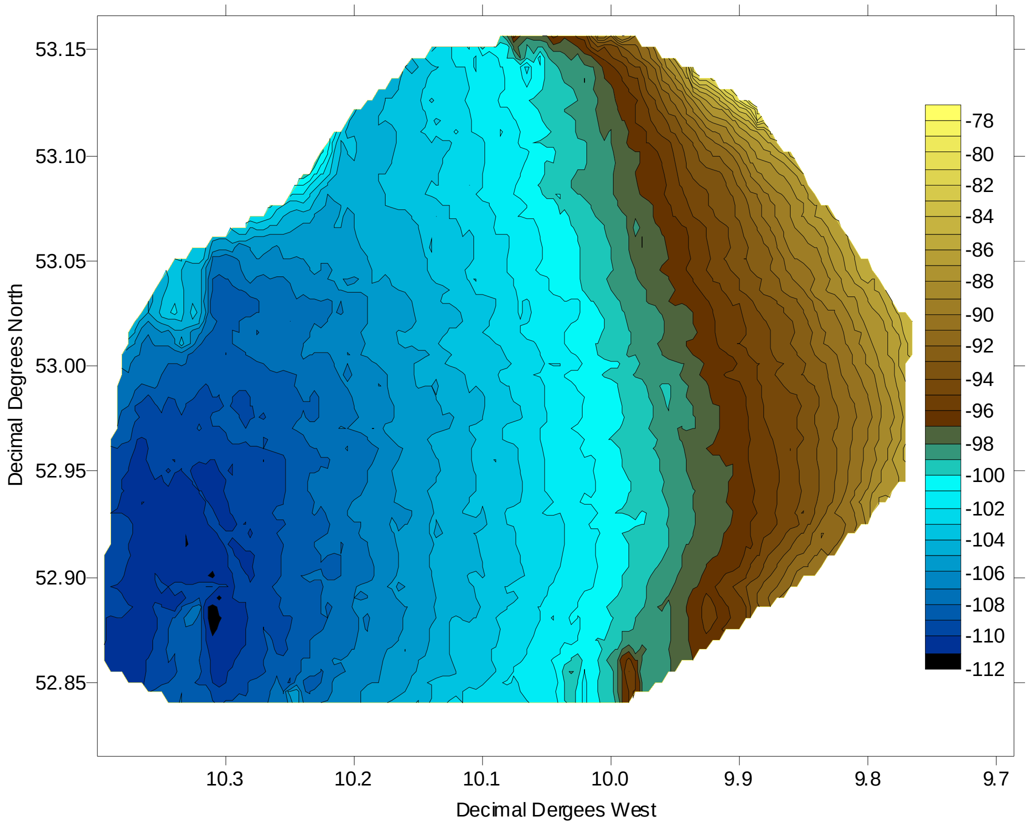


Figure A.3.2. The bathymetry of the Aran grounds.

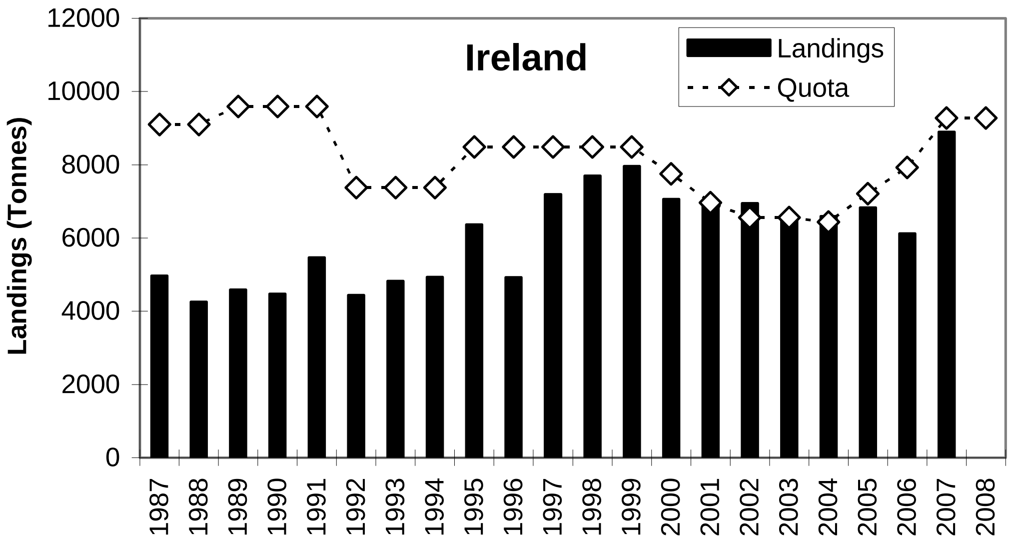


Figure B.1.1 *Nephrops* landings and quota for Ireland since the introduction of TACs in 1987.

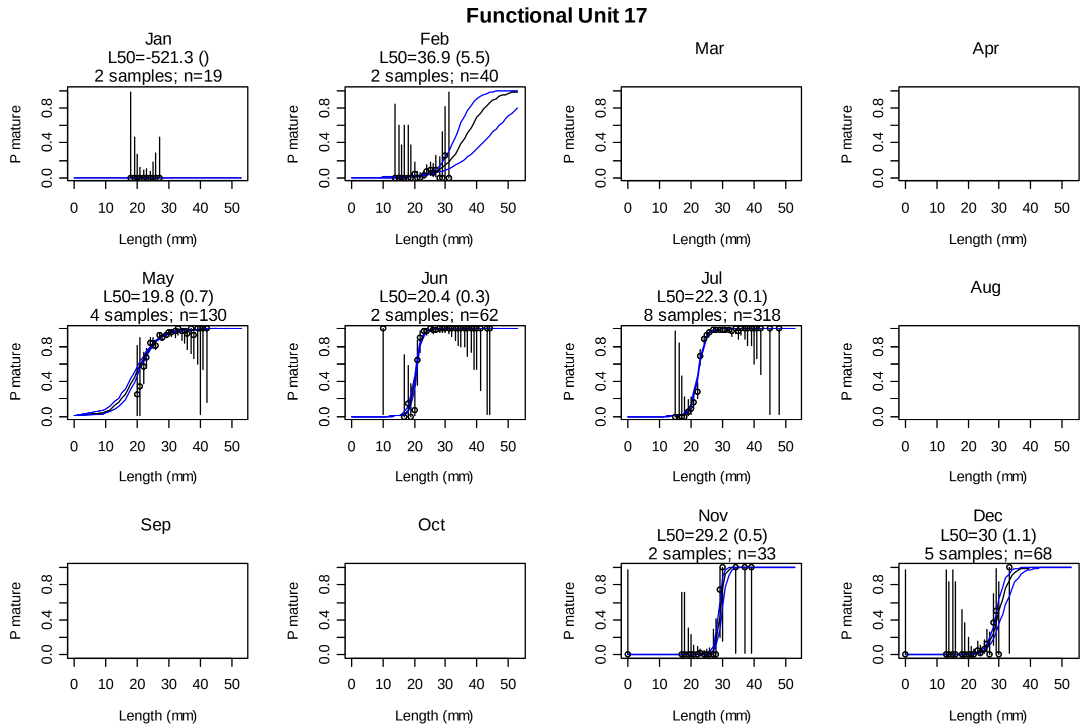


Figure B.2.1. Female proportions mature-at-length for FU 17. The 95% confidence limits of the proportions mature-at-length are indicated by the vertical bars. The black curve indicates the model and its standard errors are given by the blue lines. The L_{50} is the estimated length at 50% maturity and its standard error is given between brackets. Blank plots indicate no sampling took place.